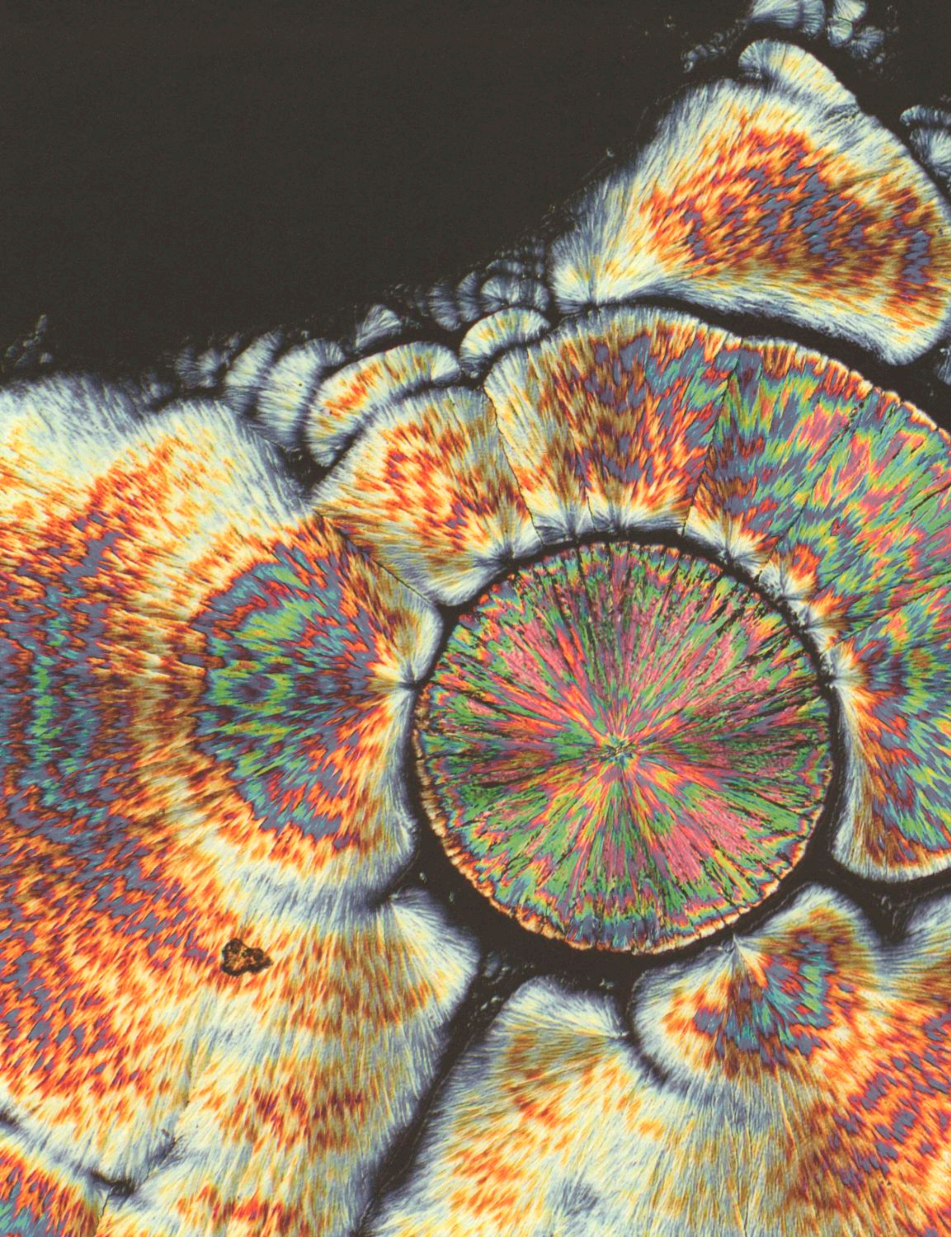
MODERNIST CUISINE

1 · History and Fundamentals



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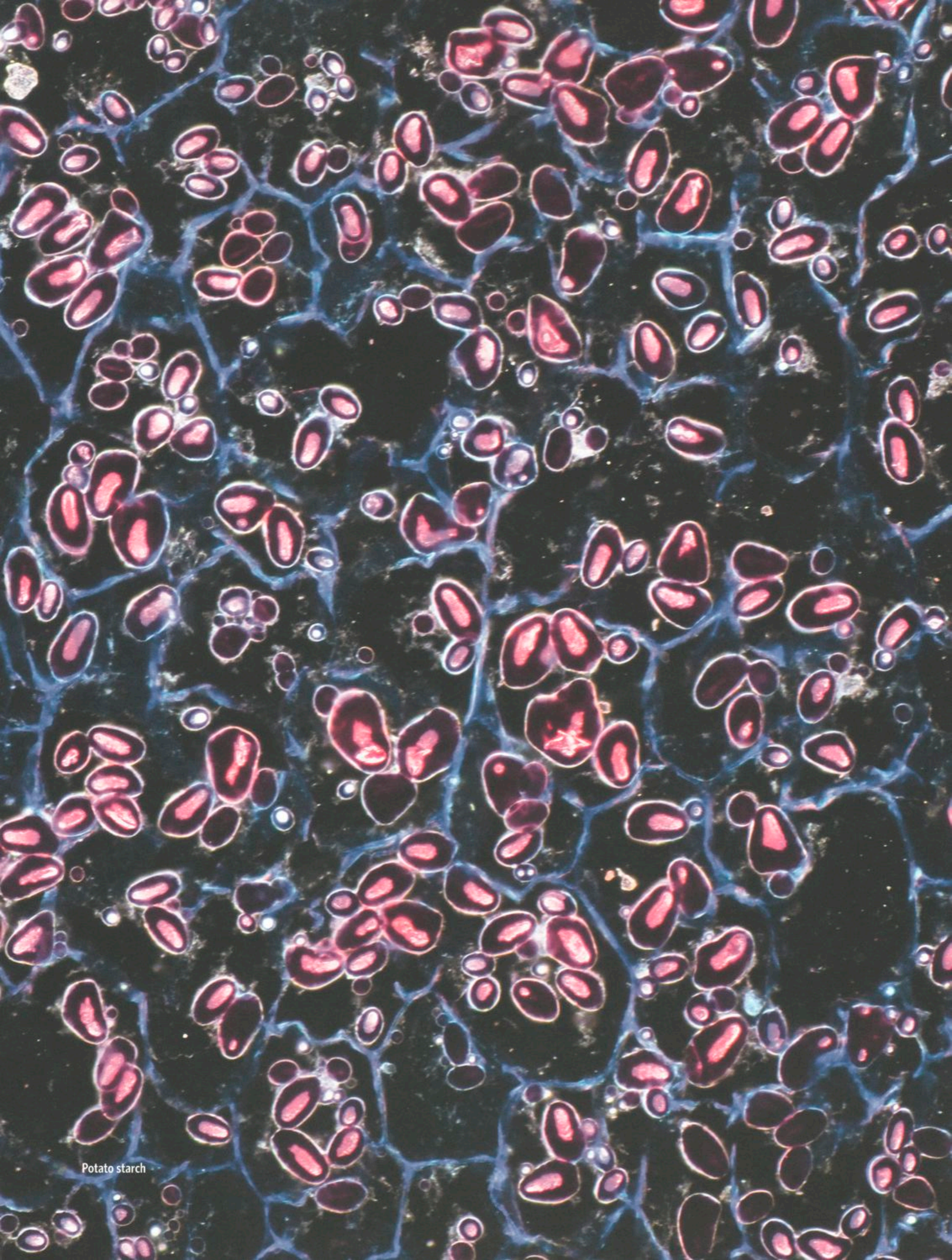

Potato starch

MODERNIST CUISINE

The Art and Science of Cooking

Nathan Myhrvold
with Chris Young
and Maxime Bilet

Photography by
Ryan Matthew Smith
and Nathan Myhrvold

The Cooking Lab
3150 139th Ave SE
Bellevue, WA 98005
www.modernistcuisine.com

ISBN: 978-0-9827610-0-7
First edition, 2011

Library of Congress Cataloging-in-Publication Data available upon request

Printed in China

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Volume 1

History and Fundamentals

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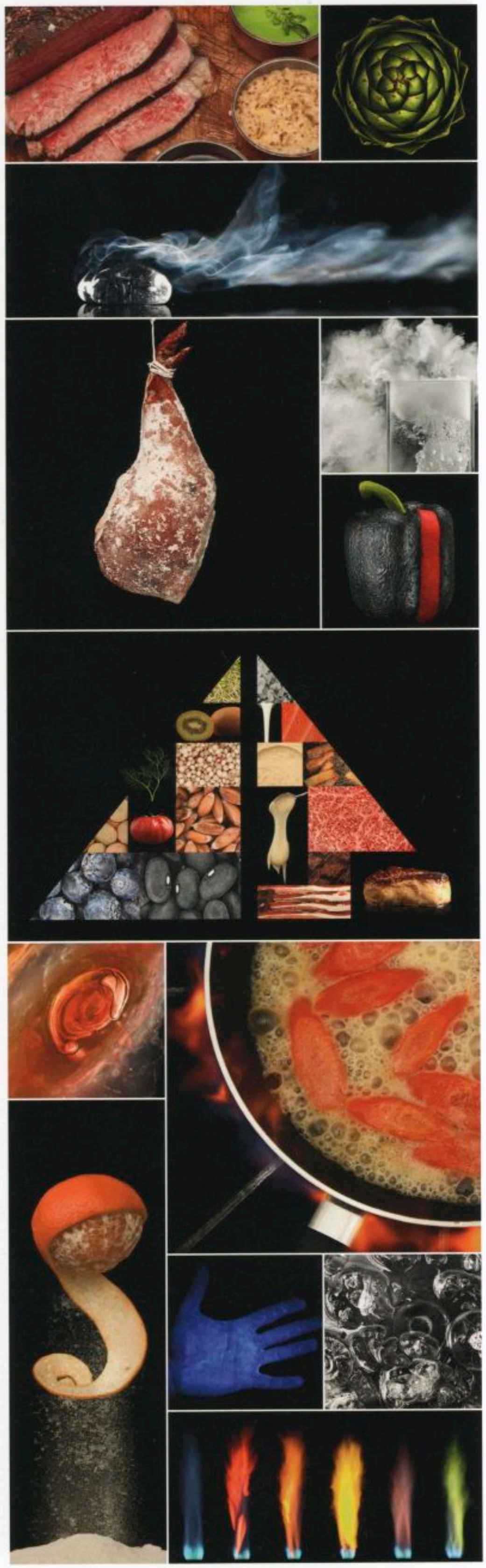
VOLUME 1: HISTORY AND FUNDAMENTALS



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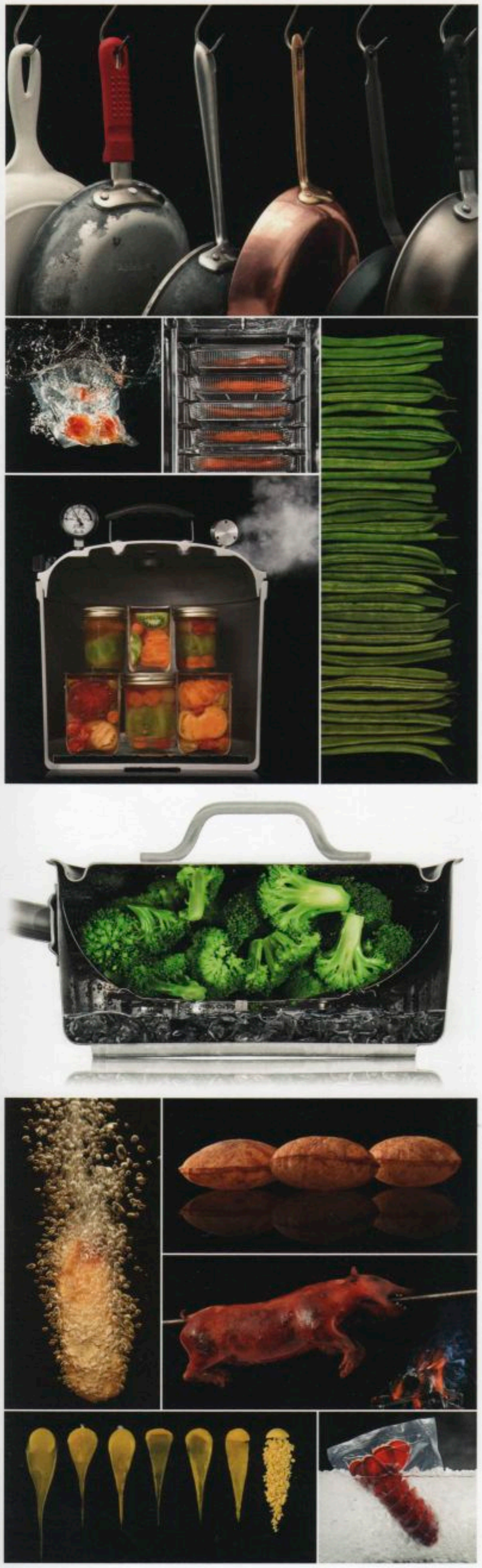
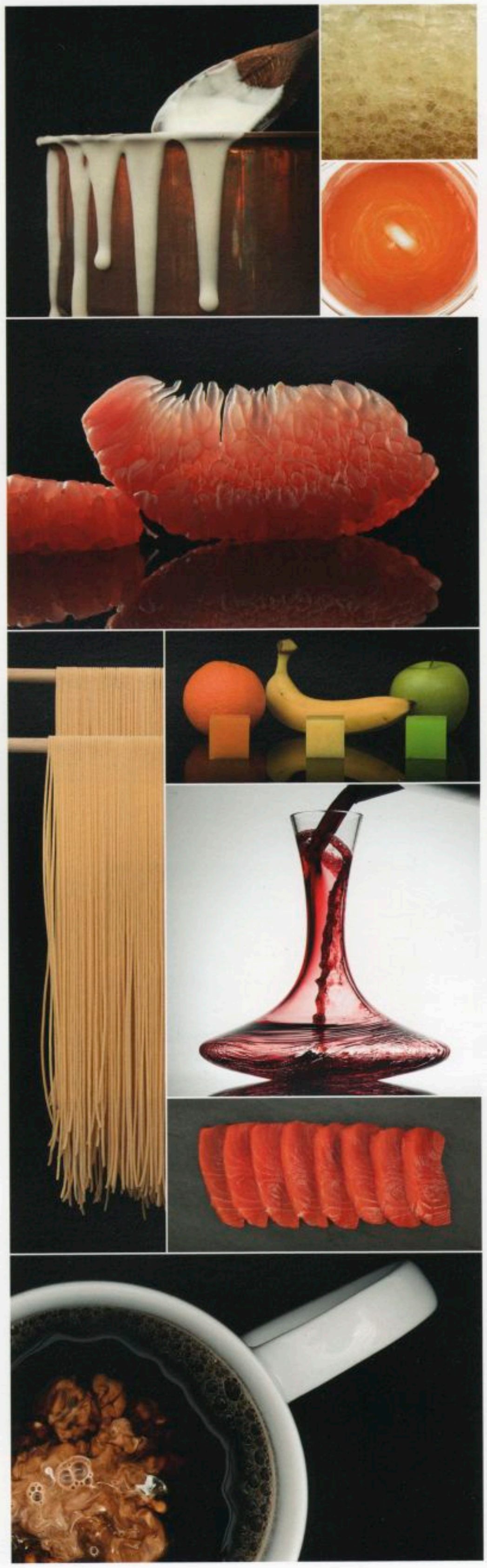


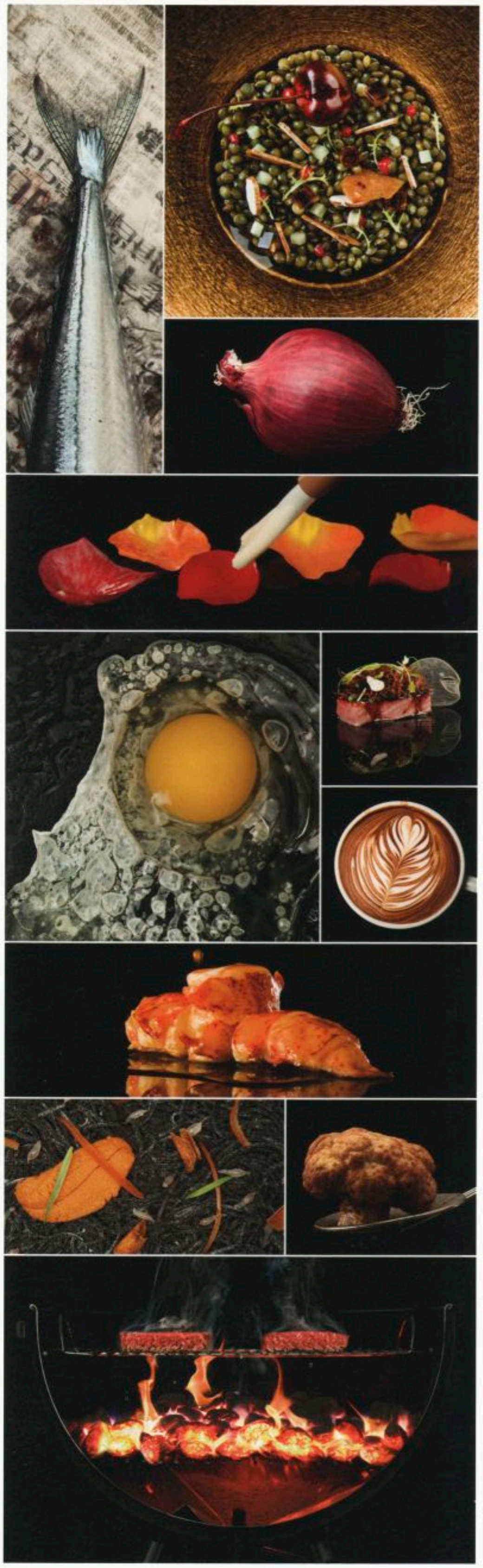
VOLUME 2: TECHNIQUES AND EQUIPMENT

VOLUME 3: ANIMALS AND PLANTS

VOLUME 4: INGREDIENTS AND PREPARATIONS

VOLUME 5: PLATED-DISH RECIPES





Foreword

When I saw the first sections of this book as it was taking shape, I knew I was facing an exceptional work of uncommon rigor and extraordinary breadth. It is no exaggeration to call this a work of brilliance. There has been nothing like it in the history of the kitchen. But that is no surprise, considering who created it.

I met Nathan Myhrvold seven or eight years ago, when he came to dinner at elBulli. Our first encounter was brief, yet I knew immediately that before me was a man with a special gift, one of the few people I know who has the ability to "read" dishes. Avant-garde chefs admire an openness to the joy that comes from experiencing creative emotions fully, and we hope to find it in those we cook for. Like other connoisseurs, Nathan was able to enjoy our culinary proposals on the physical and sensory levels; but he also understood and felt the creativity of the *ideas* on display in each plate. We chefs work for all who enjoy our food, but there are times where, in the back of my mind, I think we are most motivated by those uncommon guests such as these.

Nathan and his team have done an extraordinary job in producing this book, which reflects the huge effort that went into it. The result is a true work of art—not strictly a cookbook, but something more: a work that will change the way we understand the modern kitchen and gastronomy. This is a book that is not complex, yet rich; not easy, yet clear. I can think of few other works that pair cooking techniques with such analytical rigor.

As I read the book, two thoughts spring to mind. The first is that now is a good time to rethink how we teach nutrition and cooking in schools. I have no doubt that this work will strongly influence how these subjects are taught in the future.

I also think that there is no better example than this book of the dialog that has emerged between science and cooking. In fact, these pages arguably represent the climax of that dialog. *Modernist Cuisine* helps establish a new language by which chefs can communicate the complexities of their intellectual work. At the same time, this is a living work because it clearly lays a new stepping stone to the future of cooking. It raises our expectations of what a cookbook can be.

So turn the page and let yourself be seduced by what follows, by this extraordinary compendium of insight into the products, the techniques, the recipes, the technology, the inspiration ... all that, and more, presented in an intelligent and heartfelt tribute to gastronomy.

Ferran Adrià
Roses, Spain
July 2010

Foreword

Over the road from my restaurant, the Fat Duck, there is an annex housing a development kitchen (or lab, as it's often called) complete with sous-vide machines and water baths and rotary evaporators and vacuum centrifuges and all sorts of other cutting-edge equipment.

This wasn't always the case. A decade or so ago, when Chris Young came to work at the Fat Duck, space was at a premium, so my "lab" consisted of six small slatted wooden garden sheds that had been built in the courtyard at the back of the restaurant. It wasn't glamorous, and it definitely didn't look very hi-tech. But good scientists, like good chefs, are people who ask questions, who experiment, who like to try new things. Chris simply rolled up his sleeves and got on with it, throwing himself into my projects with enthusiasm, determination, and curiosity.

He's brought the same qualities to this book. Together, he and Nathan have assembled a highly talented team of chefs, designers, editors, and a photographer, and between them they have produced a wonderful book. The photos are spectacular. The recipes and techniques are both practical and comprehensive, drawing on the classical repertoire and on the ideas of many of the great modern chefs, as well as presenting lots of new material. Perhaps most important of all, everything is presented in a clear, concise, and accessible fashion.

I've long thought that the astonishingly rapid and diverse evolution of modern cuisine in recent years requires a new kind of cookbook that draws on lots of formats, from lots of different disciplines, in order to make its points. Using pantone charts, perhaps, to show the range of browns for different caramels, or explaining certain culinary techniques in a series of technical diagrams, as in an instruction manual. With its detailed charts and tables, and its comparative and procedural photographs, this book is, it seems to me, a bold and welcome step in this direction.

We need books that do all this. Twenty years ago, one of the key influences on modern cooking, the late, great physicist Nicholas Kurti, had to give a culinary science symposium a fancy title involving the words "molecular gastronomy" in order to secure funding and ensure the conference was taken seriously. Fortunately, since then the role of science in the kitchen has come increasingly to be accepted.

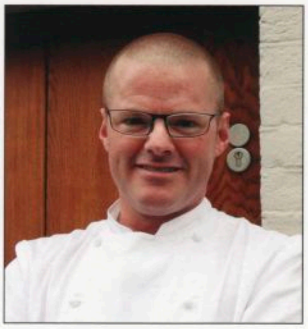
However, it's often still misunderstood. There are people who determinedly resist the use in the kitchen of things like liquid nitrogen and evaporators, seeing them as somehow inappropriate and "not cooking." Yet many of the technologies and tools we rely on every day in the kitchen—our fridges, freezers, and food processors, and even our non-stick pans and super-sharp carbon steel knives—are products of equally complex science. Where do you draw the line? The logical end result of this kind of purist thinking would have us all cooking with sharpened sticks over an open fire!

There are other people who see science and technology as somehow taking the passion and emotion out of cooking, when in fact they're just more tools for the creative chef to work with—part of the *batterie de cuisine* alongside knives and non-stick pans and freezers and food mixers.

And there are young chefs who see science and technology as the end rather than the means—a way of producing a culinary spectacle. I've been to demos where the techniques used to create a new dish are extremely impressive, but the end result is inedible. The excitement of discovering new concepts or technology mustn't blind us to the fact that what we cook should, first and foremost, be delicious. That's the bottom line.

Nathan, Chris, and Max have produced a beautiful and fascinating book that explores the possibilities of the latest scientific advances in cuisine, and they manage to communicate their excitement on the page. But they don't neglect the importance of how cooking has evolved and how important it is to get a good grounding in the basics in order to really harness your creativity. *Modernist Cuisine* will make you ask questions, experiment, and try new things—and I find that incredibly exciting.

Heston Blumenthal
Bray, England
July 2010



Our Culinary Journeys

When I was nine years old, I announced to my mother that I was going to cook Thanksgiving dinner. During a trip to the library a week or so earlier, I had become fascinated with a book called *The Pyromaniac's Cookbook*, which was all about items served flambé. Amazingly, she let me do the cooking, including nearly setting the dining table on fire. I soon learned the limitation of flaming dishes—although they may look great, their taste is another matter.

I got more books from the library and started to learn about cooking. I soon discovered Escoffier's *Le Guide Culinaire* and pored over it, along with books by Julia Child, James Beard, Richard Olney, and other authors of classic cookbooks about French cuisine.

My interest in cooking was so strong that I might have become a chef, had my interest in other things—particularly math and science—not intervened. I was very good at school and often skipped grades, to the point that I started college at 14. Every topic related to math and science fascinated me, so by the time I was finished with school, I had a quite a collection of degrees: a Ph.D. in mathematical physics, a master's degree in economics, another master's degree in geophysics and space physics, and a bachelor's degree in mathematics. By that point I was 23 years old. My next step was to become a postdoctoral fellow at Cambridge University, where I worked with Dr. Stephen Hawking on the quantum theory of gravitation. My career in science was off to a roaring start.

Life takes many unexpected twists and turns, however. Partway through my fellowship with Stephen, I decided to take a summer off to work on a software project with some friends from graduate school. By the end of the summer, venture capitalists had expressed interest in our project, so I extended my leave of absence. We incorporated the project as a startup company, and I became the CEO.

Two years later, the startup was acquired by another software company: Microsoft. Within a couple years, I was working directly for Bill Gates, and in time I became Microsoft's first chief technology officer.

While working at Microsoft in the late 1980s, I read about John Willingham and how he had won the world championship of barbecue (actually both of them; like many fields, barbecue has competing organizations that each host a "world" championship) by using an amazing barbecue cooker of his own invention. I contacted him to buy one, which took many months of delicate negotiations; John won't sell his cooker to somebody he doesn't like—he won't even sell one to most of his friends!

When the Willingham cooker arrived, I made some great barbecue with it—but it wasn't as good as the food samples that John had sent me. So I told him I had to come to Memphis for a lesson. He invited me to visit while "a little contest" (as he put it) was going on there. The little contest turned out to be one of those world championships.

I expected to just observe this master at work, but to my great surprise, John put me on the team of five people competing in the contest. "Son," he said in his distinctive Tennessee drawl, "it's the only way you're going to learn."

It was a baptism of fire ... and smoke, and meat. For three days, I worked 16 hours a day trussing whole hogs, trimming ribs, and stoking the fire. Partway through the contest, he even put me in charge of two of the dishes we entered. Fortunately, we took first place in both of my dishes and came in third in the grand championship. It was quite an education in barbecue.

By the mid-1990s, I had decided that I needed to make more time for cooking. Although I was entirely self-taught up to that point, my barbecue experience suggested that I might do better with some instruction. I negotiated a short leave of absence with Bill and applied to chef school in France.

The admissions people at École de la Varenne were a bit mystified by my résumé, which listed no cooking experience; they politely suggested that I take one of their amateur courses. I declined. The advanced professional program with "Le Grand Diplôme" was what I wanted.

Unsure of what to do, they asked Cynthia Nims, a La Varenne alumna living in Seattle, to give me an exam over the phone to see whether this could possibly make sense. I passed the exam, so they asked that I work as a *stagier* at a restaurant before they would accept me.

For nearly two years, I reported one day a week to Rover's restaurant in Seattle, run by Chef Thierry Rautureau. I arrived at noon to start on prep and worked through dinner service.

I learned a lot from Thierry. At the school, one of the chefs assigned us to bone ducks. The chef watched me closely. When I was finished with the first one, he came to me and said, "You! Where did you learn this?" I thought he was mad, but before I could answer he smiled and added, "You know a duck like a Frenchman!" Thierry had taught me well.

Chef school was also quite an experience. Besides cooking, the students would go to great restaurants for dinner. That's how I first ate at the Côte Saint Jacques and the restaurants of Marc Meneau and Marc Veyrat. I was told of a chef working in Spain near the border with France in a restaurant called elBulli, but it was too far away. It would have been fascinating to visit, because the year was 1995, and I would have seen the Modernist revolution at an even earlier stage than I did.

Learning about cooking requires a lot of eating, and I have been an enthusiastic eater on my travels around the world. Long ago, I met Tim and Nina Zagat, who became dear friends and recruited me to be the chief gastronomic officer of their company, Zagat Survey. I've eaten a lot of great food with them over the years.

My career at Microsoft kept getting in the way of my cooking, but when I retired from the company in 1999 to start a small company of my own focused on invention, I found myself with a bit more time to explore Modernist cooking techniques. In 2004, I started a discussion on eGullet, an online forum for chefs and cooking enthusiasts, to collect knowledge and observations about cooking sous vide, a remarkable way to control the temperature at which food cooks with a precision that other methods cannot match.

The writing I did for that eGullet thread ultimately led to this book. In another twist of fate, Cynthia Nims, who vetted me for chef school, also was a contributor to this book (see The *Modernist Cuisine* Team, page 5·XLVI) some 15 years after letting me into La Varenne.

If my history and circumstances had been different, I might be a chef today. But I am not unhappy with the way things turned out. I have derived enormous enjoyment from cooking and eating over the years. Ultimately, my strange culinary journey has given rise to this book, and to a way to try to make a contribution of my own to the world of cooking.

Nathan Myhrvold

In the autumn of 2001, while working in a biochemical research lab after graduating with degrees in biochemistry and mathematics, I took a hard look at the path ahead—several more years of schooling and research work—and came to the realization that a doctorate in science was not in my future. So what should I do? There was every reason to believe that I was employable in science. The only problem was that my passions, at that point, lay elsewhere. I decided to get a job as a cook.

To a lot of my friends, this seemed like a bizarre decision. But for me, it was an obvious choice: I had always enjoyed cooking, so why not pursue it professionally? I figured that I would become a better cook and make some money at the same time. (Well, I was right about the first part, anyway.)

As I look back on it, a career in the kitchen seems to have been predestined for me. If my parents are to be believed, my first word was "hot," uttered after I pulled myself up to the stove top. As a toddler, my favorite toys were pots and pans. And when I was slightly older, I attempted recipes from my mother's encyclopedic set of Time-Life's book series *The Good Cook*.

While in college, I came across an interesting book by Harold McGee titled *On Food and Cooking*. It captivated me. Often, when I should have been studying science texts, I was instead busy reading my copy of McGee. It made me realize how much I didn't know about cooking.

So I got to work filling in gaps in my knowledge, cooking my way through books such as Pépin's *La Technique* and *La Methode*. But it was Thomas Keller's *The French Laundry* Cookbook that kept me toiling away into the night, perfecting my brunoise, skimming stocks, trussing chickens, braising short ribs, and thinking about becoming a chef.

As a student, it wasn't long before I desperately needed to subsidize my hobby with a job. My grocery bill was getting out of hand! So when the time came to decide whether to go for the Ph.D. or for a job in a kitchen, I hesitated only slightly.

Unsurprisingly, there was not a lot of interest in hiring me as a cook. But I was persistent, and eventually the Seattle chef William Belickis let me volunteer as an apprentice in his kitchen at Mistral. It was a lucky break: as protégé of the chef David Bouley, William set high standards, cooked great food, and taught me solid technique.

But like many young and ambitious cooks, I thought I needed to work at an acclaimed restaurant, ideally abroad, and preferably in France. My inability to speak French posed a problem, however. Then I read an article about an obscure British chef whose restaurant had one Michelin star and who was applying scientific principles to his cooking. No less than Harold McGee had said that Heston Blumenthal was the future of cooking. It sounded perfect, and, better yet, they speak English in England!

My first meal at Blumenthal's restaurant, The Fat Duck, was an epiphany. I promptly arranged a three-month stage. It was not a glamorous existence: 18 hours of getting your ass kicked daily. If you woke up feeling remotely well rested, then you were seriously late! Still, it was a fantastic job. The food we were cooking was exciting, and Heston was an inspiration. In June, Heston asked whether I would help him get an experimental kitchen up and running. It was not a difficult decision.

Beyond the privilege of working with Heston, running the experimental kitchen for the next four years gave me the chance to work with many talented cooks and scientists. Harold McGee was among them, which finally gave me the chance to tell him, "This really is all your fault."

But all good things must come to an end, and by the late summer of 2007, I was ready to move back to the U.S. with my wife and son. My next job was uncertain, but while getting ready to move, I sent Nathan Myhrvold—whom I had met while working at The Fat Duck—a courtesy e-mail to let him know that he should use my new e-mail address if he would like to stay in touch. Three minutes later, I received a reply: the subject line read "Crazy Idea," and the message said only "Why don't you come work for me?"

And that decision, too, was not difficult.

Chris Young

When I was two years old, I put my family in peril in the name of *chocolat chaud*. I escaped from my room in the middle of the night, found a pot, milk, some Nesquik and a stool to climb on, but alas no matches. The gas was left to fill the apartment for quite a while as I pondered my next culinary venture. Fortunately, tragedy was averted that night, but my sense for culinary exploration was left uncompromised. Our family had a great passion for sharing good food, and they inspired me to communicate through creative cooking.

My grandfather was a gourmand par excellence who regaled us with stories of his experiences in great restaurants, secret wine cellars, and obscure chocolatiers. To him, food was a philosophy: "the essence of existence," he would exclaim before a feast of Gillardeau No. 2 and cold Chablis. He demonstrated the joys to be found in living with an open mind and an adventurous palate.

I began to cook seriously while studying art and literature in college. My friends and parents were patient customers as I experimented with recipes selected from my ever-growing collection of cookbooks. Looking back at those early days, I cringe at some of my interpretations of gastronomy. But the creative freedom was alluring, and soon I was catering dinners and small parties.

After college, I spent a few months at the Institute of Culinary Education in New York City, which led to a two-month externship with Allison and Slade Vines Rushing at Jack's Luxury Oyster Bar, which was serving very refined Southern food. The small team there permitted me far more responsibility than I would have had in any of the other top restaurants. It was Jack Lamb, one of the great restaurateurs of New York, who inducted me into the wild world of professional restaurants. Soon after I started work at the oyster bar, the Rushings returned to Louisiana, and Jack left it to me to run the restaurant. Who knows what he was thinking—I was only 22. But I gave it my all.

Eventually, I grew thirsty for more culinary know-how and bought a one-way ticket to Europe. I made my way to Megève, home of chef Marc Veyrat's legendary restaurant, La Ferme de Mon Père. There I discovered the wonders of foraging and cooking with wild ingredients, which Veyrat incorporates brilliantly into his innovative cuisine.

On moving to London, I landed a *stage* in the prep kitchen of The Fat Duck, Heston Blumenthal's extraordinary three-Michelin-star restaurant. I met the research chefs, Chris Young and Kyle Connaughton, who later invited me to spend a few months working with their development team and with Heston to create new dishes for the restaurant and his 2007 book, *Heston Blumenthal: Further Adventures in Search of Perfection*. Heston's exploration of clever flavor combinations and new ways of presenting and refining food had a profound influence on me.

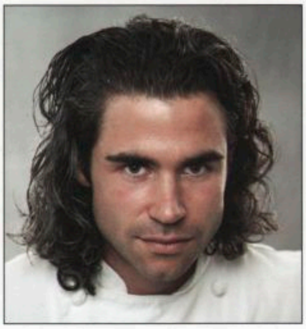
Soon after, during a visit to Lyon, I was asked by Jean Christophe Ansanay-Alex, the owner of L'Auberge de l'Ile, to help open a new restaurant in London. His approach to cooking, while imbued with the soul of traditional Lyonnais food, was incredibly nuanced and progressive; he was a French Modernist in disguise if there ever was one. From him I learned much: from making a proper *blanquette de veau* and *canneles aux pralines roses* to creating liquid-center polenta beignets and crawfish with nectarines and almond milk.

But after a few months in Lyon, I realized I was not yet committed to being settled. I moved back to the United States and, upon reconnecting with Chris Young, stumbled upon a most unconventional but extraordinary opportunity. Indeed, it wasn't until Nathan Myhrvold took me on as head chef of his ambitious book project that I began to really explore the incredible depths of Modernist cooking.

In the process of documenting a culinary revolution in progress, we have developed a strong sense of what Modernist cuisine can be, even should be. To me, Modernist cuisine is about cooking in a thoughtful way that builds on acquired insight while harnessing the precision of technology and embracing a complete openness of taste and creative spirit—all in the pursuit of delicious food.

Guided by Nathan's sensibility, deep knowledge, and incredible creativity, our culinary, editorial, and photographic teams have gone through a tremendous learning process. I hope this book will be approachable, useful, and inspiring to creative chefs and curious cooks everywhere.

Maxime Bilet



1 HISTORY

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HISTORY

Our hunter-gatherer ancestors would find many foods we eat today unrecognizable, but they would likely find a meal at a restaurant such as elBulli or The Fat Duck particularly perplexing. There, foods have unexpected textures and temperatures, and meals are served not just on plates but in an array of specialized serving vessels. Dish after meticulously crafted dish arrives at the table even after diners are well beyond sated, and leftovers are discarded, not preserved for future use. Exotic fruits and vegetables are combined and transformed in ways that people who view food merely as a means of subsistence would never contemplate. At these restaurants, food is about art, not nutrition.

How did we get from our hunter-gatherer origins to this era of culinary innovation? This chapter outlines this process, starting with the important role that cooking played in human evolution. When early hominids harnessed fire and learned to cook food, a series of physiological changes followed. The agricultural revolution led to another major advancement in food preparation, helping to usher in the idea of cooking to improve taste. Up to that time, cooking was primarily used to make food digestible or to remove toxins, but after the advent of agriculture, cooking became less of a pure necessity and more of an art.

Later, in many early civilizations around the world, the aristocracy played an important role in the development of cuisine. Wealthy families hired professional chefs to prepare their food, which led to vast differences between peasant fare and aristocratic food. We'll look at the cuisines that developed in some of the major world monarchies and discuss the role the nobility played in fostering this culinary advancement.

As cuisines diverged and matured around the world, tradition and innovation often came into conflict. Various culinary movements arose to upend the traditions of the time, but the innovations they introduced soon became codified as new traditions. In France, for example, chefs such as Antonin Carême and Auguste Escoffier established strict culinary rules and codes that had a profound influence on high-end cuisine as we know it in the Western world today.

In response to those strict rules, the Nouvelle cuisine movement developed in the mid-20th century. Setting out to shake up the French culinary establishment, the chefs associated with this movement largely succeeded; they helped to create a true revolution.

We will argue, however, that the ultimate culinary revolution is the one that has taken place in the past two decades. We call this the Modernist movement, and we'll look at what makes it so revolutionary and so modern. We'll examine the various factors that set the stage for Modernist innovations, including the revolution in industrialized food in the 1950s; Ferran Adrià's amazingly creative work at elBulli, in Spain; Harold McGee and the advent of food science for the home chef; Heston Blumenthal's embrace of science and creativity at The Fat Duck, in England; and the advent of the sous vide method. Finally, we'll discuss where the Modernist revolution is today—and where it is headed.

Fire is the fundamental cooking tool.

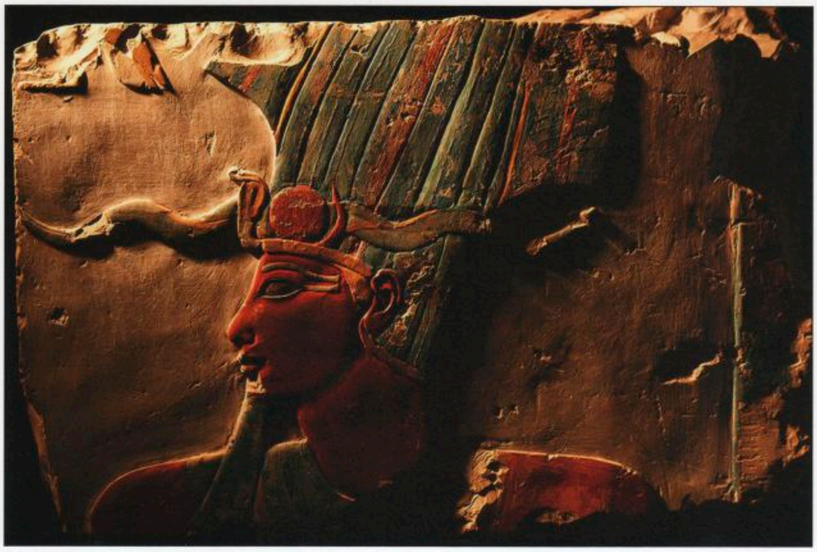
ORIGINS OF COOKING

Nobody knows who the first cook was, but at some point in the distant past, early humans conquered fire and started using it to prepare food. Researchers have found what appear to be the remains of campfires made 1.5 million years ago by *Homo erectus*, one of the early human species. In his intriguing book *Catching Fire: How Cooking Made Us Human,* Harvard University anthropologist Richard Wrangham argues that cooking wasn't just a nicety; it played an essential role in human evolution. Cooking foods makes them more digestible, so the calories and some of the nutrients in them are easier to absorb. Thus, cooking allowed early humans to tap a wider variety of food sources and gain more nutrition from them.

The first cooks didn't do much to their food in the way of preparation or technique. We don't have any recipes from prehistory, but we do have archaeological evidence of food preparation, backed up by our knowledge of how modern-day hunter-gatherers prepare their food. Meat is either roasted over a fire or boiled to make it tender; fruit is gathered and peeled; nuts are shelled. That's about it.

Necessity, rather than taste, often dictated how hunter-gatherers of the past prepared their food. Some foods had to be prepared carefully to remove toxins. Native American tribes in California developed a procedure to make acorns edible by removing their bitter tannic acid. Farther south, native peoples in Peru, Colombia, and Venezuela learned to remove the cyanide from cassava (also called manioc), a starchy root that is used today to make tapioca and is a staple crop across the tropics.

Ancient Egyptians invented many important culinary techniques, including the practice of force-feeding geese to make foie gras (see page 3·138).



Hunter-gatherers also processed foods to preserve them. Because some hunter-gatherer societies faced uncertain food supplies, particularly in winter, they developed techniques such as smoking and drying to make foods last longer. They also created preparations such as pemmican (a mixture of meat, fat, and sometimes fruit) to preserve foods. Alcohol also required elaborate preparation, and societies around the world (motivated more by pleasure than by necessity) perfected means to ferment fruit or grain into alcohol.

Agriculture was invented independently at different places and times around the world, as people domesticated local plants and animals. This advance was a major turning point in human history, because farming fed people more reliably than hunting wild game and gathering wild plants did.

Farming wasn't easy in those early days. Although farming worked well when the crops came in, a crop failure meant famine and death. Overreliance on one or a handful of crops also resulted in malnutrition when those crops lacked the necessary vitamins or nutrients. As the archaeological record clearly shows, early societies that relied on agriculture had many health problems, including starvation and vitamin deficiency. Gradually, however, agricultural societies improved their farming skills, increased their productivity, and decreased the risk of famine. Farming became more productive than hunting and gathering.

Yet agriculture also made the diet boring. Whereas hunter-gatherers relied on a wide variety of plants and animals, which changed with the seasons, farmers were more restricted in the crops they could plant and thus ate the same foods over and over. This motivated people to come up with ways to make their diets more interesting and palatable. A new reason for cooking was born: improving the taste and variety of food.

Agriculture also enabled the development of civilization. For the most part, hunter-gatherers could not stay in one place very long, nor could they live together in large numbers. Agriculture changed that. Farm fields needed to be tended, so farmers had to stay put. Agriculturalists needed permanent buildings for homes and other uses. In response, cities and towns sprang up.

Because agriculture freed at least some of society from the task of providing food, people began to spend time doing other things. Visual arts existed before civilization, as cave paintings and petroglyphs show. So did music. But each of these art forms got an enormous boost from the advent of civilization, as did writing, religion, and politics. In societies nurtured and supported by farmed food, all aspects of human culture flourished, including cooking. Culinary customs were born. Traditional cooking had begun.

Various forms of traditional flatbread have been invented all over the world.

Peasants, Chefs, and Kings

In most traditional human societies, the task of daily food preparation fell primarily to women—mothers and grandmothers—and both men and women were heavily involved in food procurement. Civilization allowed more people to specialize in other occupations, and this trend eventually produced a class of professional chefs, whose main job was cooking for others. Tomb paintings, sculptures, and archaeological remains from more than 5,000 years ago clearly show that ancient Egypt already had many different food-related jobs, including butchery, baking, brewing, and winemaking. All of these professions had their own shops and facilities, often with multiple employees working in well-organized kitchens.

Culinary professionals generally cooked quite differently from the mothers and grandmothers who were cooking only for themselves and their families. Baking leavened bread, for example, was largely a professional activity, because ovens were expensive to own and operate. It took a lot of fuel to heat the earth, clay, or brick interior of an oven, and once you did, it would be wasteful to cook only one loaf of bread. Anyone who could afford to own and operate a large oven was either a professional or someone who could afford to employ one. Most people couldn't, so they bought or bartered for their bread.

Flatbreads, in contrast, could be cooked simply in a pan or even on a flat rock. Cultures all over the world invented various forms of flatbread—from the tortilla in Mexico to the *chapati* in India to *lefse* in Norway. Because flat breads didn't require an oven or any elaborate preparation, they were typically made at home as part of peasant cuisine.

The professionalization of baking, brewing, and winemaking occurred for three reasons: capital equipment was expensive; increasingly complicated food products required skill and expertise to prepare; and there was a growing number of affluent customers. Rich people wanted to employ chefs and culinary artisans both for their practical uses and as status symbols. People willing to pay more for a better meal created a ready market for new recipes and techniques.

Civilization is defined in many ways, but most commonly as a human society that has developed advanced agriculture, long-distance trade, specialized professions, and at least some urban populations.

In early civilizations, wealth was synonymous with political or religious power, so the primary employers of professional chefs were kings, aristocrats, or priests. Much the same phenomenon occurred in the arts. Painters produced commissioned works for the king or the high priest; jewelers made the king's crown and the queen's jewels; architects designed the palace and temples.

This divide between professional chefs cooking for the wealthy and peasants cooking for themselves drove the development of many cuisines. Each side influenced the other. Professional chefs sought to do things differently than the masses, to create a distinct culinary experience for their elite

As early as the 17th century, England had a fascination with the Continent and with French chefs. More often than not, when English gentry wanted to eat well, they imported a French chef, a pattern that continued for most of the next 350 years.

clientele. Common people sought to adopt some of the finer things in life by copying the dishes served at royal tables.

Countries with a long history of a large and stable aristocracy or ruling class developed the most complex, highly refined, and elaborate cuisines. These were the people who could employ professional chefs—and use food as a form of one-upmanship.

France is perhaps the best example. Despite having a vibrant regional peasant cuisine, France has been dominated by aristocratic food for centuries. Early on, French nobles and other members of the ruling class used dinners as status symbols. Most of the early French chefs, such as La Varenne and Antonin Carême (see Early French Gastronomy, next page), climbed the career ladder by trading up to ever more powerful and wealthy patrons.

France is especially interesting because it achieved renown for its cooking very early. La Varenne's book *Le Cuisinier François,* published in 1651, was translated into English in 1653. Titled *The French Cook,* the English edition included the following preface, which took the form of a dedication to a wealthy patron (as was customary at the time):

> TO THE RIGHT HONORABLE
> John, Earl of Tannet
> My very good Lord. Of all Cookes in the World the French are esteem'd the best, and of all Cookes that ever France bred up, this may very well challenge the first place, as the neatest and compleatest that ever attend the French Court and Armies. I have taught him to speak English, to the end that he may be able to wait in your Lordships Kitchin; and furth your Table with severall Sauces of haut goust, & with dainty ragousts, and sweet meats, as yet hardly known in this Land.

Besides the quaint punctuation and spelling, this preface clearly lays out what would be the story for the next three centuries: France had a reputation for having the world's best chefs.

Chinese food is another example of an aristocratically driven cuisine. The enormous variety of Chinese dishes stems from the imperial court, which governed China for more than 1,000 years (under one dynasty or another). The same sort of thing occurred with the Moghul rulers of northern India and with the kings of Thailand. In each country, the monarchy and its cadre of bureaucrats and aristocrats supported full-time, professional chefs, who created a rich and varied cuisine.

England also had an elaborate monarchy, which ruled for a thousand years, but the geography made the development of a sophisticated cuisine difficult. Plant and animal diversity is a direct result of climate: a cold climate leads to relatively low diversity, providing less varied ingredients for a chef to work with.

As a result, far northern (or in the Southern Hemisphere, far southern) cuisines do not have the variety of dishes that equatorial regions produce. The Viking kings of Scandinavia and the tsars of Russia had well-established courts

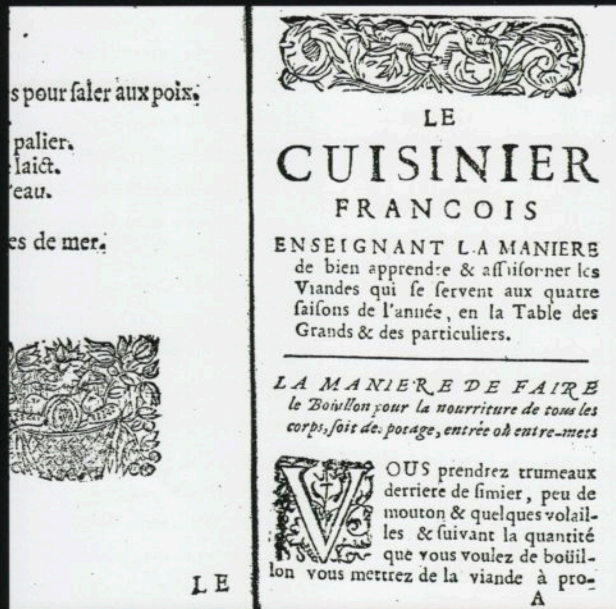
Cooking traditions were documented in cookbooks with period recipes and techniques, as well as in paintings like these: a cook preparing liver alongside a butcher in a 14th-century kitchen (left) and an elaborate medieval Italian banquet (right).

THE HISTORY OF

Early French Gastronomy

French cuisine was arguably born in the 17th century. The surviving cookbooks before that point from France, England, and Italy show a remarkable uniformity, describing food heavily spiced, mainly with ginger, cinnamon, and black pepper. The use of spices and the flavor profiles were virtually identical in all three countries.

But in the 1650s and 1660s, French chefs and cookbook authors began to take a radical new approach to food that emphasized fresh ingredients and flavor for its own sake. Writers François Pierre de La Varenne (in *Le Cuisinier François,* 1651) and Nicolas de Bonnefons (in *Les Délices de la Campagne,* 1654) extolled the virtues of vegetables prepared with simple seasonings that allowed their true flavors to shine. These authors also helped systematize culinary skills by identifying basic sauces and flavorings, such as roux, mayonnaise, and velouté.


s pour ſaler aux poix.

palier.
laict.
eau.

es de mer.

LE

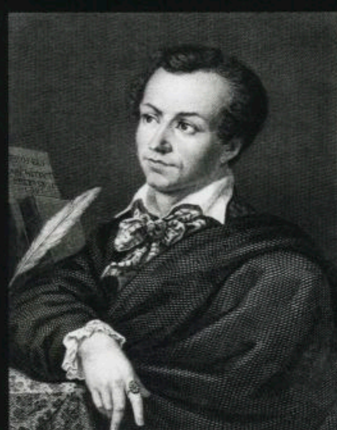
LE
CUISINIER
FRANCOIS
ENSEIGNANT LA MANIERE de bien apprendre & aſſaiſonner les Viandes qui ſe ſervent aux quatre ſaiſons de l'année, en la Table des Grands & des particuliers.

LA MANIERE DE FAIRE le Boüillon pour la nourriture de tous les corps, ſoit de potage, entrée où entre-mets

VOUS prendrez trumeaux derriere de ſimier, peu de mouton & quelques volailles & ſuivant la quantité que vous voulez de boüillon vous mettrez de la viande à pro-
A

Le Cuisinier Francois (The French Chef) was La Varenne's master work.

The next major advancement in French gastronomy came in the early 19th century, after the French Revolution. Antonin Carême became famous by cooking for royalty (including Napoleon and Britain's future king George IV) and the extremely wealthy (including the Rothschilds of Paris). Carême disliked the cuisine of the prerevolutionary regime and aimed to create a culinary ethic befitting the new France. In his multivolume book *L'Art de la Cuisine Française aux XIX^e Siècle* (1833-1834), he advanced the notion that cuisine was both an art and a science. The revolution also helped spur the development of restaurants, as the cooks of the deposed aristocracy looked for work. Carême brought into French restaurant kitchens a new emphasis on sanitation and purity, but he also prized beautiful presentations, rich ingredients, and good service. His ideas quickly caught on in Parisian restaurants and the rest of France.


Antonin Carême was a chef to royalty.

Around the same time, lawyer and politician Jean Anthelme Brillat-Savarin was developing the concept of gourmandise. In his book, *Physiologie du Goût* (1825), he explained that humans distinguish themselves from other animals by treating food not only as nourishment but also as art. This collection of recipes, essays, and stories about food instantly became a best seller (to the great envy of Carême). Unfortunately, Brillat-Savarin died of pneumonia two months after the book's publication.

A few decades later, building on Carême's developments, chef and author Georges Auguste Escoffier systematized French cooking in a way that had never been done before. His *Le Guide Culinaire* (1903) lists dishes according to their order of presentation and includes the first à la carte menu. Escoffier radically simplified food service by advocating the abandonment of elaborate garnishes and the use of seasonal ingredients. He also streamlined the organization of professional kitchens.

Escoffier's friend Prosper Montagné, a chef in the kitchens of high-end European hotels such as The Ritz, helped disseminate Escoffier's views in his 1938 book *Larousse Gastronomique.* This encyclopedic tome, which remains in print to this day, contained 3,500 recipes, plus a wealth of information about culinary history, cooking techniques, ingredients, and more. It is considered one of the definitive works on classical French cuisine—a culinary style that held sway for roughly three decades after Escoffier's death in 1935. At that point, it was supplanted by Nouvelle cuisine (see page 24).

Abu l-Hasan "Ali Ibn Nafi," known as Ziryab, was a prominent court member in the Umayyad Dynasty of Córdoba between 822 and 857. He is credited with the introduction of asparagus and the creation of the three-course meal (soup, main course, and dessert). He also introduced crystal goblets to table service, and it is even said that he invented the tablecloth.

The Forme of Cury is the oldest cookbook written in English. It was compiled about 1390 by the master cooks of King Richard II. Researchers studying it made a surprising announcement in 2003—the book contains a recipe for lasagna. The dish, called *loseyns* in Old English (pronounced "lasan"), consists of noodles rolled as flat and wide "as paper," cooked in broth, layered with cheese, and baked. This recipe predates any Italian reference to the dish, which leads to the surprising conclusion that lasagna may be British.

and ruled for centuries, but like England, they did not have elaborate cuisines (and, like the English, they imported their share of French chefs).

Sweeping views of history, like the patterns in cuisine discussed here, are always simplifications of a more complicated situation, so there are exceptions. Spain fits the theory only up to a point. It has a Mediterranean climate and had a long-standing monarchy and aristocracy that accumulated enormous wealth by exploiting the New World. Yet traditional Spanish cuisine owes more to farm and peasant life than to that of the great Spanish court. That is less true in Andalusia, where cuisine from the Islamic courts made a lasting contribution.

There are many wonderful traditional German foods, but most come from the peasant table, such as the numerous varieties of hearty sausages and hams. One reason may be that Germany never had a long-standing aristocracy of sufficient scale. Germany was not unified as a country until the late 19th century. Before that time, the region was carved into pieces ruled by various European empires or complex confederations of countries such as Prussia, Bohemia, Swabia, and Bavaria. Germany also suffered from its northern location, which limited the diversity of indigenous fruits, vegetables, and herbs.

Italy provides an even better example of how political fragmentation can affect cuisine. Blessed by a favorable climate, the region produces a full range of fruits and vegetables, which is ideal for culinary diversity.

Italy would not be unified as a country until 1870. In the interim, the region was a patchwork of duchies, principalities, city-states, republics, and territories controlled by foreign monarchs. There was no permanent or centralized Italian monarchy, and thus no royal court for which chefs could create new dishes.

Italy did have one permanent fixture, the Papacy, and some distinctive foods were developed for its religious feasts and celebrations. But this was not the same sort of imperial haute cuisine found in France or China.

Italy was the birthplace of the Renaissance and played a central role in the creation of modern Western civilization. Yet Italy has always sought legitimacy for its food in its peasant origins. Some experts argue that Italy's great cities—such as Rome, Milan, and Florence—have been the centers of its culinary innovation, but the culinary tradition within Italy tends to be rooted in the countryside. Although professional chefs and city dwellers have made many contributions to the cuisine, the heart of modern Italian cooking is still

THE HISTORY OF

Apicius

Marcus Gavius Apicius was a famous Roman epicure who lived in the early 1st century A.D. Early histories tell us that Apicius went to great lengths to find good ingredients—for instance, he once sailed all the way to Libya to eat some supposedly great prawns, only to return home without finding any to his satisfaction. One of the first cookbooks in recorded history is attributed to him, but historians have since concluded that the 400-plus recipes in the book—titled *De re coquinaria,* or *The Art of Cooking*—were not compiled until the 4th or 5th century and derive from many sources. Today the book is often referred to as *Apicius*.

Like many contemporary cookbooks, it is divided into sections based on main ingredients, although unlike contemporary cookbooks, it did not specify measurements and often omitted preparation techniques, simply saying "cook until done." The book included sections on meats, vegetables, legumes, fowl, and seafood. The meat chapter offered recipes for domestic livestock as well as venison, boar, and even dormouse (a small member of the squirrel family), while the fowl section included recipes for crane, ostrich, flamingo, and peacock. Most of the recipes in the book—even sweet dishes that we would consider desserts—included a sauce made with *garum,* a fermented fish sauce (see page 5·121).

This sauce and the plethora of spices are typical of the sophisticated and elaborate Imperial Roman cuisine, which is almost nothing like what we think of as Italian food. Instead, it is closer in spirit to Thai or Indian cuisine today, although it has a flavor profile that is quite distinct from theirs or those of other extant cuisines.

THE HISTORY OF
Laser

Silphium appears on a coin from Cyrene, a Greek colony in what is now Libya. Silphium, the source of laser, was its major crop.

Laser, a seasoning used in ancient Greece and Rome, was one of the first "it" ingredients. Extracted from silphion, one of the wild giant fennels known as silphium, laser was a resinous juice used extensively in ancient Mediterranean cuisines, primarily in sauces. References to the ingredient were peppered throughout the first Roman cookbook, *Apicius* (see previous page). People also ate silphium stalks, roots, and leaves, whose flavor may have been similar to that of parsley or celery. Farmers were supposedly unsuccessful in their attempts to grow silphium, so it became a rare and expensive commodity—literally worth its weight in silver.

Why was the seasoning so sought after? In addition to being a versatile culinary ingredient, laser was used for medicinal purposes (primarily as a digestive aid) and possibly as a contraceptive. Some scholars believe that its birth-control properties were the real reason for its popularity. In any event, silphium became extinct around the 1st century A.D., probably due to overharvesting or overgrazing.

Its closest living relative is asafetida, a far more pungent (even foul-smelling) plant that is used as a condiment in parts of South America and India. The Romans also used it, but they complained that it was vastly inferior to laser. "The Cyrenaic kind [laser], even if one just tastes it, at once arouses a humour throughout the body and has a very healthy aroma, so that it is not noticed on the breath, or only a little; but the Median [asafetida] is weaker in power and has a nastier smell," wrote Pedanius Dioscorides, a Greek pharmacist and botanist practicing in Rome in the 1st century A.D.

considered to be in the nation's fertile land and the people who farm it.

At an earlier point in history, the Italians did have a central political authority—when ancient Romans ruled their empire. The Roman Empire had a fully developed imperial cuisine that drew on foods from all over the known world. Roman food preparations have been passed down in the ancient cookbook *Apicius* (see previous page). The cook who compiled this book wrote for other professional chefs, and he described a rich and varied cuisine. Many of the recipes call for imported spices and show considerable sophistication.

But from a culinary perspective, Roman is not the same as Italian. Virtually none of the dishes mentioned in *Apicius* are recognizable as the Italian cooking we know today.

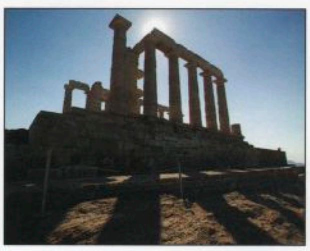
One of the key Roman condiments and seasonings was *garum*, a fermented fish sauce similar to Asian fish sauce and thought to be a very early predecessor of Worcestershire sauce (see page 5·121). The Romans added their fish sauce to everything, including desserts, but it doesn't appear in today's Italian recipes at all.

The Romans also used lovage extensively, along with cumin and coriander. These flavors are rarely (if ever) encountered in contemporary Italian cuisine. Meanwhile, basil, which is a staple seasoning in Italian cooking today, is mentioned only once in *Apicius*.

Among the most sought-after Roman seasonings was laserpicium, or laser (see above), the extract of a plant that the Romans loved so much, they ate it to extinction. Losing laser was a blow

The asaroton is a style of Roman mosaic depicting the unswept floor after a banquet. As one might guess, it was popular in dining rooms. These mosaics tell us a lot about ancient Roman eating habits—and how messy the banquets were. It also tells us that the Romans had a sense of humor. Why else would they have used using expensive mosaics to mimic a morning-after mess?

As Italian as fermented fish sauce? Amazingly, that was the omnipresent seasoning of both the Romans (garum) and the ancient Greeks (garos).



The ancient Greeks invented much of our current political structure, as well as the origins of our mathematics and philosophy. While we can still see parts of their seminal contributions to literature and architecture, many works documenting their cuisine have been lost or are not well known.

The ancient Greek historian Herodotus tells us that the ancient Egyptians "never sow beans, and even if any happen to grow wild, they will not eat them, either raw or boiled." Yet today, the national staple dish of Egypt is *fuul*, or *fool*—stewed fava beans.

to Roman cuisine on the order of what would happen to French cooking if black truffles became extinct.

Garlic is only rarely called for in *Apicius,* and when it is, the quantity is minuscule—often not enough to taste. Imagine Italian food without garlic or basil; now imagine it loaded with lovage, cumin, coriander, and fish sauce. Ancient Roman cuisine clearly did not have the same flavor profile as the Italian food of today. The amazing conclusion is that ancient Roman cuisine was utterly different from what we think of as Italian cuisine today.

The fall of the Roman Empire in about 500 A.D. ushered in the Middle Ages, a 1,000-year period during which many vestiges of Roman culture, including recipes, were obliterated. Italian food as a concept disappeared and was replaced by a pan-European medieval cuisine that had little to do with the previous Roman cuisine. Medieval European cuisine as a whole seems to have had little regional variability—the Italian cookbooks of the era contain recipes that are virtually indistinguishable from those of France, England, and other European countries.

Medieval cuisine was highly flavored with imported spices, particularly pepper, cinnamon, ginger, and saffron. The love of imported spices was shared with ancient Roman cuisine, but the spices, dishes, and flavor profiles were entirely different.

An analysis of an early English cookbook found that fully 40% of the savory dishes contained large amounts of cinnamon. Ginger was the second most popular spice in savory dishes. This food bears little resemblance to European cuisine today. Only a few rare dishes hint at the highly spiced past: gingerbread, for example, or the cardamom-laced breads of Scandinavia. The flavor profile of European food in the Middle Ages was in many ways closer to the spice-oriented profile we associate with Indian or Thai food today. Ultimately, the medieval cuisine disappeared as various regions developed their own culinary traditions.

Similarly, contemporary Greek food is mainly of recent peasant origins, although it reflects some Turkish influences from the Ottoman Empire, which ruled Greece for centuries. The cuisine today bears few similarities with the delicate, often sophisticated cooking of ancient Greece.

In antiquity, the seafaring Greeks learned from neighboring civilizations and brought home new flavors, such as lemons from the Middle East, especially during the exploits of Alexander the Great. Greeks took their culinary expertise with them to Rome, where Greek cooks introduced composed dishes to the Romans and the rest of Europe.

Early Greek traders settled in southern France 2,500 years ago, founding Massalia (now Marseilles) and introducing wine to the region that would later produce Côtes-du-Rhône vintages, according to a recent Cambridge University study.

The chief record of early Greek food and drink remains fragments from lost literature, which have survived only in quotations recorded in later works such as the comedies of Aristophanes. What may be the world's first gourmet travel book, *Life of Luxury*, is a mock epic poem written about 330 B.C. It is preserved in excerpts quoted in Athenaeus's *Philosophers at Dinner*, from 200 A.D. The poet who wrote it, Archestratos of Gela, Sicily, toured the cosmopolitan ancient Greek world from the Black Sea to southern Italy, recording the cuisine. He favored fish dishes prepared simply with light seasoning such as fresh thyme and olive oil, or with cheese sauces and pungent herbs such as silphium. *Garos* (fermented fish sauce) or herb pickles were balanced with honey.

Sicily was also home to the ancient Greek colony of Sybaris, known for its elaborate food and entertainment—source of the word "sybaritic" today. The colony held cooking contests and crowned the winning mageiros (cook). Sybaris even had a law protecting culinary inventions: "And if any caterer or cook invented any peculiar and excellent dish, no other artist was allowed to make this for a year; but he alone who invented it was entitled to all the profit to be derived from the manufacture of it for that time."

In contrast, the mainland Greek city-state of Sparta had a strict military culture marked by frugality and the avoidance of luxury—source of the word *spartan.* The most prevalent dish, for example, was black broth, a thin soup of pork, pig's blood, and vinegar. A Sybarite writer noted, "Naturally the Spartans are the bravest men in the world. Anyone in his senses would rather die 10,000 times than take his share of such a sorry diet."

In general, the ancient Greeks valued their chefs. Consider this passage about Demetrius of Phalerum, a diplomat who governed Athens in the early 4th century B.C.: "He bought Moschion, the most skillful of all the cooks and confectioners of that age. And he had such vast quantities of food prepared for him every day, that, as he gave Moschion what was left each day, he (Moschion) in two years purchased three detached houses in the city." That's the kind of success any chef today would like to have. It's made all the more poignant by the word "bought"; Moschion, like many cooks of his era, was a slave. Unfortunately, the recipes of Moschion, the legally protected dishes of Sybaris, and even the bad black broth of Sparta have all vanished.

That is a sad fact of culinary history. One of the great losses to human culture is that the food of many empires did not survive. Homer records many feasts in the *Iliad* and *Odyssey,* but frustratingly without recipes. Egyptian cooks in the pharaohs' courts did not record their recipes. Yet Egypt invented foie gras! What other delicacies did it have? We may never know. When civilizations die or disperse, their cooking often dies with them. Some peasant dishes may survive, but the refined dishes of the upper classes usually don't.

Among the most significant losses in the history of gastronomy is the disappearance of ancient North and South American recipes, including those of the Aztec, Incan, Mayan, and Mound Builder civilizations.

Mayan cuisine relied heavily on chocolate, domesticated 3,000 years ago in what is now Honduras. Au Cacao, or Lord Chocolate, a king who ruled the Mayan city-state of Tikal, was named after the prized ingredient. The Mayan word for cacao, *kakawa,* means "god food," and the cacao tree was considered sacred (as was the maize plant).

The Mayans also had a rich culture that produced an elaborate society centered on great stone cities. They made many major discoveries in mathematics and astronomy. It seems likely that a group of people who worshipped chocolate and named their kings after it probably cared enough about food to have a distinctive cuisine with some pretty good recipes.

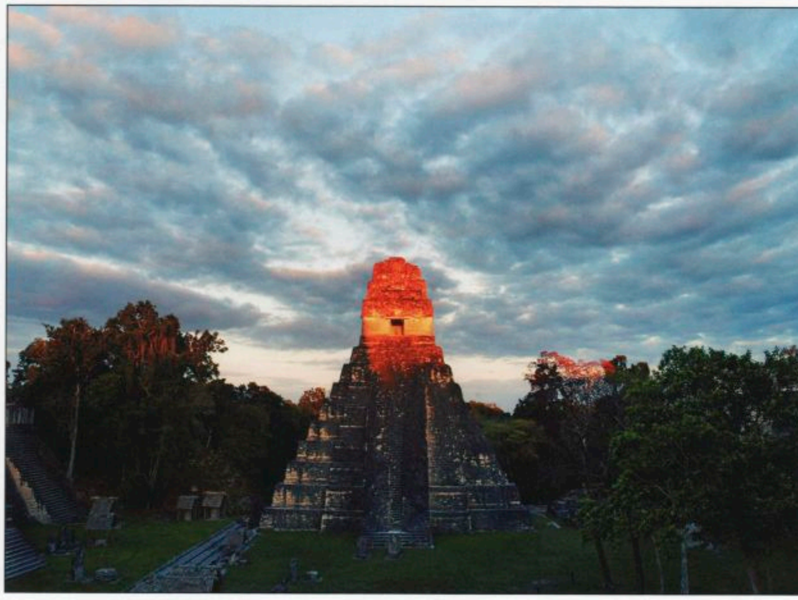
But we'll never know. The Mayan civilization began to decline in 900 A.D., some 600 years before the Spanish conquistadors arrived. A large number of Mayan books, which might have included a Mayan equivalent of *Apicius,* were confiscated and burned by Bishop Diego de Landa in 1562. Today, only three survive, none of which mentions cooking. The peasant cuisine in the area that has survived seems unlikely to represent the full range of aristocratic Mayan cuisine.

The story of Aztec cuisine is similar. In this case, we have one eyewitness report from Bernal Díaz del Castillo, a conquistador who accompanied Hernando Cortés. Díaz was present at a dinner served to Motecuhzoma, the Aztec emperor:

> For his meals his cooks had more than 30 styles of dishes made according to their fashion and usage; and they put them on small low clay braziers so they would not get cold. They cooked more than 300 dishes of the food that Motecuhzoma was going to eat, and more than a thousand more for the men of the guard.

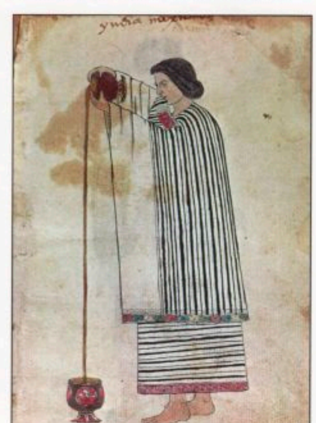
No one knows what delicacies would have been served in this 30-course tasting menu.

Other civilizations, such as the Inca of Peru and the Mound Builder culture of Cahokia, in the central United States, likely had many great recipes as well, but the efforts of their professional chefs are lost to history.



Tikal, one of the great cities of the Mayan world, was once ruled by Au Cacao, whose name translates as "Lord Chocolate."

An early Spanish drawing from 16th-century Mexico shows chocolate being poured from a great height into a bowl.



EVOLUTION AND REVOLUTION

Much of the motivation for the discovery of the New World was related to cooking. Christopher Columbus and other early explorers were looking for better ways to trade spices—an extremely lucrative and strategic business, due to the high reliance on spices in European cuisine at the time.

By some measures, Spain has had more influence on Western cuisine than any other country in the world. The new fruits and vegetables that Spanish conquistadors brought back to Europe from their explorations of the New World utterly changed European cuisine. Explorers from other European countries—including the Norwegian and Icelandic Vikings, the Portuguese, and the English—also imported New World foods, but Spain took the lead in making agricultural use of the newfound plants, including tomatoes, potatoes, beans, corn, cocoa, and chili peppers.

One of the themes of this book is exploring the culinary revolution that has occurred in the past 20 years and that continues to unfold in cutting-edge kitchens around the world. Like all revolutions, it is defined in part by its context—the previous world order that it is rebelling against and changing. Understanding this context is essential to appreciating the new regime.

The Myth of Tradition

There is a large and vocal school of thought in the world of food and gastronomy that celebrates tradition. People who advocate this point of view seek out the authentic and original aspects of cuisine, placing in high esteem food experiences that conform to traditional styles and values. This group's motto might be, "Old ways are best." People in this camp are generally more interested in a recipe from Grandma's farmhouse than they are in a contemporary chef's latest creations.

This view is possible, however, only if you shut your eyes to history. What we call "traditional" cuisine is a convenient fiction. Culinary practices have been changing constantly throughout history. Investigate a "traditional" food closely enough, and you'll find that it was new at some point, perhaps not even all that long ago. Tradition, at least in the food world, is the accumulated leftovers from changes wrought in the past.

Italian food provides a great example. It is one of the most popular national cuisines in the world; you can find Italian restaurants in every major city on earth. The cuisine is a favorite of many traditionalists, who see it as a deeply authentic, artisanal, homey kind of food. Italian cuisine is certainly wonderful, but the notion that it is steeped in native tradition is unfounded. Almost all modern Italian cuisine is based on ingredients and recipes borrowed from outside Italy.

Pasta isn't Italian. The Chinese ate noodles at least 3,000 years earlier than the Italians did. One theory says that pasta was brought back to Italy by Marco Polo in the late 13th century, but more recent scholarship suggests that Arab traders introduced pasta to Muslim Sicily several centuries before Polo's trip. Either way, pasta is surely not of Italian origin. *Mozzarella di bufala* is Italian, but the water buffaloes that produce it aren't—they are native to Southeast Asia. Tomatoes are indigenous to the Americas, as are the corn used to make polenta and the chocolate and vanilla used in desserts. Potatoes, which work so nicely in potato gnocchi, are from South America, as are the hot peppers that flavor many Italian sauces. Rice, now used in Italy to make risotto, originated in Asia. Eggplants came from India. Carrots came from Afghanistan. Almonds came from the Middle East.

How about espresso—surely that counts as Italian? Indeed it does, because the technique was invented in Italy, though of course the coffee bean was originally imported from the Arabian Peninsula. And espresso only seems traditional now; it was originally invented as a fast food in the early 1900s (see Espresso's Invention, page 4·372). The word *espresso* actually means "fast."

It would be difficult to find a traditional Italian menu based only on ingredients that are native to Italy. Even if you did, that menu would likely bear little resemblance to medieval Italian or ancient Roman cuisine.

What caused these shifts? Why did the ancient Romans avoid basil and garlic, while modern-day Italians love them? Why do Italian cooks now eschew fermented fish sauce, cumin, and lovage? And what about the medieval phase, when there was no Italian food as such and Italians ate the same heavily spiced foods as the English?

Those changes didn't happen overnight. A period of gradual evolution de-emphasized some flavor profiles and increased the popularity of others. Certain ingredients lost their appeal, while other, newly discovered ones came to dominate the culinary landscape.

This is not to devalue Italian food—far from it. Italian chefs deserve tremendous credit for creating a delicious and varied cuisine. The point we are making here is that it's wrong to view Italian cuisine as a collection of carefully maintained culinary traditions from the past. Indeed, it devalues the creativity of Italian chefs to imagine that they are just passing along their grandmothers' recipes verbatim. The history of Italian food is not about faithfully preserving authentic traditions; it is about creativity, innovation, and novelty.

Similar stories occur around the world. At a recent Sichuan-style dinner in Beijing, one of us tried to find a dish on the table that was entirely Chinese—and failed, because most Sichuan food has chili peppers in it, and they are native to South America. The Chinese province of Sichuan has a long-standing interest in spicy foods, including the native Sichuan peppercorn and imported black pepper. However, the imported chili so appealed to people that they adopted it with great enthusiasm. Chilies weren't the only foreign imports on the table; other dishes had eggplant, okra (from Africa), and corn.

This pattern holds true even in less prosperous societies, such as subsistence-farming communities in Africa, where the major staple crops include cassava and corn (both from South America). These two foods are the most important sources of nutrition for Africa. Other major crops in Africa that originated elsewhere include bananas (from Southeast Asia) and peanuts, sweet potatoes, and beans (all from South America). The only staple crops native to Africa are millet, sorghum, and okra, but they are very much in the minority.

Imported ingredients gain acceptance at different rates. New World explorers brought many new ingredients back to Europe, but they didn't all become popular right away. Some, such as chocolate and tobacco, were instant sensations. Others took decades or longer to infiltrate a country's cuisine.

A recent example is the kiwifruit, which was introduced to England in 1953 and the United States in 1962. In the U.S., the kiwi's chief champion was Frieda Caplan, a distributor of exotic fruits and vegetables. At the time, kiwifruit was grown only in New Zealand, and marketing it was an uphill battle. But Caplan's efforts, along with its adoption by chefs of the Nouvelle cuisine movement (see page 24), made the fruit popular worldwide.

Today, kiwifruit can be found in practically any supermarket in the United States. An Internet search in 2010 for kiwifruit recipes returned more than 1.5 million hits. At some point in the future, recipes that include kiwifruit will be considered part of traditional American cuisine, and likely the cuisines of several other nations as well. Interestingly, the kiwifruit isn't even native to New Zealand; it originally came from southern China.

Like new ingredients, new techniques are typically introduced one or a few at a time. Thus, people don't actually experience a "change in cuisine" as such; they just try a new dish. If they like it, more people begin to make and eat it.

In 1981, chef Michel Bras invented a chocolate cake with a liquid center. Its fame spread, but it was a complicated and exacting recipe to to make. Then, in 1987, Jean-Georges Vongerichten prepared a simple chocolate cake (based on a recipe from his mother) for a catered party of 300. Hurrying to serve the group, he and his team crowded their ovens and rushed the cakes to the table, only to discover they were grossly underbaked and still liquid in the center. Expecting the worse, Vongerichten entered the banquet room to apologize, only to be greeted by a standing ovation. They loved the liquid center cake. It created a sensation, and "molten chocolate cake" of one form or another is now found on restaurant menus and in home kitchens around the globe.

In this evolutionary approach, nobody sits down to a totally new cuisine all at once; instead, the culinary development occurs gradually, one new dish at a time.

This is also what happens with biological evolution: wildly divergent species are produced by the accumulation of small changes. And it's the process that shapes human language. English and German split from a common Germanic ancestor language, just as French, Spanish, Italian, and Romanian diverged from the Latin of the ancient Romans. As with a language, you can't change a cuisine overnight, but over a surprisingly short period, you can nonetheless change it completely.

People who subscribe to the traditional view of culinary history tend to forget this. The influential food writer Michael Pollan recommends that we eat only foods that our great-grandmothers would recognize. At first, this sounds like sage advice, particularly if you are tired of the recent onslaught of junk food. But consider this: if your great-grandmother and her great-grandmother (and so forth stretching back in time) had taken Pollan's advice, where would we be? It doesn't take very many generations of this great-grandmother rule to erase all of what we know today as traditional foods.

Michel Bras's chocolate *coulant* is a two-part recipe. A frozen ganache core is surrounded by a crisp, cookie-like dough made with rice starch. The assembly is baked in a special mold.

Vongerichten's cake is a simple one-part chocolate cake batter made with ordinary flour; its only distinction is being baked briefly in a very hot oven. Both cakes attain a liquid chocolate center, but by different means. The simpler version was easier for chefs of less skill to copy, which helped it gain popularity. Today, the vast majority of all recipes for the cake are closer to Vongerichten's approach.

Kiwifruit is an example of an exotic fruit that took a while to gain acceptance.

Tomatoes were imported to Europe from the Americas by Spanish conquistadors in the mid-1500s, but three centuries elapsed before the fruits were fully accepted, due to lingering concerns over their safety.

That may seem like an unfair criticism. After all, Pollan's rule is driven by his concern that much of what we eat is not good for us due to modern interference with natural foods. It's easy to assume that generations long ago didn't face the same kind of technological processing of foodstuffs.

Actually, they did! The history of food shows us that just this sort of concern about health has shaped the adoption of many culinary changes throughout the ages. Tomatoes were considered poisonous when first imported to Europe. This worry was false, but it had some rationale behind it: tomatoes are part of the deadly nightshade family. Lingering suspicions about tomatoes kept them out of the diets of many Europeans for a hundred years or more. Ironically, people in Florence and the surrounding region of Tuscany were among the late adopters of tomatoes, lagging more than a century behind other Mediterranean regions. Many other imported foods, including potatoes, suffered similar delays as health suspicions made people wary of them. Ironically, tobacco, which we now know is very harmful to our health, was adopted very quickly in Europe.

A lot of progress has been made in our scientific knowledge of what is good and bad for us, which is another reason to question the great-grandmother rule. Would you really want to be treated by your great-grandmother's doctor rather than by a physician today?

A major theme of this book is about changes in what we eat. These changes are controversial and are opposed by culinary traditionalists. We believe everyone is entitled to personal culinary preferences. If people want to eat only what they think of as traditional foods and avoid recent innovations, that's their prerogative. But as we make these choices, it is important to remember that every aspect of cuisine was an innovation at some point in time, and in many cases not that long ago. Making a choice based on tradition alone is worse than drawing the proverbial line in the sand; it is like trying to draw a line in a river.

Of course, very simple dishes, such as grilled fish or roast chicken, are not unique to any time period. (Chickens originated in Asia, by the way.) But once you get past these dishes to those that express characteristic preparation techniques or characteristic flavor profiles, you rapidly discover that everything was new and radical at some point in time.

True Revolution

Gradual change is the norm. Every now and then, however, culture is altered more radically—by revolution rather than evolution. Disruptive changes of this kind are relatively rare in the food world, but they are common in other disciplines, such as music, art, architecture—even science. Indeed, much of our understanding of art and cultural history is based on the study of revolutionary cultural movements.

Visual art is perhaps the best example. Throughout the history of Western art, movements or schools have set the criteria that defined the look of the age. Sometimes these movements were inspired by technological advances—such as the development of oil paints, which provided a vastly different range of color and tone than did the egg tempera paints that came before. But more often, the origin of a new school or movement had to do with aesthetics pioneered by a group of artists who broke away from their predecessors with a new look.

Of all of the artistic movements in history, Impressionism is probably the most relevant for understanding the development of modern cuisine, in part because of the movement's familiarity. In many ways, Impressionism blazed the trail for the rest of modern art. It was part of the first wave of Modernism, a metamovement that would ultimately shake the foundations of art, architecture, graphic design, and literature.

The Impressionists were among a group of artists who painted in disparate styles but were united by their rebellion against the strict and formulaic rules of their time. Their starting point as a group was that their paintings were refused entry to the exhibitions organized by the art establishment of that era, so they put on their own exhibitions (and were heavily criticized for it—see The Rough Start for Impressionist Art, page 18).

The Impressionists were the first artists to be self-consciously modern. They believed that art wasn't just about creating a realistic rendition of a subject; to them, art was first and foremost an intellectual dialogue. For the Impressionists, simply rendering the subject accurately was beside the point; indeed, excessive attention to accuracy would get in the way of what the artist was attempting to communicate. We accept that idea today; in fact, it is central to our definition of art. But in the 1870s, when the Impressionists were getting off the ground, it was a still a radical concept.

Impressionism was the subject of public ridicule when it first emerged. Indeed, the very word "Impressionism" came from a bitingly satirical newspaper essay by an art critic, who based the name on Monet's painting *Impression, Sunrise*. The critic's goal was to ridicule the movement, but the young artists accepted the name and moved forward undaunted. Ultimately, the Impressionists won. Public perception changed, and what was previously considered ugly or unfinished came to be viewed as beautiful and artistic.

Today, Impressionism is probably the most popular artistic style. People who like modern art regard the Impressionists as the progenitors of the modern movement. And those with more classical tastes still find the paintings beautiful. Impressionism is the ideal crossover genre, beloved by people who still feel a lingering desire for representational and realistic art as well as by those who buy into a more abstract agenda.

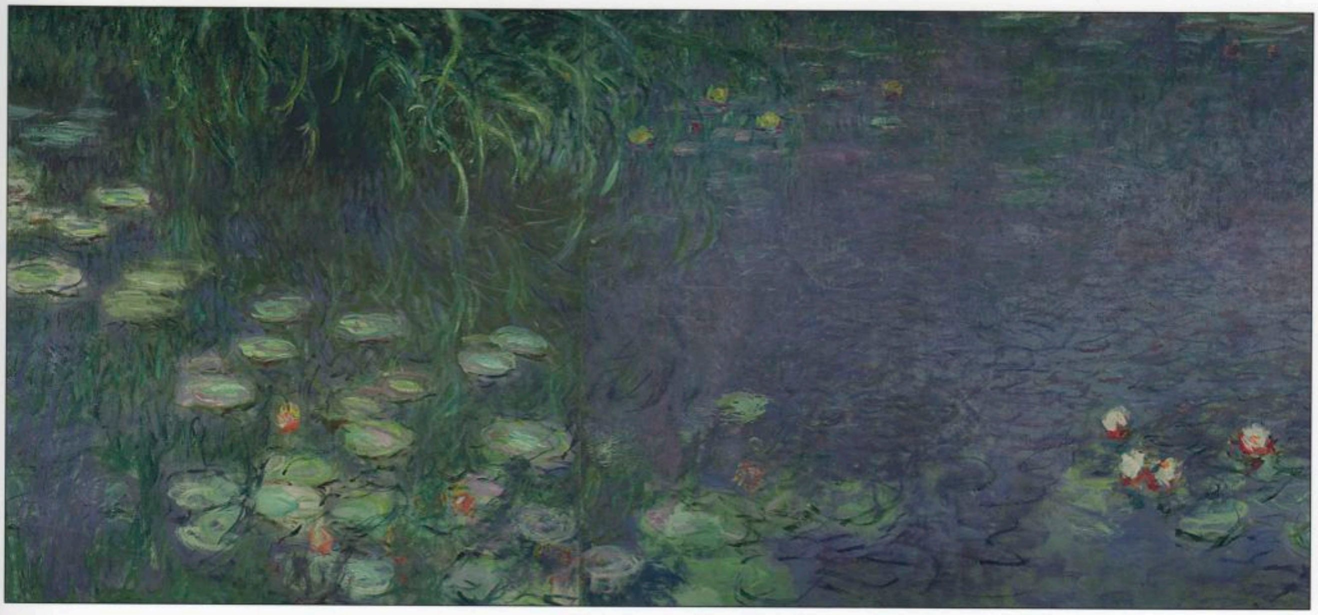
The greatest legacy of the Impressionists is that they were among the first to establish the model of artists rebelling against the system. Following the Impressionists, one wave after another of artists launched new movements or schools: Cubism, Dadaism, Surrealism, Abstract Expressionism, Minimalism, and many more. In this model, bands of artists, sharing some common goals but disagreeing on others, challenge the status quo to determine the course of the art world.

At first, these movements are the *avant-garde*, a French term synonymous with "vanguard"—literally, the troops sent out in advance of a main military force. Typically, avant-garde movements are at first controversial and misunderstood, and the participants revel in that outsider status. Ultimately, at least in successful movements, the artists are accepted to some extent by the art world and gain some degree of fame.

We have become so used to this pattern that it is almost viewed as a job requirement: young artists are expected to be part of an avant-garde. They either join the movement du jour or conspire to create a new one. It would seem very strange, at least within popular perception, for young artists to be willing conformists to the existing order.

The specific artistic goals differ, of course, and both artists and art critics might violently disagree with this broad-brush analysis. Amusingly, toward the end of their careers, most of the original Impressionist artists disliked Picasso's Cubism and other artistic movements that had become current at that time. Their reaction was little different from the reaction of the art establishment in their day, because by that point they had become the establishment.

Impressionism was the most famous of the artistic movements that marked the late 19th century, but broadly similar trends were happening in architecture, literature, music, and other fields of human cultural endeavor as well. Critics and analysts have termed this broader metamovement "Modernism," a megatrend that did much to



Monet's water lily paintings are classic examples of Impressionism. Today, we think they are beautiful, but they were highly controversial when they were first exhibited.

define the cultural agenda for the 20th century.

Change was in the air in every field. Architects such as Le Corbusier, Antoni Gaudí, Walter Gropius, Adolf Loos, Ludwig Mies van der Rohe, and Frank Lloyd Wright changed the way buildings were designed. New technologies had their play. Photography and cinema were invented and quickly became major art forms in their own right. There was a strong sense that the world's cultural values needed to be reviewed, renewed, and reformed across every discipline.

Some analysts and observers like to view Modernism as a reaction to the technological and social trends that were occurring at the same time: the rise of industrialization; the movement of the population from farms to cities; the rise of democracy in the Western world; and the changes wrought by new technologies. These were powerful trends that created a new world order. That wrenching change, some argue, drove Modernism.

Other observers put it the other way around: the sense of progress, renewal, and change gave social thinkers a reason to revisit and revise ideas that would otherwise have been sacrosanct. This is a more introspective tale of Modernism, driven by the notion that all areas of human life deserved to be "modern," to be rethought from scratch. Either way, the avant-garde was a key element of Modernism, a theme explored by Renato Poggioli in his influential book, *The Theory of the Avant-Garde.*

The Curious Case of Cuisine

Interestingly, virtually all of the cultural revolutionaries who launched these movements ate very conventional food. It is truly striking that Mod-

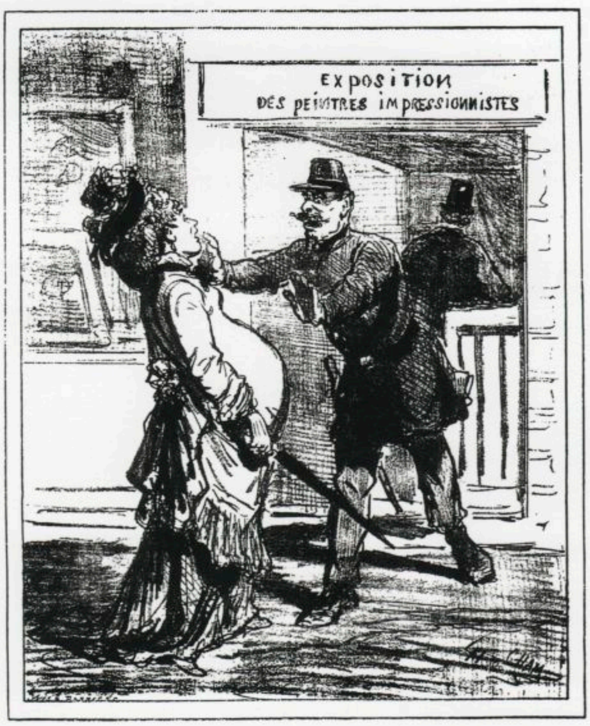
THE HISTORY OF

The Rough Start for Impressionist Art

As widely esteemed as Impressionist painting is today, it was misunderstood, ridiculed, and even reviled by critics and the public when it first emerged.

Like their predecessors in the Barbizon School of art, the Impressionists often painted landscapes and outdoor scenes. But they approached their subjects differently, depicting the play of light and shadow with bright, vivid colors. Impressionist paintings were characterized by quick brush strokes, an emphasis on the changing qualities of light with the passage of time, a strong sense of movement, unusual visual angles, and an interest in capturing contemporary life.

At first, many art critics and viewers were openly hostile toward the Impressionists. They saw the works' sketchy, unfinished qualities as evidence that the artists lacked "skill and knowledge." At the 1874 exhibition, Monet's painting *Impression, Sunrise* (from which the name Impressionism was derived) became a particular target of criticism, largely because viewers were confused by it. Manet chose not to exhibit with the rest of the group, but the art press nevertheless dubbed him "the chief of the School of Smudges and Spots." At the group's second exhibition, in 1876, visitors and critics derided the artists for what they saw as haphazard technique and "vulgar" or "discordant" representations of everyday objects. Newspapers of the era carried cartoons suggesting that the paintings were so horribly ugly that they



— Madame! cela ne serait pas prudent. Retirez-vous!

The cartoon suggests that pregnant women should not be allowed into Impressionist exhibits. The paintings were considered so ugly, it was feared they would make the women miscarry.

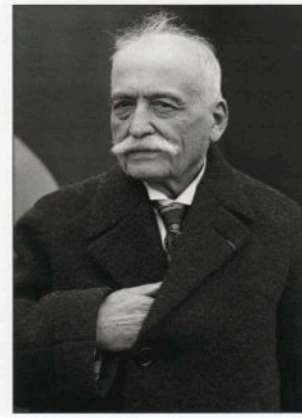
ernism, which brought so much change to so many areas of human culture, never touched on cuisine. Indeed, if you view cuisine as a major cultural institution, it has had unusually few big movements and revolutions.

Among European countries, France has long been considered to have the greatest national interest in cuisine, as the dedication to La Varenne's book suggests. So France is a logical place to look for culinary evolution and revolution.

The haute cuisine of France has been subject to many revisions and innovations over the years, as evidenced by the evolution of the nation's cookbooks. These books both documented and standardized the culinary practices of their eras. La Varenne, along with other cookbook authors such as Nicholas de Bonnefons and François Massialot, recorded the development of a new French cuisine that replaced that of the Middle Ages. They codified the cuisine that was being created for 17th-century French aristocrats.

Following in the footsteps of La Varenne, Antonin Carême documented French cuisine in a series of books culminating in *L'Art de la Cuisine Française*, published in five volumes beginning in 1833. Carême was also one of the first celebrity chefs, popularly known as "the king of cooks and the cook of kings." Over the course of his career, he cooked for the prince regent of England, the tsar of Russia, and the Rothschild banking family.

Half a century later, as the Impressionists were shaking up the art world, Auguste Escoffier became the natural successor to Carême. Escoffier's *Le Guide Culinaire* was first published in 1903 and served as the definitive manual for classic French cuisine. It streamlined and codified the



August Escoffier codified French high-end recipes and kitchen management in the early 20th century, and his methods dominated haute cuisine for decades.

could could cause pregnant women to miscarry or they could be used as a military weapon.

Slowly, however, some parts of the press warmed to the style. As one writer put it, the vitriolic criticism aimed at the Impressionists was perhaps "the clumsy, somewhat primitive expression of a profound bewilderment." At an exhibition in 1877, Impressionist painters met with some praise as well as criticism, and they began to find collectors and dealers (most of them friends of the artists) who wanted to buy their work. These supporters proselytized for their friends, sometimes drawing mockery themselves from the hostile critics.

Things changed dramatically for the Impressionists around 1880. The support of art dealers such as Paul Durand-Ruel (a dynamic, inventive dealer who championed Monet, Renoir, Pissarro, and Sisley) and Georges Charpentier (a book publisher who wrote columns defending Impressionist painters and hosted one-man exhibitions for Renoir, Manet, Monet, and Sisley) helped launch Impressionism into the mainstream art world.

Much like Impressionism, the Modernist culinary movement was often misunderstood by the public in its early days. Avant-garde chefs, like their counterparts in painting, were lambasted by some of their contemporaries. And as happened with the masters of Impressionism, the creative geniuses of Modernist cooking eventually surmounted the initial confusion to achieve prominence and acclaim (see page 62).

BIEN FÉROCE!
Les Turcs achetant plusieurs toiles à l'Exposition des impressionnistes pour s'en servir en cas de guerre.

A period illustrator depicted Impressionist paintings as so vile they could repulse the enemy in battle.

cooking of Carême and others, and it introduced numerous innovations in everything from kitchen organization and management to food service and presentation. One of Escoffier's most enduring contributions to cuisine was organizing brigades of chefs to cook for large banquets. His system for managing both kitchen and service staff has been the foundation of kitchen organization for the past century.

Escoffier was known in the press of his day by a title very similar to the one applied to Carême: "the king of chefs and the chef of kings." Like Carême, Escoffier spent much of his career outside France, working with César Ritz to create the Savoy Hotel in London and later The Ritz hotels (including The London Carlton).

Although Escoffier cooked for kings and dignitaries, most of his career was spent preparing food for the public in these fancy hotels. He also planned the menu and staffed the kitchens for the cruise ships of the Hamburg-Amerika Line. His clientele was wealthy. But compared to Carême's era, sophisticated cooking was now a far more democratic and public event, available to anyone who could afford it. It was no longer confined to royalty or private households of the ruling elite.

Many food writers hail each of these major shifts in cuisine as something of a revolution. Yet if you trace the development from La Varenne to Carême and Escoffier, there are far more similarities than differences between their philosophies. Innovation surely occurred, and the cuisine changed—sometimes dramatically. But there was no revolution to speak of. It would take another generation or so for that to take place.

Fast and Cheap: The Revolution at the Low End

The story of gastronomy is usually told from the perspective of the high end: the great chefs and their wealthy or privileged patrons. Even the story of peasant cuisine is typically the story of well-fed peasants who grew their own food. But the masses have to eat, too, and just like everyone else, they would prefer to eat tasty food.

The latter part of the 20th century saw a revolution in eating unlike anything that had occurred before, because it was a revolution of the masses, at least in the highly developed nations of North America and Europe. Several trends combined to utterly change what the typical person ate, yet this story is not often told by chefs or food critics.

The fundamental impetus for the change was economic: the newly minted middle class needed to eat. They had disposable income but little time. They also lacked much of the context present in traditional societies. City dwellers didn't have gardens or farms near by, and fewer had extended family in the community. The adult women were more likely to have a job or career than to be dedicated to homemaking and food preparation. Millions of people did not have the time, the skills, or the help to cook for themselves—but they did have enough money to eat well.

As busy people demanded food that required little or no preparation, a new type of food company rose to meet the need. Soft-drink manufacturers had already helped pave the way: In 1900, Coca-Cola introduced premixed, ready-to-drink sodas, and other beverage companies soon followed suit. These drinks were very different from the beverages that people made at home (such as coffee, tea, or punch) and were far more convenient. These new beverages caught on quickly, creating a market in soft drinks that did not previously exist.

Next came yogurt. The fermented milk product had been popular in places such as Greece, Bulgaria, and Turkey ("yogurt" was originally a Turkish word) for at least 4,500 years. Daniel Carasso was born in 1905 to a Sephardic Jewish family in

Greek-born entrepreneur Daniel Carasso (shown) popularized yogurt with his Groupe Danone (later Dannon), one of the first companies to industrially process yogurt. By 1947, fruit was added to satisfy the American taste for sweet flavors.

Salonica, Greece, where his family settled after being cast out of Spain in the 15th century. In 1916, the family returned to Spain and started the Groupe Danone yogurt factory in Barcelona. Fleeing Nazi fascism, they moved to New York and changed the name of their company to the more American-sounding Dannon.

At the time, Americans were unfamiliar with yogurt, and initially the company operated at a loss. Then, in 1947, Dannon's owners made a concession to the American taste for sweet flavors by adding strawberry jam to their recipe. "Fruit on the bottom" yogurt was born, and sales grew tremendously as Americans started to embrace the seemingly strange and exotic new product.

In the early 1920s, Jay Catherwood Hormel was creating a new market of his own. Hormel, an alumnus of Princeton University and a veteran of World War I, returned from the war to work in his father's meatpacking business. He developed a number of innovative new packaged meat products, starting with America's first canned ham. Then, to use the scraps left over after the hams were trimmed, he introduced Spam, a processed meat product that has been famous—and infamous—ever since.

Ettore Boiardi came to the United States at age 16, landing at Ellis Island. He worked his way up in the kitchen of the Plaza Hotel in New York City, starting as a dishwasher and eventually rising to the position of head chef. He then moved to Cleveland, Ohio, and opened his own restaurant, Il Giardino d'Italia. It was successful—so much so that he was barraged with requests for his pasta sauces.

In 1928, he opened a factory to produce canned sauces, marketing them under the name "Chef Boy-ar-dee" so that Americans could pronounce his name correctly. To maintain quality control, he grew mushrooms for the sauces in the factory basement. His canned goods became a sensation, and by the time of Boiardi's death in 1985, his company had annual sales of more than $500 million.

The Great Atlantic & Pacific Tea Company began as a tea shop in New York City, with a thriving mail-order business. In 1912, its owners branched out and opened a self-service grocery store with a standardized layout. It sold everything a household might want. This model quickly became popular, because it was faster and cheaper than going to separate stores for dry goods, produce, and meat. The grocery company, which went by the less formal name A&P, continued to innovate, receiving patents on shopping carts and what we know today as the checkout counter. By the 1930s, A&P had nearly 16,000 stores in the United States and combined sales of $1 billion annually. The era of the supermarket had begun.

Next, some remarkable innovations took place in the restaurant sector, led by entrepreneurs such as Ray Kroc, Harland Sanders, and Dave Thomas.

In 1954, Kroc—a paper-cup salesman—met the McDonald brothers, who ran an unusually efficient hamburger stand (and bought a lot of Kroc's paper cups). He decided to go into business with them and do something nobody had done before:

Normal Rockwell painted this portrait of the colonel himself, Harland Sanders.

expand the business from its small community (San Bernardino, California) to the world at large.

Similarly, Harland Sanders made fried chicken at the gas station that he ran in Corbin, Kentucky—and the chicken soon became more popular than the gasoline. He invented a special pressure fryer to speed up the cooking (see page 2·120), and at age 65 he took $105 from his Social Security check to fund the development of his franchise business.

Dave Thomas, who would later start the Wendy's hamburger chain, took over four failing Kentucky Fried Chicken franchises in Columbus, Ohio, and turned them around by radically simplifying the menu, an idea that soon swept the budding industry. The era of fast food had begun.

Cuisine Goes Corporate

The concept of quick, ready-to-eat food had been around for centuries. Many cultures had developed street food that was sold from stands; it has long been a staple at open-air markets and in cities. What was different about the 1950s fast-food trend is that the individual restaurants were controlled by what soon became large corporations. This corporate control afforded a certain assurance of consistency and provided the resources for advertising, so the new franchises could establish their brands with consumers. This coincided with the ability to advertise and market brands through newspaper, radio, and later television.

Another important breakthrough that occurred around the same time was the invention of the microwave. In 1945, Percy Spencer, an engineer working for Raytheon building radar sets, noticed that a chocolate bar in his pocket had melted when microwaves from the radar unit had heated it up (see page 2·182). Raytheon immediately patented the idea of a microwave cooking device and created the first home microwave oven.

At first, the appliances were clumsy and extremely expensive, but prices dropped and popularity grew. In 1970, the company sold 40,000 microwave ovens, but by 1975 sales had increased to 1 million ovens per year. The rise of the microwave worked in concert with the new prepared foods: the microwave was the ideal way to heat them up. As more people bought microwave ovens, supermarkets stocked more prepared foods designed for them. Using a microwave was a way to get a hot meal without really cooking.

These are just a few of the hundreds of transformations that took place in the world of food during the 20th century, providing convenience, speed, and low price to millions of people. These changes were profound and far-reaching. For the first time in history, a large fraction of the things people ate came from factories. This was true for ready-to-consume foods and drinks, such as Coca-Cola, Dannon yogurt, and Spam. In a slightly different sense, it was also true for fast foods, such as Kentucky Fried Chicken and

This early McDonald's restaurant sign boasts over 1 million people served. Today the chain serves about 52 million people every day. By March 2010, McDonald's had, since its founding, served an estimated 245 billion meals.

McDonald's hamburgers. Fast foods may have been heated or fried at the local franchise outlet, but the restaurants were owned and operated by large corporations, and ingredients were provided by an industrial supply chain.

Saying that the food came from a factory sounds bad to most food lovers. The rise of fast food and convenience food (aka junk food) is often blamed for the epidemic of obesity and other diet-related health problems, as we discuss in chapter 4 on Food and Health, page 211. This industrialization is also blamed for a general decline in the quality of the dining experience.

There is plenty of truth in these claims; the rise of prepared food and fast food did lead to many negative changes. But we must also recognize the forces at work. People want food quickly and cheaply. They prefer national brands they feel they can trust. Manufacturing on a large scale allows prices to be low, which further stimulates sales. This combination of factors virtually guarantees that large companies will grow to fill the need.

When one decries the evils of fast food and manufactured food, an important question to ask is "Compared to what?" It would be wonderful if everyone could afford to sit down to traditionally cooked meals, but that simply isn't practical for many people. And what may be hard for a food critic, foodie, or chef to understand is that some people don't even want a home-cooked meal. Those of us who love food can scarcely understand that, but empirically it is the case. The fast food and convenience food industries exist because people have voted with their pocketbooks and their stomachs. It is both unrealistic and elitist not to recognize this. Although it would be great to offer the world better food choices, society has collectively chosen the course we are on today.

When the fast-food revolution spilled over to France, the home of grand culinary traditions, one could easily predict there would be trouble, and at first there was. McDonald's was viewed as an agent of American culinary imperialism. Things came to a head in 1999, when a French farmer destroyed a McDonald's restaurant by driving his tractor through it, as a protest against globalization and the threat to traditional lifestyles that he called "Coca-Colonization."

THE HISTORY OF

Slow Food

The slow food movement began in Italy in 1986, when Italian food writer Carlo Petrini started an organization called Arcigola to protest the opening of a McDonald's in Rome. Three years later, Arcigola became Slow Food. The central idea of the movement was to unite leftist politics and gastronomic pleasure. In 1989, delegates from 15 countries endorsed the Slow Food Manifesto, which proclaims that "suitable doses of guaranteed sensual pleasure and slow, long-lasting enjoyment" are the only way to save oneself from the frenzy of modern life.

In more practical terms, the Slow Food mission was to preserve traditional foods and ecofriendly food-production methods. "I always say a gastronome who isn't an environmentalist is just stupid, and I say an environmentalist who isn't a gastronome is just sad," Petrini told *The New York Times*.

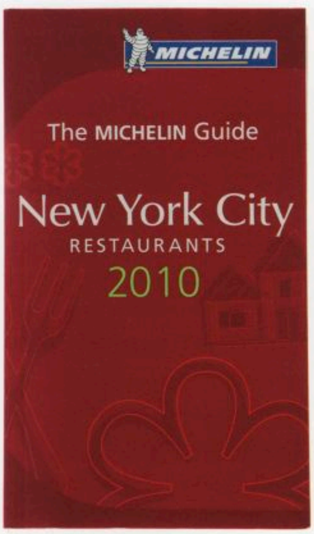
Slow Food came to the United States in 1998. Its philosophy of "ecogastronomy" coincided with many of the principles of New American cuisine, which placed an emphasis on seasonal, regional ingredients and sustainable agriculture. Among Slow Food's adherents in the U.S. were authors Michael Pollan and Eric Schlosser. Chef Alice Waters (see page 28) also felt an immediate connection with Petrini's values and has since become one of the leading American figures in the organization. Many other prominent chefs have participated in Slow Food events or have been involved with the organization at some level.

Critics of Slow Food see the movement as elitist and exclusive, arguing that artisanal food products and organically grown produce are out of reach economically for most people and do nothing to solve America's hunger problems.

By mid-2010, Slow Food claimed more than 100,000 members in 132 countries. It ran its own university and put on major events around the world.

Scientists in a 1960s food lab study raw vegetable specimens.

For more on James Kraft's invention of processed cheese, see page 4·222. For more on Clarence Birdseye's innovations in freezer technology, see page 306.



Le Guide Michelin—first published in France by the Michelin tire company in the 1930s as a way to promote car travel—assigned its star ratings with travel in mind: a three-star designation means "worth a journey," and two stars means "worth a detour." The star ratings in the guide have been the standard of career achievement for chefs in France from the onset. Recently, the guide has expanded to include New York City, Tokyo, Las Vegas, and other major cities.

But the harsh words and tactics didn't last. Today, France is the second most profitable country for McDonald's (the United States is still first), with 1,140 restaurants. Incredibly, McDonald's is also the largest private-sector employer in France. Even in the land of haute cuisine, fast food seems to have a place.

One side effect of the industrialization of food is that the discipline of food science was born. New inventions in food technology have often led to the creation of enormous corporations. James L. Kraft developed a method for making pasteurized processed cheese, which led in part to the launch of Kraft Foods. Clarence Birdseye invented a way to quickly freeze food, inspired by techniques he gleaned on ice-fishing trips in Labrador, Canada. As food companies grew, so did the amount of research they put into perfecting and improving their products.

Universities, particularly land-grant colleges that focused on agriculture, created food-science departments to study every aspect of the food chain, from harvest to processing. Without the food industry, there would have been far less reason to apply science and technology to food.

The first part of the 20th century had a Modernist revolution in every major cultural institution—except food. But that time period *did* have a food revolution of a different kind. It occurred at the low end of the market. This revolution wasn't sparked by a group of artists and intellectuals with Modernist ideals, as it was with the Impressionist painters or the Bauhaus architects. Instead, the food revolution encompassed a wider cast of characters: gas station attendants and paper-cup salesmen who turned into fast-food magnates; chefs who became canned-sauce icons; and tea-shop owners who turned into supermarket titans. This revolution utterly changed what people in developed and industrialized nations ate.

Perhaps one of the reasons that high-end cuisine stayed relatively constant from Escoffier through the 1960s is that people were already absorbing tremendous change in what they ate. The rise of fast food, supermarkets, and industrial food caused a revolution in people's everyday diets. High-end restaurant food was, comparatively, an island of stability in what was otherwise a storm-tossed sea of culinary change.

The Nouvelle Revolution

It is hard for us today to appreciate just how rigid the system of Carême and Escoffier had become by the 1950s in France. It was a highly regimented repertoire. Chefs could, and did, invent new dishes, but there was much reverence for the past and its rules. Indeed, the veneration of the past was so strong that it constrained the creativity of chefs in the present. Who were they to challenge the cuisine of Escoffier and Carême?

By the 1960s, a few young French chefs started to take issue with the system. Many of them had trained with Fernand Point, a brilliant chef whose career began in the age of Escoffier but then took a different turn. Point developed his own experimental cuisine, anticipating the changes that his protégés would perfect. Ultimately, his role as a mentor for the next generation of chefs was more important than his own direct contributions.

His former students began to experiment and abandon tradition, creating lighter menus, introducing lower-fat sauces and vegetable purees, borrowing ingredients from non-French cuisines, and plating dishes in the kitchen instead of at the table (see Plated Dishes, next page). All of this experimentation stirred up controversy. By 1972, it had a name: Nouvelle cuisine.

Early influential figures in Nouvelle cuisine included Paul Bocuse, Michel Guérard, and the food critics Henri Gault and Christian Millau of *Le Nouveau Guide*. Gault and Millau, with their friend André Gayot, founded the *Guide* in 1969 to

THE INVENTION OF
Plated Dishes

Go to any fine restaurant in the world, and at least part of your meal will most likely arrive as an attractive arrangement of several kinds of food on a single plate—what chefs call a "plated dish." This approach is such a common method of presentation, and food pairings are now such a focus of haute cuisine, that one might assume that restaurants have always served food this way. In fact, the plated dish is a relatively recent innovation.

In the classic cuisine formalized by Escoffier (see Early French Gastronomy, page 9), food was brought to the table on serving platters and dished onto plates there, either by the diner (in causal settings) or by the waiter or maître d'hôtel (in high-end restaurants). This approach was common in numerous cuisines around the world. Chinese food, for instance, was traditionally served in a similar manner, with food placed on the table for people to serve themselves. This "family-style" approach was also used to serve Italian, German, and American food.

The first plated dish was salmon in sorrel sauce.

The French chefs Pierre and Jean Troisgros, at the urging of their father, Jean-Baptiste, pioneered the practice of plating in the late 1960s, becoming the first chefs in a top-quality restaurant to embrace the new trend. At the time, the Troisgros brothers were running the kitchen at the Hôtel Moderne in the city of Roanne. Cooking in a style that would later be termed Nouvelle cuisine, they emphasized high-quality ingredients, lightness and simplicity, and creativity and self-expression.

They felt constrained in their artistic expression, however, because, at that time, tradition required the chef to place each finished dish on a large platter. This was *service à la Russe,* which meant the table was set with empty plates (often with a centerpiece of fruit, flowers, or other decorative elements), and guests were served tableside. Virtually all aspects of the presentation happened away from the chef and out of his or her control.

Jean-Baptiste Troisgros, who frequently chatted with customers in the dining room, picked up on their desire to see some sort of "signature from the chef" on their plates. He encouraged his sons to start plating food in the kitchen. Pierre and Jean soon realized that standard plates were too small for the artful presentations they had in mind, so they commissioned new plates, about 32 cm / 12½ in across, to serve as a larger palette for their work. They first began using these plates in 1966 for two dishes in particular: salmon in sorrel sauce (a signature dish of the restaurant to this day) and beef entrecôte.

The innovation was very well received, according to Pierre's son, the celebrated chef Michel Troisgros. "Customers liked having more space on their plate, more room to breathe," he says. Plating dishes in the kitchen has numerous advantages. It gives the chef more control and allows him to prepare more complicated dishes. From a restaurateur's perspective, it is faster and cheaper because it allows the restaurant to operate with a smaller waitstaff, who require less training. The combination of aesthetic and economic advantages rapidly made plating popular. Within a decade, the practice had spread throughout Europe and made its way to the United States.

In many restaurants, however, dessert is still served in the old style. Carts displaying whole cakes and other sweets are rolled to the table before being cut. Even elBulli had a desert trolley until 1992 (see page 33). The cheese course is another bastion of tradition; it, too, is often served from a cart brought to the table.

Plated dishes can now be found in restaurants in every part of the globe. They are so common that it seems as though food has always been presented fully plated. But that is not the case. The plated dish was a radical innovation, albeit one that caught on.

protest the Michelin guide, which they criticized as "a stubborn bastion of conservatism" that ignored "the new generation of French chefs who had guts." The inaugural issue of *Le Nouveau Guide* featured a cover story on Bocuse, Guérard, Louis Outhier, Alain Senderens, and 44 other chefs under the headline "Michelin: Don't Forget These 48 Stars!" In 1973, Gault published "The Ten Commandments of Nouvelle Cuisine" (see next page), giving the movement a name and essentially launching a publicity campaign that helped Nouvelle cuisine reach a wider audience.

Many of the chefs championed by Gault and Millau quickly garnered respect and Michelin stars, but the new style drew fire from established French food critics, particularly La Reynière (aka Robert Courtine), the prominent critic at *Le Monde*. Nouvelle cuisine was seen as a threat to French tradition and was often attacked on nationalist grounds. Senderens says that in 1978, when he introduced soy sauce into his cooking after a trip to China, "a food critic ripped me to shreds." In 1979, the sociologist Claude Fischler wrote an article for *Le Monde* titled "The Socrates of the Nouvelle Cuisine," in which he subtly mocked the movement's emphasis on letting ingredients express their true flavors: "The artist in this field is no longer characterized by his overpowering authority, but rather by the opinionated modesty of an exponent of the maieutic art: In place of the cook as mercenary of the kitchen stove, we now have the Socratic cook, midwife at the birth of culinary truth."

In the United States, one of Nouvelle cuisine's chief critics was celebrity chef Julia Child, author of the best-selling *Mastering the Art of French Cooking*. Child saw the new movement as an affront to the logic and grandeur of French cuisine. She particularly disliked the Nouvelle cuisine penchant for serving barely cooked meat and vegetables, which she believed did not properly develop the "essential taste" of the ingredients. She also accused Gault and Millau of "pushing the Nouvelle cuisine relentlessly," to the point of "browbeating" restaurants that didn't embrace a Nouvelle cuisine ethos.

Other American gastronomes shared Child's wariness of the new movement. As renowned San Francisco cooking teacher Jack Lirio quipped to *Newsweek* in 1975, "Without butter, cream, and foie gras, what's left of French cooking?"

Despite this criticism, the movement took hold of the culinary landscape in France and around the world in the 1970s, and it continued to shape French cuisine for many years thereafter. The extent of Nouvelle cuisine's impact is evident in a longitudinal study that followed roughly 600 elite French chefs (those with one or more Michelin stars) from 1970 through 1997. Northwestern University sociologist Hayagreeva Rao and colleagues analyzed each chef's top three signature dishes and found that in 1970, 36% of the chefs had just one Nouvelle-cuisine signature dish—which, in many cases, was a copy of Troisgros's famous salmon in sorrel sauce (see The First Plated Dish, previous page)—and 48% had none. By 1997, only 6% had none, and 70% were predominantly Nouvelle cuisine (with two or more signature dishes in the Nouvelle style). The study, published in 2003, concluded that this was a true social movement, not a mere culinary trend.

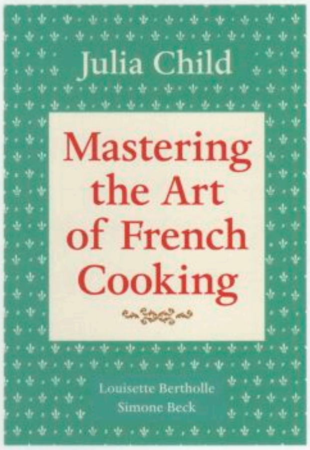
Nouvelle cuisine was a successful revolution; it succeeded so well that today we view French cuisine through its lens. High-end chefs still make great dishes of the pre-Nouvelle years, but usually as a self-conscious throwback to a lost age.

The first wave of Nouvelle cuisine represented a real revolution, analogous in some ways to Impressionism in its rebellion against the establishment and the attendant controversy. Many long-cherished aspects of Escoffier's *grande cuisine,* such as sauces made with meat extracts and thickened with flour-based roux, were discarded.

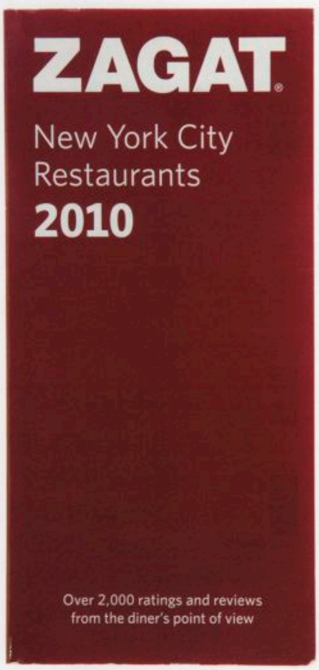
The system of the restaurant changed as well. Escoffier had championed service *à la Française,* in which empty plates were set before each diner and waiters served and carved food at the table. Nouvelle cuisine featured plated dishes, assembled in the kitchen by chefs. All the waiter did was set the plate in front of the diner.

Yet in another sense, Nouvelle cuisine was a rather limited revolution, because it was all about techniques and ingredients. The famous ten principles of Nouvelle cuisine championed by Gault and Millau all have to do with rather technical aspects of cooking.

They were a big deal to chefs and food critics, who were steeped in the traditions of *la grande cuisine,* but they seem quite ordinary to us today. High-end food was, ultimately, still high-end food,



Julia Child's book brought French cuisine to the United States. It both led to a shift in American home cooking and paved the way for French restaurants in the U.S. Her love of French food was traditional; she disliked Nouvelle cuisine and spoke out against it.



In the United States, the leading restaurant guide is the Zagat Survey. Unlike the Michelin guide or Gault Millau, Zagat's results are based on voting by the public. Many consumers view the guide as being far more accurate and reliable than the others.

just with a slightly different set of techniques.

As Nouvelle cuisine won the battle for the hearts and minds of both chefs and diners, the revolution matured into a new culinary establishment. Successive generations of chefs carried forward the torch of culinary innovation, but in an evolutionary rather than a revolutionary fashion. In part, that is because Nouvelle cuisine carved out some notion of independence for the chef. Escoffier (and Carême before him) had explicitly sought to establish rules and conventions. Nouvelle cuisine gave more leeway to the individual chef, so there seemed to be little incentive to rebel.

As young chefs rose to prominence, they extended the range of Nouvelle cuisine, although at that point it was no longer new. Joël Robuchon, named "chef of the century" by Gault Millau in 1989, was known for relentless perfectionism. His cuisine was Nouvelle in the sense that it followed the ten commandments, but at the same time it was clearly his own. Much the same could be said of Frédy Girardet, the self-taught Swiss master chef who was often listed as the best chef in the world. Again, he was clearly staying inside the boundaries of Nouvelle cuisine but developing a unique repertoire.

Within the movement, some chefs were known for tending toward more unusual and daring foods and combinations. Michel Bras, Pierre Gagnaire, and Marc Veyrat took their own paths, each fiercely original and extremely inventive. Yet none of these chefs has been described as being outside the mainstream, and all were lauded by both the Michelin and Gault Millau guides.

Outside of France, Nouvelle cuisine sometimes had an enormous impact and other times had barely any, depending on the country and its local gastronomic culture. In the United States, Nouvelle cuisine was deeply influential, helping to inspire "New American" cuisine (see next page).

American chefs borrowed techniques from Nouvelle cuisine, but more important than any single technique or principle was the idea of revolution itself. American chefs weren't steeped in *la grande cuisine;* instead, they rebelled against the doldrums of mass-produced, uninspired American food. These chefs created a distinctive New American cuisine based on regional ingredients and food traditions, but with a clear nod to Nouvelle techniques.

THE HISTORY OF

The Ten Commandments of Nouvelle Cuisine

In the late 1960s and early 1970s, the French culinary world was radically altered by the advent of Nouvelle cuisine (see Early French Gastronomy, page 9). In 1973, food critic Henri Gault published "The Ten Commandments of Nouvelle Cuisine," an article defining the principles of the new culinary movement he saw taking place in France. These commandments were as follows:

1. *Tu ne cuiras pas trop.* (Thou shalt not overcook.)
2. *Tu utiliseras des produits frais et de qualité.* (Thou shalt use fresh, quality products.)
3. *Tu allégeras ta carte.* (Thou shalt lighten thy menu.)
4. *Tu ne seras pas systématiquement moderniste.* (Thou shalt not be systematically modernistic.)
5. *Tu rechercheras cependant ce que t'apportes les nouvelles techniques.* (Thou shalt nevertheless seek out what the new techniques can bring you.)
6. *Tu éviteras marinades, faisandages, fermentations, etc.* (Thou shalt avoid pickles, cured game meats, fermented foods, etc.)
7. *Tu élimineras les sauces riches.* (Thou shalt eliminate rich sauces.)
8. *Tu n'ignoreras pas la diététique.* (Thou shalt not ignore dietetics.)
9. *Tu ne truqueras pas tes présentations.* (Thou shalt not doctor up thy presentations.)
10. *Tu seras inventif.* (Thou shalt be inventive.)

Commandment four (thou shalt not be systematically modernistic) is of particular interest in the context of what happened next: the Modernist revolution in cuisine. The Nouvelle cuisine movement, from the very onset, was trying to be new without going all out for Modernism.

The same effect occurred in the United Kingdom, where a generation of "New British" chefs emerged, adamant that British food was not synonymous with bad food. Chefs such as Nico Ladenis, Marco Pierre White, Gordon Ramsay, and Fergus Henderson took principles of Nouvelle cuisine and applied them in their own characteristic ways.

A number of French expatriates, such as Albert and Michel Roux, Raymond Blanc, and Pierre Koffmann, joined their ranks, bringing French Nouvelle cuisine directly to British diners. As in the United States, this helped lead a movement toward higher-quality food and dining.

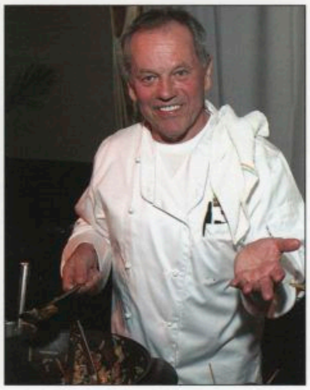
In Spain, the effect of Nouvelle cuisine was much more limited. It was clearly an inspiration for the Spanish Basque chef Juan Mari Arzak, who created his own distinctive style that would later inspire Spanish Modernist chefs. But throughout the 1960s and 1970s, Spanish food was largely unaffected by the developments in France.

Italy had even less of a reaction to the Nouvelle revolution. In part, that is because Italian cuisine has always been highly regional and did not have centralized standards. There was no set of oppressive *grande cuisine* rules to rebel against.

A few Italian chefs—including Gualtiero Marchesi, Nadia Santini of the great restaurant Dal Pescatore, and Luisa Marelli Valazza of Al Sorriso—used some principles of Nouvelle cuisine to inform their interpretations of Italian culinary themes. A more recent example is Heinz Beck, who was born in Germany but for years has been considered one of the top chefs in Rome. The refined and sophisticated Italian cuisine produced by these chefs definitely owes some-

THE HISTORY OF

New American Cuisine



In the 1970s, fine dining in the United States usually meant one of two things: either a steak house with a menu straight from the 1950s, or a "Continental cuisine" restaurant that served ersatz, heavy, and uninspired food. Food writer Calvin Trillin lampooned this type of restaurant, saying that they might as well all have the same name: "La Maison de la Casa House."

News of Nouvelle cuisine in France encouraged a generation of American chefs to rebel and create something of their own. The two culinary movements shared many tenets: eschewing heavy stocks and sauces, showcasing fresh and local ingredients, and cooking those ingredients minimally (or not at all).

The New American movement looked to the culinary traditions of many different regions for its inspiration, including California, the South and Southwest, and Cajun country. As diverse as these culinary styles were, they were unified by a spirit of creativity among their proponents, including Alice Waters and Jeremiah Tower at Chez Panisse in Berkeley, California; Larry Forgione at The River Café and An American Place in New York City; Charlie Trotter at Charlie Trotter's in Chicago; Paul Prudhomme at K-Paul's Louisiana Kitchen in New Orleans; and Wolfgang Puck (pictured) at Ma Maison and Spago in Los Angeles. Through their experimentation, these chefs laid the groundwork for an American cuisine that had the techniques and refinements found in Nouvelle French food but that was based on American tastes and traditions.

Waters opened Chez Panisse in 1971 and hired Tower as head chef two years later. Working together in the kitchen, the two borrowed heavily from Nouvelle cuisine, but they also forged their own distinctly Californian style—which included high-end pizzas, whole baked garlic with white cheese and peasant bread, and cream of fresh corn soup with crayfish butter. Tower, a self-taught chef, had a brash confidence and a penchant for taking chances.

More important, Waters, Tower, and subsequent chefs at Chez Panisse helped launch a revolution in how food was purchased, working directly with farmers and purveyors to acquire the best possible ingredients. They became some of the first and most vocal proponents of small farms and sustainable agriculture, a trend that has gathered momentum over time. They also championed artisanal baked bread and had enormous influence on American bakers.

As Waters wrote in her *Chez Panisse Menu Cookbook*, "We as a nation are so removed from any real involvement with the food we buy, cook, and consume. We have become alienated by the frozen foods and hygienically sealed bread. I want to stand in the supermarket aisles and implore thing to the Nouvelle movement, but it never constituted a revolution.

Today, many of the original leaders of the Nouvelle cuisine movement are retired from day-to-day activities in the kitchen but remain involved with the restaurants that bear their names. Subsequent generations of French chefs have extended the scope of French cuisine, but all through gradual evolution.

What started as Nouvelle cuisine is now one branch of what could be called "New International" cuisine. Around the world, one can find national cuisines that were clearly inspired by the Nouvelle movement, borrowing both cooking techniques and the general attitude of rebellion. This includes various "New" takes on Asian cooking, or so-called Fusion, which melds Asian spices and techniques within a Western, Nouvelle-inspired backdrop.

In the later stages of Nouvelle cuisine and in New International cooking, innovation has mainly been limited to flavor combinations. The first step was mining traditional regional cuisines for their approaches and flavors. Next, chefs sought to bridge the gap between Western and Asian cuisines.

Then new and exotic ingredients found their way onto menus. Wagyu beef and fish such as hamachi and toro (tuna belly) have always been found in Japanese restaurants. Today, you might find them on the menu at nearly any New International restaurant anywhere in the world. Meanwhile, ostensibly Japanese restaurants, such as Nobu, incorporate their own take on foie gras, jalapeño peppers, and other completely non-Japanese ingredients.

Although France started the ball rolling, it is

the shoppers, their carts piled high with mass-produced artificiality, 'Please ... look at what you are buying!'"

Forgione was also an early supporter of small-scale farming. In 1978, after two years in London, he returned to the U.S. and soon became frustrated at how difficult it was to find quality ingredients. While heading the kitchen at The River Café, he worked diligently to purchase free-range chickens, ducks, and wild game (including muskrat, beaver, and elk). The River Café became the first New York restaurant to serve fresh buffalo in 70 years. Forgione also procured periwinkles, sea urchins, and other seafood from Hawaii, as well as specialty produce such as cattail shoots and fiddlehead ferns. In 1983, he opened his own restaurant, An American Place, and continued to shine a spotlight on small farmers and seasonal ingredients.

In Chicago, Charlie Trotter espoused a similar philosophy at his eponymous restaurant, which he opened in 1987. The famously perfectionistic chef combined French technique, Japanese-style presentation, and a strong emphasis on American ingredients, including Maine lobster, Alaskan halibut, Hudson Valley foie gras, and fresh organic vegetables. He pioneered both the craze for microgreens and the practice of serving diners at a table in the kitchen. He was also one of the first high-end chefs to offer a vegetable tasting menu.

Meanwhile, Prudhomme was making his name with a very different, but nevertheless ingredient-driven, menu. K-Paul's, which opened in 1979, served dishes inspired by the Cajun and Creole communities of rural Louisiana, including jalapeño and cheddar biscuits, free-range roast duck with rice and orange sauce, sweet potato–pecan pie, and Prudhomme's signature blackened redfish (the progenitor of all other "blackened" dishes). He treated Cajun and other Louisiana-based cuisine as a framework for innovation, and he soon attracted attention from the press and the public. Prudhomme became a household name after he launched his line of spice blends, which are now distributed worldwide.

Puck's name is equally recognizable today. His career took off in 1975, when he began his seven-year tenure as chef at Ma Maison, becoming a favorite of Hollywood stars. When Puck opened Spago, in 1982, it quickly became one of the most popular restaurants on the West Coast. His culinary style, which he called "L.A. Provincial," was similar to Waters's and Tower's in emphasizing regional ingredients and a casual atmosphere. He specialized in haute pizzas (with then-unusual toppings such as fresh duck, Santa Barbara shrimp, and smoked salmon with caviar) and California-style dishes such as Sonoma baby lamb with braised greens and rosemary. Puck spun his early success into an international empire that now includes high-end restaurants, a chain of bistros, a catering business, and consumer products (such as his ubiquitous frozen pizzas).

These New American pioneers became some of the first celebrity chefs. Their popularity coincided with the growing American interest in good food and made top-quality ingredients de rigueur in fine restaurants. The stage was set for the emergence of a new Modernist cuisine.

hard to argue that the French are leading the New International movement. There is no single driving force or capital city of New International.

But if one insisted on finding a representative city, it might be, of all places, Las Vegas, Nevada. At some point in the 1990s, Las Vegas casino owners discovered that food was a great potential draw for clientele. Casinos dove into the food world with the same gusto and excess that they have shown in their billion-dollar hotels and glitzy theater shows. Casino owners courted restaurants and chefs that were considered to be among the greatest in the world.

Today, Las Vegas has an incredible number of top chefs running restaurants across the culinary spectrum, from fast food to high end. The majority of the establishments at the high end are showcasing their own take on New International. This includes restaurants by Thomas Keller, Charlie Palmer, and Bobby Flay from the United States; and Pierre Gagnaire, Guy Savoy, and Joël Robuchon from France.

Other chefs who have set up shop in Vegas include globetrotting transplants such as Nobu Matsuhisa from Japan, Peru, and Los Angeles; Jean-Georges Vongerichten from France by way of New York; Julian Serrano of the restaurant Picasso, from Spain and San Francisco; and Wolfgang Puck from Austria, France, and Hollywood.

Another case could be made that New York is the center of New International cuisine. Chefs such as Daniel Boulud, Eric Ripert, David Bouley, Alain Ducasse, and Charlie Palmer, along with Vongerichten, Matsuhisa, and Keller, all have restaurants there. And as the headquarters of the United Nations, New York is as close to being the capital of the world as we are ever likely to see.

The best chef cooking in the New International style, many would argue, is Keller. Trained in France, he in many ways has inherited the mantle of perfection and elegance in execution that once belonged to Robuchon or Girardet.

Las Vegas is the capital of bad taste in some ways, with ersatz copies of everything from the Eiffel Tower to an Egyptian pyramid. Underneath the fake glitz, Las Vegas has many serious restaurants.

L'Atelier de Joël Robuchon is a chain of eight identical restaurants in cites around the world.

Others would argue that the best chef is Ducasse, who reinterpreted the food of Mediterranean France through a New International lens. He is arguably the most famous and influential chef in France today and also has global reach, with restaurants around the world.

The discussion of which city is the center, or which chef is the best, is ultimately self-defeating, because the New International style isn't a movement so much as it is an entrenched orthodoxy. There is no single city or country at its hub, because high-end cuisine has globalized. There is no single leader because you need a leader only if you are going somewhere.

At this stage, changes in the New International style amount to a steady evolution of a mature discipline. Each chef is innovating, but to a large degree they are all going in their own directions. Taken as a whole, there is no net movement.

One of the most surprising trends in the New International style is that well-respected chefs have in some ways taken the path of Harland Sanders and Ray Kroc, turning what had once been single restaurants into empires. Ducasse started the trend, with the then-audacious goal of having two Michelin-three-star restaurants. In 1998, he succeeded in becoming the first "six-star" chef since the 1930s, and many other chefs have followed in his footsteps. Indeed, by 2010 Ducasse had 19 stars, and Robuchon had 25, summed across their restaurant empires.

Like them, Vongerichten and several other chefs have empires of restaurants with different names, niches, and price points. These restaurants are mostly high-end, with a set of less formal dining options. The empires' principal common theme is the chef/owner.

Other major figures, such as Puck, have a few high-end restaurants, but their empires are weighted toward the low end, creating chains of cafés, fast-food outlets, and even canned food, following the lead of Ettore Boiardi. Perhaps the most surprising player is Robuchon, who came out of retirement to open a set of eight identically named restaurants—L'Atelier de Joël Robuchon—in cities around the world. The Nouvelle cuisine master and chef of the 20th century came back to create the first haute cuisine restaurant chain of the 21st century.

The fundamental reason for this expansion is the same one that drove the fast-food revolution: customers like to have familiar names and brands to rely on. That is even true at the very high end. Why risk a local chef's attempt to be the best in the world if you can instead walk into a restaurant run by Robuchon or Ducasse?

Like Ettore Boiardi in the 1920s, Wolfgang Puck has gone into the canned food business.

THE SEEDS OF MODERNISM

It isn't always easy to determine the origins of an artistic movement. Which of its antecedents, anticipators, and early experiments were crucial, and which were not? One example: did the abstract seascapes painted by Joseph Mallord William Turner in the 1840s anticipate the Impressionists of the 1870s, or did he inspire them? If it's the latter, why did it take 30 years for the seeds he planted to germinate? Or, as one ophthalmologist has suggested, did Turner's late work simply tell us that his eyesight was clouded by cataracts?

Numerous other theories have been advanced to explain the origins of Impressionism. Were artists of the movement—who rebelled against the then-current art orthodoxy—a product of the times, reflecting the major social changes that each of these artists felt and interpreted? Or was it the other way around: their commentary became part of the zeitgeist and changed the world more than the world changed them?

This is the stuff of great debate for art historians, and in many cases there is no single answer—at least none that is universally accepted. At a far enough remove, all of these theories seem to have some merit. Major artistic movements are sometimes anticipated and certainly draw inspiration from others. Movements are also a product of their times, and, in turn, they affect their worlds. Over time, influence occurs in all directions.

Similarly, in tracing the origins of Modernist cuisine, we can point to various precursor movements. Starting in the mid-1980s, a number of culinary trends were set in motion that would ultimately lead to what we call the Modernist revolution in cuisine—a change in the techniques, aesthetics, and intellectual underpinnings of gastronomy. This revolution is a central theme of this book.

We do not claim that our account here is the only way to make sense of the history of the Modernist revolution. We focus on four major precursors to the revolution, but it goes without saying that some readers will have different accounts, versions, and analyses. Nevertheless, exploring these four developments provides a glimpse into the early days of the new cuisine and the factors that shaped it.

Ferran Adrià and elBulli

The restaurant now known as elBulli, near Roses on Catalonia's Costa Brava, had a rather ignominious start. It was built in 1961 as a miniature-golf course—at best, a small diversion for those visiting the northeastern coast of Spain. The proprietors, Hans and Marketta Schilling, named the establishment in honor of their French bulldogs (*bulli* in Spanish). Within a few years, the miniature-golf course was retooled as a modest seaside bar and grill serving French food, with a French expatriate chef from Alsace. Despite its remote location, the restaurant was ambitious. It was awarded its first Michelin star in 1976. Five years later, Juli Soler took over as general manager (see next page), and the following year the restaurant gained a second star under chef Jean-Paul Vinay.

Around the same time, the young Ferran Adrià came to work as an apprentice in the elBulli kitchen. Adrià had no formal culinary training. Born in a suburb of Barcelona in 1962, he became interested in cooking at the age of 17 while working as a dishwasher at a small French restaurant in a nearby town. The chef there let him prepare the salads and made him memorize Escoffier. Soon Adrià was working in kitchens around Spain. When he showed up at elBulli, he quickly impressed the staff and was hired in 1984 as *chef de partie*.

The entrance to elBulli, Spanish chef Ferran Adrià's groundbreaking Modernist restaurant on the Costa Brava of Catalonia, is unpretentious. It was named for the original owners' pet bulldogs, bulli in Spanish.

Later that year, Vinay left the restaurant, and Soler promoted Adrià to cohead chef. Together, Adrià and Soler embarked on a journey that would transform the former miniature-golf course into the most influential restaurant in the world.

At first, the food Adrià prepared was quite conventional, as was befitting a French-style, Mediterranean-influenced seaside restaurant. Adrià soon undertook a study of French Nouvelle cuisine, serving as a *stagier* under Georges Blanc in Vonnas and Jacques Pic in Valence. Adrià started revising his menu, initially working with the local flavors and traditional dishes of the Catalan coast.

In 1987, he visited the restaurant Chantecler in Nice and heard a lecture given by its chef, Jacques Maximin, who had two Michelin stars and was an important figure in the Nouvelle cuisine movement. Someone in the audience asked Maximin what creativity meant to him.

"Creativity is not copying," Maximin responded. It is likely that nobody else in the room found that significant, but for Adrià, those words were a major turning point. He became fully committed to his role as a chef and began to develop the new culinary philosophy that would later make him famous.

The path from line cook to chef commonly begins with an internship, called a *stage*—a French word, pronounced "staajh," for a training course or work experience. *Stagiers*, as the kitchen apprentices are known, typically work long hours and receive more experience and instruction than money.

A Focus on Innovation

In the late 1980s, Adrià and Soler initiated the tradition of closing the restaurant for half the year. One reason was economic—there were too few customers to warrant staying open year-round. But the time also allowed Adrià and his budding culinary team to learn more about food and try creative experiments. By 1990, Adrià had earned elBulli a second Michelin star. (The restaurant had been demoted to one star when Vinay left.) That year, Adrià and Soler bought the restaurant from the Schillings.

Visits to chefs Michel Bras and Pierre Gagnaire heightened Adrià's appreciation of the more daring side of Nouvelle cuisine. But Adrià's creativity soon took him in a different direction.

Bread was the first casualty. Adrià decreed in

BIOGRAPHY OF

Juli Soler

As co-owner of elBulli outside Barcelona, Juli Soler is largely responsible for the restaurant's stunning success. With chef Ferran Adrià, Soler—who started at elBulli as general manager—helped orchestrate its transformation from a respectable but fairly traditional French establishment into a hotbed of culinary creativity. In recent years, elBulli has been widely considered to be the best restaurant in the world and Adrià the best chef.

Soler began working in the food world at age 13, with a job as an assistant waiter at a Barcelona-area restaurant. He left to pursue his love of music and ran a record store until 1981, when he was offered the position of general manager at elBulli. At the time, the restaurant's chef had just decided to leave, and its future was in doubt. Soler quickly turned it around by hiring a talented new head chef, Jean-Paul Vinay. Two years later, elBulli received its second Michelin star.

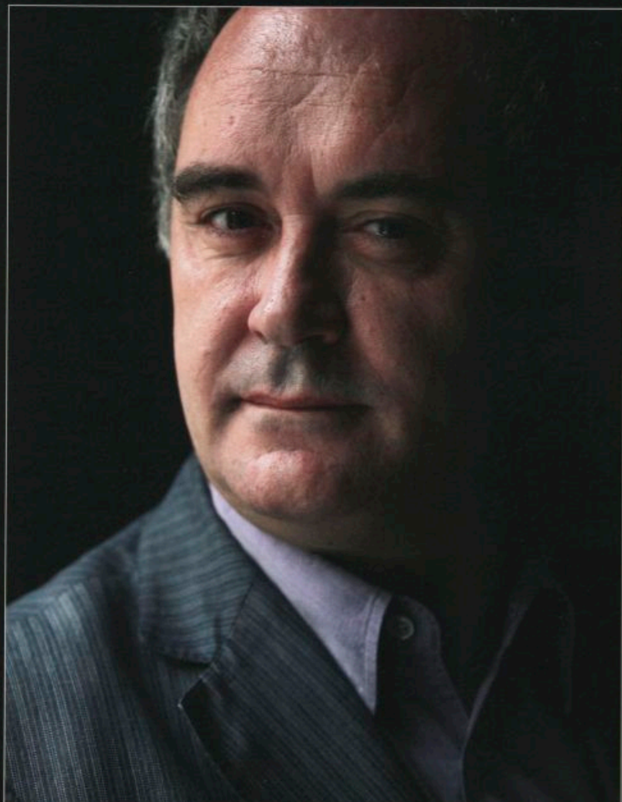
Around this time, Adrià came to work as a *stagier* at elBulli, and Soler quickly recognized his talent. In 1984, Soler hired Adrià as *chef de partie*. Almost immediately, Adrià and assistant chef Christian Lutaud began making plans to leave elBulli and open a place of their own; Vinay also was preparing to depart. Soler persuaded Adrià and Lutaud to stay, promoting them both to *chefs de cuisine*. Soler encouraged them to travel and seek out new ideas, and Adrià and Lutaud were soon experimenting with techniques they had gleaned from their *stages* in some of France's top kitchens. Soler continued to work as manager and maître d'hôtel.

In 1987, Adrià took sole charge of the kitchen and made a decision that was somewhat radical at the time: he would develop his own recipes instead of depending on cookbooks. Soler fostered Adrià's burgeoning creativity. They began a tradition of closing the restaurant for half the year, in part to give the kitchen ample time for idea generation.

In 1990, Soler and Adrià became business partners and bought elBulli. Today, Soler manages the thousands of e-mails the restaurant receives, works on the elBulli cookbooks, and brings in new gadgets for use in the kitchen. Soler is also in charge of the wine cellar and has built an impressive list of more than 1,400 wines.

THE FUTURE OF
Ferran Adrià

Widely hailed as the greatest chef in the world, Ferran Adrià has changed the face of gastronomy and inspired countless imitators and admirers. His inventive Modernist cooking at elBulli in Spain constantly challenges diners' expectations. An Adrià dish might change temperature radically in the middle of a bite, for example. Or a normally solid ingredient such as chicken might be served in liquid form, while the sauce is turned into a solid.



Adrià's culinary alchemy does not take place in a vaccum, however, and credit for elBulli's success is shared by his business partner, Juli Soler (see previous page), and his younger brother, pastry chef Albert Adrià. Albert arrived at elBulli in 1985 and did a two-year apprenticeship in the savory kitchen before turning to pastry. He quickly became one of the most influential pastry chefs in the Modernist movement. In 1998, he became manager of the restaurant's research laboratory, elBullitaller, overseeing the creation of new concepts, techniques, and recipes for each season at elBulli. Based on the research conducted at elBullitaller, Albert and Ferran have launched a line of products–including gelling agents, emulsifiers, thickeners, and more–called Texturas (buy online at albertyferranAdrià.com). Albert remains an integral part of the creativity expressed at elBulli.

Today, reservations at the 55-seat, Michelin three-star restaurant on the Costa Brava are often booked a year in advance. More than a million requests come in for only 8,000 meals served each year.

Meanwhile, Ferran Adrià continues to reinvent himself, both in the kitchen and through his involvement in a wide array of ventures, including beer making, textile design, and even fast food. In early 2010, Adrià announced that elBulli will close as a restaurant at the end of the 2011 season and become a nonprofit foundation dedicated to gastronomy. The culinary world is eagerly waiting to see what Adrià's next move will be.

1997 that he would no longer serve it because it was too ordinary an element, something that could be eaten anywhere. A series of tapas-like snacks took its place. Eventually these snacks—one- or two-bite dishes—would become a central focus of elBulli cuisine.

Next to go was the dessert trolley, which disappeared in 1992. At the time, a dessert trolley was considered mandatory for a high-end European restaurant; for Adrià, it represented an artificial constraint on how the chef presented food to his clients. The cheese trolley, another bastion of fine-dining tradition, held on for another five years before it, too, was banished from elBulli.

Adrià sought to systematically analyze and improve every aspect of the restaurant. In the early 1990s, he and his team formed a "development squad" devoted to generating new ideas and creating techniques that had never existed before. The six months each year during which the restaurant was closed became sanctified as a time for idea generation and immersion in creativity.

Adrià documents this creative exploration in a series of brilliant and unconventional books, with a precision and intellectual seriousness that may be unique in the annals of gastronomy. Although

In 1987, Jean-George Vongerichten created a radical new cuisine based on vegetable juices, oil infusions, and vinaigrettes. This move was as dramatic a departure as anything happening at elBulli at the time. But Vongerichten subsequently moved more to mainstream New International cooking, whereas Ferran Adrià continued a path of relentless innovation.

The intervertebral pads of tuna are one of the innovations in ingredients from elBulli.

Chefs love the fine-grained texture produced by this Microplane grater. Ferran Adrià put this simple tool at the center of several creative dishes.

the elBulli books are referred to as cookbooks, they contain no recipes in the printed versions. (The recipes are on CD-ROMs that accompany the books.) Instead, the pages are dedicated to Adrià's analysis of what motivated his cuisine and how it evolved over two decades, from 1983 through 2005. Adrià devotes almost as much space in the books to discussing ideas that didn't work (the "back to the drawing board" moments) as he does to chronicling his successes.

Most cooking is an intensely practical effort, and that is reflected in most cookbooks, which generally focus on specific details. When chefs philosophize, it tends to be about things such as quality of ingredients or their preferences for certain techniques.

Adrià's books are quite different: they explicitly and self-consciously analyze the process of culinary creativity. A new idea for a dish isn't just a cool trick or a good flavor combination; it is part of an agenda to rethink the theory behind cuisine. Happy accidents and serendipity occurred at elBulli, just as they do at other restaurants, but the difference is that at elBulli, these accidents were viewed through the lens of an analytical, intellectual approach to cuisine. The menu at elBulli isn't just what's for dinner; it is cuisine as art.

Adrià's creative journey was a long one. The dishes that he produced in the late 1980s and early 1990s were nothing like his later creations, but each dish provides an insight into the evolution of his thinking as a chef.

Many elBulli innovations were related to discoveries or revelations. In one of my favorite passages in the elBulli books, Adrià writes about visiting his friend José Andrés in the United States. He stopped by a kitchen store—the kind found in any suburban shopping mall—and bought a Microplane grater, well known for years to American chefs. Microplanes are excellent graters; they are very sharp and yield a fine-grained and fluffy result, even from ingredients like hard cheeses and nuts. Adrià was enthralled. He enthuses in his book about the unique texture and flavor that the Microplane grater gives food. His discovery of this humble tool led to the creation of many new elBulli dishes, including cauliflower "couscous" (see page 3·388).

Although Adrià is known for his exotic and science-inspired techniques, his real interest is in how the act of preparing food can transform the art of cuisine. Exotic laboratory equipment is but one means to that end; another is a humble little handheld grater from a suburban kitchen store. His mission isn't to create a scientific cuisine, but rather to give diners a new experience with food, using whatever tools are available.

Other elBulli innovations revolve around new ingredients. For example, while breaking down tuna for a dish, Adrià noticed that these fish have intervertebral pads. The small, circular, translucent pads are the tuna equivalent of the discs that all vertebrates, including humans, have in their spines. Adrià and his team painstakingly removed the discs from tuna spines and learned to cook and serve them in various dishes. A similar thing happened when the staff was experimenting with green pinecones: the chefs discovered immature pine nuts (at first they thought they were insect larvae) and immediately created several new dishes with them.

The elBulli books are filled with hundreds of such instances. A new ingredient (a fruit or vegetable from Asian cuisine or a new hydrocolloid gel from the world of food science) or a new piece of equipment (a cotton-candy machine or the ISI whipping siphon) serves as the point of departure for new dishes. In some cases, new ingredients and techniques allow Adrià to do something that was previously unheard of.

In 1994, for example, he developed his first savory foam: a white-bean *espuma* served with sea urchin in an urchin shell. Foams have, of course, long been used throughout classical cooking. Whipped cream, sabayon, mousse, meringue, soufflés, and even bread are all examples of foams. Bread, soufflés, and some meringues are cooked foams that are served stiff. Other meringues, whipped cream, mousse, and sabayon are served soft and have traditionally been relegated to dessert and pastry use; dishes such as fish mousse or *sauce mousseline* are rare savory examples.

Yet some unwritten law of culinary tradition had kept foams in those well-defined niches; using a foam outside those bounds was heresy, which is exactly what attracted Adrià. Foam has a familiar and very popular texture. Everyone has had a traditional foam such as whipped cream, and most people have liked it. When Adrià cast foam in a savory role, he created a new and unexpected experience, at once familiar and surprising.

Dining as Dialogue

Along the way, Adrià developed perhaps his most important piece of culinary philosophy: the idea that dining is a dialogue between the chef and the diner. In haute cuisine up to that point, the vocabulary of that dialogue was constrained by tradition and convention. Diners come to a meal with a tacit understanding of what is possible and familiar, based on their previous dining experiences. The chef, at least in traditional cuisine, comes prepared to cater to diners' preconceptions. Adrià broke those constraints by creating novel foods that could not help but provoke a reaction, forcing diners to reassess their assumptions.

This intellectual approach to cuisine became central at elBulli. It wasn't enough for the food to be delicious; it also had to elicit thoughts and feelings. While other chefs might work to optimize the purely gastronomic qualities of their food, such as taste and texture, Adrià had a higher goal. Did the food make people think, make them react emotionally? How did it change the dialogue? Adrià's preferred term for his culinary style, "technoemotional" cuisine (first coined in 2008 by Catalan journalist Pau Arenós), reflects this dual goal. Culinary technology produces the effect, but the ultimate impact is emotional. In sharp contrast to the overly serious formal cuisine of Escoffier, one of the central emotions that Adrià sought to elicit is humor. Laughing with surprise or seeing the wry humor in a culinary joke is a central part of the elBulli experience.

Before Adrià, chefs focused primarily on making dishes that were unique in their details—their specific combinations of flavors and textures. Only rarely did chefs seek to make a dish that was the first of its class. Instead, they tended to focus their creativity on developing a small number of signature dishes that marked their careers. Usually those dishes would be served for many years. We have been enjoying Joël Robuchon's mashed potatoes at his various restaurants for more than two decades.

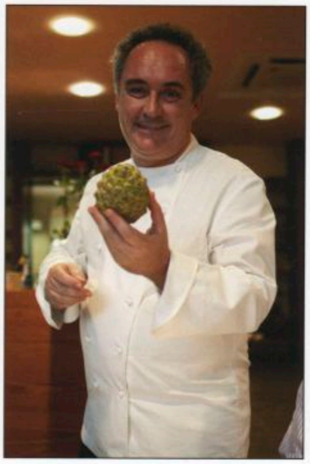
Adrià took culinary creativity to an extreme and came to view unprecedented novelty as the cornerstone of his cuisine—something that should occur in every dish, every night. This is the direct opposite of the "signature dish" approach. At elBulli, each dish is supposed to be a new creation. And that dish generally is not repeated after the first season in which it is served. If you really like a dish at elBulli, enjoy it now, because chances are you will never have it again (unless you make it yourself).

Changes in menu structure, which had started with the elimination of bread and the dessert trolley, continued. Every aspect of the culinary process was examined and reimagined. Why are dishes served late in the meal sweet, while others are not? What is the role of cocktails in the dining experience? Why should food be served with traditional silverware?

The reexamination led to conceptual advances, such as the notion of "deconstruction." Adrià started to create dishes that had familiar flavor themes but were presented in entirely unconventional ways. Here is what he says about deconstruction in his book *elBulli 1994–1997:*

> It consists of taking a gastronomic reference that is already known, embodied in a dish, and transforming all or some of its ingredients by modifying its texture, shape, and/or temperature. This deconstructed dish will keep its essence and will still be linked to a culinary tradition, but its appearance will be radically different to the original.
>
> For this game to be successful, it is essential that the diner has gastronomic memory, since the absence of references turns the concept of deconstruction into mere "construction" based on nothing.... The result has a direct relationship with the diner's memory, in that although he may not see that he has been served a familiar dish, he later establishes a direct connection between the flavor of what he is eating and the classic recipe; in other words, he recognizes it.

This is a passage that would be more at home in a book of literary criticism than in a cookbook. Adrià's deliberate theorizing was new to the art of cuisine. Other chefs had played tricks on diners—for example, baked Alaska was a 19th-century invention in which a meringue served hot from the oven hid the surprise of cold ice cream inside. Many chefs had created new takes on old dishes. But the systematic invention of new concepts like



Immature pine nuts from green pinecones are another example of innovative ingredients at elBulli.

Many chefs throughout history have created dishes that have an element of surprise, like baked Alaska, but they did not build a cuisine with the goal of eliciting emotion at its foundation. As a result, their most innovative dishes were considered as nothing more than parlor tricks.

The chef Thomas Keller is famous for injecting whimsy and humor into his cuisine, for example by serving salmon tartare in an ice cream cone (see page 3·68) or creating dishes with names like "oysters and pearls," which evoke references outside the food world. This kind of reference is a sort of second cousin to deconstruction.

deconstruction was unique to Adrià and elBulli.

Self-conscious invention is a familiar approach in other arts, such as literature, where it is common to reference previous novels, paintings, and poems and to juxtapose them with other concepts in a new framework. Indeed, literary allusions and references are a primary tool for writers and poets. Yet this approach had never been used in cuisine in the way Adrià employed it.

Viewed in this light, we see how limited the Nouvelle revolution of the 1960s and 1970s was: it was something of a tempest in a teapot by comparison. Adrià's approach didn't merely combat single features of culinary tradition, such as roux-thickened sauces. It attacked every convention in food, including many that we didn't even realize *were* conventions until his innovation pointed them out.

The World Catches On

For many years, Adrià's quest for a new cuisine was a lonely venture set on a remote seashore along the Catalan coast. It is remarkable that he and Soler managed to keep a steady clientele in the face of so much change. The food at elBulli is intellectually challenging; it demands much of its diners. Not everyone wants a challenge for dinner. Yet without clients who appreciated his food, Adrià could not have proceeded.

THE EXPERIENCE OF

A First Meal at elBulli

Chef Grant Achatz wrote the following account of his first experience at elBulli, which appeared in *The New York Times*:

I arrived at The French Laundry early one night so that I could get some prep done for a VIP table, when I saw Thomas Keller gliding through the kitchen toward me. Every morning he would greet each cook with a handshake, and depending on the time, a smile. As he approached on this day, I noticed something in his hand. He placed the October 1999 issue of *Gourmet* on the stainless steel counter in front of me and asked me to open to the page marked with a yellow sticky note.

I thumbed to the page, finding an unfamiliar, gruff-looking chef surrounded by floating oranges. Who is this guy, I wondered ... and why is he juggling citrus fruits?

In a short time, that guy would become known as the best chef in the world. His name was Ferran Adrià.

Chef Keller looked down at the magazine and spoke softly. "Read this tonight when you go home. His food really sounds interesting, and right up your alley. I think you should go *stage* there this summer ... I will arrange it for you."

Seven months later, I landed at the Barcelona airport. I had not planned very well and had neglected to make arrangements for traveling to elBulli, two hours north by car. My *stage* started the next day.

As luck would have it, while walking through the airport I ran into a group of American chefs. Wylie Dufresne, Paul Kahan, Suzanne Goin, Michael Schlow, and a couple of journalists had been brought over by the Spanish Tourism Board to promote Spanish gastronomy. We talked for a bit before I asked where they were headed. A restaurant called elBulli, Wylie said, have you ever heard of it? Needless to say I hitched a ride with them on their posh tour bus.

When I arrived with the American chefs, I felt a bit like a leech. After all, I was just a sous chef at the time; they were all established chefs on a funded trip. None of them knew me, and furthermore I was there to work. When we arrived at elBulli the co-owner and maître d'hôtel, Juli Soler, welcomed the group at the door, and the Spanish official who was leading the tour pulled him aside and explained my story.

I was prepared to put on a chef's coat, right then and there, and start working. Juli walked off to the kitchen, and when he returned he said, "Ferran wants you to eat with the group." Well, now I really feel like a parasite, but if you insist....

I was a 25-year-old sous chef at what most considered, at the time, to be the best restaurant in the world. I had grown up in a restaurant since the age of five. I graduated with honors from what most considered the best culinary school in the world. I thought I knew food and cooking.

I had no idea what we were in for. Honestly, none of us did.

When the dishes started to come I was disoriented, surprised, amazed, blown away, and, to my dismay, blind to what was happening. Trout roe arrived, encased in a thin, perfect tempura batter. I shot Wylie a skeptical glance and he immediately returned it. We bit into the gumball-size taste ... there was no apparent binder holding the trout eggs together, and the eggs were still cold, uncooked! How did they hold the eggs together and then dip them in a batter

Eventually, word spread to the rest of the world that something extraordinary was occurring in a most unlikely place. In 1996, Robuchon gave an interview in which he was quoted as saying that Adrià was the best chef on earth. That put the food world on notice, and soon a blizzard of press brought elBulli to the attention of the world at large. The publication of the first elBulli books, also in the 1990s, brought Adrià's ideas to a still wider audience.

Adrià has always been happy to learn from others, and his books are quite generous in crediting the people who have helped him along the way. He learned about liquid nitrogen from Heston Blumenthal in 2004. Similarly, Adrià's use of spherification was unique in a restaurant setting, but it had been known to industrial food scientists for decades. Related techniques with alginate gels had long been used in such mundane items as olive pimentos and cherry pie filling.

Modernist cooking is in many ways founded on the innovations created at elBulli, but this is not the story of just one chef and one restaurant. Adrià's innovations could have started and ended in the kitchen of elBulli. He could have been just another chef making food his own way.

Indeed, that is largely what happened with the most daring chefs in the French Nouvelle cuisine movement. Chefs such as Michel Bras, Marc Veyrat, and Pierre Gagnaire each had his own

William Julius Syplie Peschardt filed a British patent in 1942 on what we now call spherification using alginate.

For more on spherification see page 4·184.

without dispersing them into hundreds of pieces? And how are the eggs not totally cooked? This is cool....

A small bowl arrived: Ah, polenta with olive oil, I thought. See, this food isn't that out there. But as soon as the spoon entered my mouth an explosion of yellow corn flavor burst, and then all the texture associated with polenta vanished. I calmly laid my spoon down on the edge of the bowl after one bite—astonished.

What the hell is going on back there, I thought. I know cooking, but this is the stuff of magic.

And on it went ... pea soup that changed temperature as I ate it; ravioli made from cuttlefish instead of pasta that burst with a liquid coconut filling when you closed your mouth; tea that came in the form of a mound of bubbles, immediately dissolving on the palate; braised rabbit with hot apple gelatin.... Wait, how is this possible? Gelatin can't be hot!

The meal went on in this fashion, for 40 courses and five and half hours.

Still, I walked into the elBulli kitchen the next day expecting some familiarity. A kitchen is a kitchen, right?

I was ushered into a small prep room with seven other cooks, one of whom was René Redzepi of the now famous restaurant Noma, in Copenhagen. He was my ears and voice during the stay at elBulli. See, he spoke French, and I do not speak any Spanish. Listening to the elBulli *chef de cuisine*, an Italian chef would translate to the French guy and he would pass on the instructions to René, who would then translate into English for me. The group was incredibly international.

Chefs were coming from all over the world to learn this new style of cooking, yet it did not feel like cooking at all. "Concepts" better describes the dishes. There were no flaming burners, no proteins sizzling in oil, no veal stock simmering on the flat top.

Instead I saw cooks using tools as if they were jewelers. Chefs would huddle around a project like wrapping young pine nuts in thin sheets of sliced beet or using syringes to fill miniature hollowed-out recesses in strawberries with Campari with precision. Everything was new and strange to me: the way the team was organized, the techniques being used, the sights, and even the smells. To me it was proof that this was a new cuisine, because none of it was routine.

I have returned to elBulli to dine twice since the summer of 2000. Each time I was in a different state of maturity as a chef and a diner, and each time Ferran managed to make me feel a childlike giddiness. He evoked a sense of wonder and awe in the medium that I know best.

People often ask me if the style of cooking he pioneered is a trend, fad, or flash in the pan. My belief is that every 15 to 20 years, with an obvious bell curve of energy, most professions change. Technology, fine arts, design, and yes, cooking, follow the same predictable pattern. A visionary creates the framework for a new genre, others follow and execute, and the residual effects remain, embedded in the cloth of the craft. If we look back to Nouvelle cuisine, founded in the early '70s by Bocuse, Chapel, Troisgros, Guérard, Vergé, and Oliver, we see the pattern clearly. Protégés of great chefs eventually forge their own paths to help create a new style. This lineage carried us into the Keller, Bouley, Trotter, and Boulud generation in the United States, and subsequently chefs like Wylie Dufresne, Andoni Luis Aduriz, Homaro Cantu, and I forged our own paths.

distinctive cuisine, which flirted with rebellion against culinary norms. These chefs made some very exciting dishes, such as Bras's famous *coulant*, or his *gargouillou*, and those dishes influenced and inspired many other chefs to create similar items. But none of these other chefs ignited a movement that others followed. Instead, each chef's signature style remained confined largely to his own restaurant.

For more on gargouillou, see page 3·294.

For Adrià, the story was different. As we will see, several parallel developments in the culinary world helped give his innovations greater resonance and a wider reach.

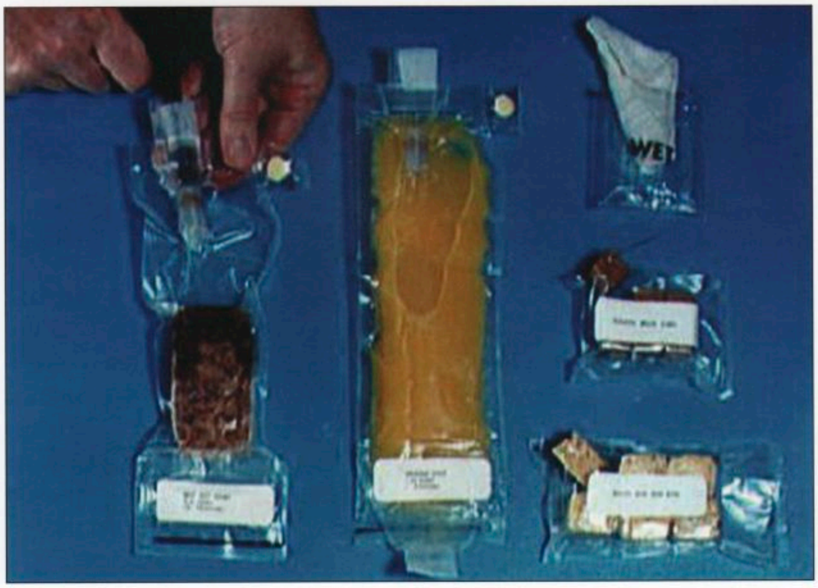
From the Vacuum of Space to Vacuums in the Kitchen

It was the 1960s, and NASA had a problem. The manned space program required that astronauts eat in outer space, perhaps on missions that lasted weeks or months. But the agency did not want to stock spacecraft pantries with bulky metal cans of food, which would weigh down the craft. So NASA began to experiment with sealing food in heat-safe plastic bags.

Because the Nacka system did not cook food fully in the package, it was not quite true sous vide cooking. The AGS system took that leap.

Similar experiments occurred around the world as people looked for more convenient ways to prepare food for various institutions. In the early 1960s, two Swedish hospitals worked with the Stockholm City Council to develop the Nacka system. The idea was to centralize the preparation of fresh meals at one large kitchen facility. The food would be packaged so that it could then be distributed to hospitals within the city.

Vacuum-packed food developed by NASA for the manned space program.



In the Nacka system, main courses were prepared traditionally and then vacuum-sealed in plastic bags while still hot (at temperatures of at least 80 °C / 176 °F). After sealing, the bags were boiled for an additional 3–10 min, then refrigerated. At service time, the bags were reheated, and the food was served. Swedish hospitals provided more than 5 million of these meals to patients in the early 1960s. Patients and other testers found them to be a considerable improvement over standard hospital food.

Next came the Anderson, Greenville, Spartanburg (AGS) system, developed during the late 1960s by a partnership of three South Carolina hospitals and the plastic-film manufacturer Cryovac (then a division of W. R. Grace). Like Nacka, the AGS group's goal was to improve the quality of centrally prepared hospital food.

The group's project manager, Ambrose T. McGuckian, initially reviewed every existing method of preparing convenience foods. Although the Nacka system was selected as the most convenient and economical, the cooked food rated barely satisfactory in tests of taste and quality. McGuckian's insight was that raw ingredients could be vacuum-sealed and then cooked inside the bags by using carefully controlled temperatures and times. The results were vastly superior.

The AGS system is the first example of a cooking method, now called sous vide, that is widely used in Modernist cuisine. The AGS system was not adopted by hospitals ultimately, and McGuckian went on to consult with other food-service companies. In fact, the first meals prepared sous vide in a restaurant almost certainly were served in 1970 at the Holiday Inn in Greenville, South Carolina, where McGuckian was a consultant.

Commercial applications of the sous vide method began to pop up around the world. The first appearance in France was in 1972, when hams were cooked sous vide. At the time, French law did not allow restaurants to serve refrigerated food products with a shelf life of more than six days, so this novel approach did not gain much of a following. This case is an early example of culinary technology, innovation, and scientific knowledge outpacing legislated food standards—a theme that is continually repeated in sous vide cooking.

Toward the end of the 1970s, sous vide technology crossed the English Channel to London, where the French chef Albert Roux began a collaboration with Groen and Cryovac to promote the new cooking method. In 1983, Roux opened a factory in southwestern France to supply low-cost meals made sous vide to the French national railway system (SNCF) and to British Airways.

By the late 1980s, Roux brought sous vide to the restaurant industry in Britain as part of an early quick-service restaurant chain called Rouxl Britannia. The concept was simple: high-quality food could be economically prepared at the Home Rouxl central kitchen by skilled cooks using sous vide technology. The refrigerated meals would then be distributed to restaurant outlets around England, where they would simply be reheated and plated by less-skilled cooks.

Unfortunately, for myriad reasons, Rouxl Britannia eventually failed in the early 1990s. The most frequently cited issue was that the public never warmed up to the idea of restaurants that just reheated food made elsewhere.

In France, cooking sous vide caught on more successfully. At around the same time that Roux was starting his early experiments with sous vide cooking in England, the French chef Georges Pralus was experimenting with it for a decidedly smaller culinary audience. During the early 1970s, Pralus worked with the pioneering Nouvelle cuisine chefs Pierre and Jean Troisgros at their restaurant in Roanne (see next page).

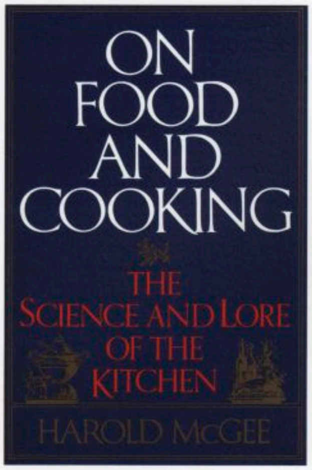
Pralus set out to solve a problem they were having with their *terrine de foie gras*: shrinkage and weight loss from the juices and fat that ran out during cooking. Initially, Pralus approached the problem by using the time-tested technique of *cuisine en papillote*, in which foods are wrapped in oiled paper bags and then cooked, a method that helps to retain the aromas and contain the juices. Next, he began to experiment with wrapping the foie gras in heat-resistant plastic. Although the initial results were not successful, perseverance eventually paid off. By encasing the foie gras in multiple layers of plastic and cooking it at low temperatures for a long period of time, Pralus reduced shrinkage from about 40% by weight to about 5%. The extraordinary results, obtained in 1974, led to better *terrine de foie gras* at Maison Troisgros, and it also led to a collaboration between Pralus and Cryovac. Ultimately, multilayer, heat-resistant plastic bags were produced to retain substantial vapors and juices during cooking.

Sous vide cooking caught the attention of the most influential food critic of the Nouvelle movement, Henri Gault. In the early 1980s, SNCF hired Gault to oversee the creation and execution of world-class cuisine for the launch of its Nouvelle Première trains. Although SNCF had a long tradition of outstanding service and cuisine on its luxury train lines, providing high-end cuisine on numerous routes was a culinary and logistical challenge. After some consideration, Gault decided that the only way to meet the challenge was by using sous vide cuisine.

Gault recruited Robuchon to oversee recipe development. He also contracted with the food researcher Bruno Goussault to provide technical support. Robuchon developed exceptional recipes for the rail service but insisted on cooking foods at 54–68 °C / 129–154 °F. Goussault helped convince the French health authorities that food safety could be assured at those temperatures.

These early experiments with cooking sous vide were developed in the context of institutionalized food service, primarily to reduce costs and ensure quality control. But the next phase of sous vide cooking marked a turning point, as a few high-end chefs began using sous vide as a culinary technique in its own right. Part of this shift was due to tireless campaigning and education by Pralus and Goussault. By the early 1990s, the long road from NASA,

The first sous vide meals served in a restaurant likely were made in 1970 at the Holiday Inn in Greenville, South Carolina, pictured here in a postcard from the era. Their use of sous vide techniques was an outgrowth of the AGS system developed first for South Carolina hospitals by Ambrose McGuckian.



Harold McGee's magnum opus taught a generation of chefs that science held new and often surprising answers for them. It was never translated into French and was not available in Spanish until 2007. As a result, its influence has been largest in the English-speaking world, although it is also available in Chinese, Dutch, Italian, and Japanese.

the hospitals of Stockholm, and the Greenville Holiday Inn reached its climax: sous vide cooking was ready to enter the mainstream, which meant the high-end kitchens in France, Spain, and elsewhere.

Sous vide cooking represents such an important new technique that we cover it in detail in chapter 9 (page 2·192). But it is just one of dozens of technological innovations that have been adopted by Modernist chefs—from gelling and thickening agents, such as xanthan gum and gellan gum, to emulsifiers such as diglycerides and propylene glycol alginate. In each case, industrial and commercial needs motivated the invention of a new technology.

Creating a new means of cooking or a new ingredient is difficult and expensive. High-end cuisine is too small and fragmented a marketplace to inspire this kind of innovation. It takes larger-scale commercial and industrial goals to pay for the research and development of new technologies. But once they exist, they can easily be appropriated by chefs and used as tools for the expression of culinary creativity. The story of sous vide mirrors the story of many other technologies that were developed by the food science industry, mostly for commercial users.

Starting in the mid-1980s, several of these technologies became available to chefs. Most chefs were either unaware of them or were not interested. For those who were open to the ideas, however, new possibilities began to appear. Without the infusion of technology, the Modernist revolution would have lacked an important source of inspiration.

Science in the Kitchen

Humans are a storytelling species, and this trait extends to cooking. Virtually every cookbook from *Apicius* onward has attempted to explain what happens to food as it is cooked and to outline the reasoning behind certain cooking techniques. As a result, a body of culinary wisdom has developed and become part of what every young chef learns. Science is also a form of storytelling, but with an important difference: you can confirm truth of the story that science tells by using data, experiments, and observations.

In 1984, Harold McGee published the first edition of his magnum opus, *On Food and Cooking*, a landmark book that explores the scientific facts behind culinary beliefs (see next page). At that point, the discipline of food science had existed for decades, and researchers had uncovered many interesting facts about the science of cooking. But these discoveries were not being communicated to chefs or the public at large. So McGee undertook the task of telling the world the real story of how cooking works. In some cases, he

BIOGRAPHY OF

Georges Pralus

The French chef Georges Pralus is often credited as the father of sous vide cuisine in France, although he shares that title with his compatriot Bruno Goussault (see next page). In 1974, Pralus was enlisted by three-star chef Pierre Troisgros to help develop a new way to cook *terrine de foie gras* that would prevent the 30–50% weight loss that occurred when traditional cooking techniques were used. Pralus came up with the idea of wrapping the foie gras in several sheets of heat-resistant plastic before cooking. After some experimentation, he found a wrapping method that limited the weight loss to just 5%. Later, he began using vacuum-sealed plastic bags instead.

Some chefs were skeptical that food cooked in plastic would taste as good as traditionally cooked food. But the influential French chef Joël Robuchon quickly recognized the potential of this new technique and endorsed Pralus. Thanks in part to Robuchon's support, Pralus and the Sealed Air Corporation, the manufacturer of Cryovac packaging, opened a school in 1979 to teach sous vide techniques, and they worked with Goussault to develop and disseminate this Modernist method of cooking (see page 2·192). Pralus taught the technique to some of the top French chefs, including Paul Bocuse, Alain Ducasse, and Michel Bras. Today, Pralus continues to teach chefs and culinary students around the world.

BIOGRAPHY OF

Harold McGee

Harold McGee is one of the leaders of the movement to inform chefs about the science of how cooking works. His seminal book, *On Food and Cooking*—an encyclopedic tome first published in 1984 and updated in 2004—explains in detail the science behind a wide range of culinary techniques. It also catalogs the history and flavor profiles of various ingredients. *Publishers Weekly* called the 2004 edition of the book "a stunning masterpiece." Today, this best-selling book is required reading for anyone interested in the science of cooking.

McGee began working on his book in the late 1970s, after studying astronomy at Caltech and receiving a doctorate in literature from Yale University. He thought food science "was interesting information that my friends and I, who were not professional cooks, would enjoy knowing," he explains. Few in the United States were thinking or writing about the science of cooking at that time, but interest in food seemed to be growing among Americans. "I was lucky to have an aspect of food to explore that was largely unexplored at the time," McGee says. His book was featured in *Time* and *People* magazines and won an award in Britain.

McGee published a second book, *The Curious Cook: More Kitchen Science and Lore,* in 1990. He has written articles for a variety of publications, ranging from scientific journals like *Nature* and *Physics Today* to popular magazines like *Food and Wine.* He also writes a column on food science for *The New York Times.*

McGee's newest book, *Keys to Good Cooking,* was published in 2010 by Penguin Press. Unlike his previous books, McGee says, "it's actually very ungeeky, very basic; it reacquaints people with kitchens and how they work" and helps home cooks understand "the kinds of things that most cookbooks don't bother to tell you."

BIOGRAPHY OF

Bruno Goussault

Though not a chef, Bruno Goussault has become one of the most influential proponents of sous vide cooking in France. He has worked for more than three decades to perfect sous vide techniques and has taught the process to some of the world's most innovative chefs, including Thomas Keller, Michel Richard, Joël Robuchon, and Wylie Dufresne.

Goussault is generally credited with promoting, in the early 1970s, that cooking sous vide at temperatures well below boiling could improve the tenderness and flavor of food. Up to that point, sous vide cooking had largely been limited to institutional uses, and cooking temperatures were held near boiling to prolong shelf life. When Goussault presented his findings in 1974 at a food-industry conference in Strasbourg, France, they caused quite a stir.

That same year, about 300 miles away, chef Georges Pralus was experimenting with sous vide cooking in Pierre Troisgros's kitchen (see previous page). In 1979, Pralus and the Cryovac company opened a school to teach sous vide techniques. Pralus and Goussault worked together to develop and disseminate sous vide techniques. In 1981, Cryovac hired Goussault to help systematize the curriculum at its sous vide school.

Soon after that, Goussault worked with Robuchon to create a menu for the first-class cars of the French national railway system (see page 2·192). In 1991, Goussault launched his own consulting company, the Centre de Recherche et d'Études pour l'Alimentation (CREA), in Paris. The CREA trains chefs in sous vide as well as other Modernist cooking techniques. Goussault also serves as chief scientist at Cuisine Solutions, an international frozen-food company that specializes in meals cooked sous vide.

found that no one knew why a certain culinary phenomenon occurred, so he engaged with scientists to find out.

His book became a sensation, in part because it overturned many long-held but erroneous pieces of kitchen wisdom—such as the idea that searing meat "seals in the juices." (Searing actually causes meat to leak more juices.) McGee taught us that most of the stories we had been told about food were just that—clever stories that would not survive a confrontation with scientific reality.

On Food and Cooking isn't a cookbook; it contains neither recipes nor detailed techniques. But it has nonetheless been extremely influential among chefs. The New York chef Daniel Boulud calls the book "a must for every cook who possesses an inquiring mind." And in the words of the food writer Michael Ruhlman, "*On Food and Cooking* is, in my opinion, hands down the most important book about food and cooking ever written."

Over time, the trend that McGee started has expanded enormously. He followed *On Food and Cooking* with *The Curious Cook* in 1990, and similar books by other authors soon emerged: *CookWise: The Hows and Whys of Successful Cooking* (1997) and *BakeWise: The Hows and Whys of Successful Baking* (2008), both by Shirley O. Corriher; *The Science of Cooking* by Peter Barham (2001); and *What Einstein Told His Cook: Kitchen Science Explained* (2002) by Robert L. Wolke (who also contributed to this book, see page 5·XLVI). Each of these books expanded on McGee's objective to apply scientific principles to food. Many aspects of McGee's scientific approach are found today on television shows about food, including *America's Test Kitchen* and Alton Brown's *Good Eats*.

In a strong sense, McGee provided a template for one of the themes of this book, which is using science to explain how cooking works. *On Food and Cooking* was enormously influential for us, both when it first came out, and then again more recently as this book came together. Chapter 7 on Traditional Cooking (page 2·2) is in many ways an homage to McGee and the culinary-science movement that he helped launch.

In 1985, McGee's book was reviewed for the scientific journal *Nature* by physicist Nicholas Kurti (next page). Soon after Kurti visited McGee, they became friends. Elizabeth Cawdry Thomas was a Cordon Bleu alumna who ran a cooking school in Berkeley, California, and was married to a prominent scientist at the University of California there.

In December 1988, she attended a conference at Erice, a beautiful medieval Sicilian hill town that had become home to a scientific conference center. Over dinner with Ugo Valdre, a physicist at the University of Bologna, she discussed her

Edouard de Pomiane was a French scientist who doubled as a food writer. He wrote more than a dozen books on food and hosted a popular radio show starting in the 1920s. He advocated a scientific approach to food, but food science was still in its early stages, so he had fewer scientific insights to share than McGee, Corriher, Wolke, and This have these days.

THE CONTROVERSY OF

The Origins of Molecular Gastronomy

Hervé This has told the story of molecular gastronomy in many publications. In March 1988, he and Nicholas Kurti together decided they would launch a new scientific discipline and an international conference called "molecular and physical gastronomy." Some time later, Kurti phoned Antonino Zichichi from This's office in Paris to ask if their conference could be held at Erice. Zichichi agreed, and in 1992 the first workshop on "molecular and physical gastronomy" was held. Kurti and This organized that conference and several more in succession, launching their new discipline. The rest, as they say, is history.

Or is it? History can sometimes be elusive. In researching this chapter, we talked to Erice participants and examined digital scans of original documents available on the website of Harold McGee (www.curiouscook.com/cook/erice.php). A very different story emerged from these sources.

These versions of history appear completely incompatible on key details about who did what, and when—or perhaps more to the point, who should get credit for what. Hervé This reviewed a draft of this chapter, and he told us it was incorrect. He reiterated his version of events, but declined to explain how to reconcile it with the documentary evidence. Instead, he said that other documents in his cellar supported his story, but he couldn't waste time digging them out.

Which story is correct? We don't know, because we were not there. The narrative above and on the next page seems to best match the available documents and recollection of participants, but we note that This has a different account.

BIOGRAPHY OF

Nicholas Kurti

An experimental physicist with a passion for food, Nicholas Kurti (1908–1998) is often considered the father of molecular gastronomy—both the discipline and the term itself.

Kurti was one of the leading physicists of his time. Born in Hungary, he worked at Oxford University from the 1930s through the mid-1970s and specialized in ultralow-temperature physics. (The Clarendon Laboratory, where he worked, was nicknamed "the coldest spot on earth" after Kurti discovered a way to create temperatures a millionth of a degree above absolute zero.)

Toward the end of his career, Kurti began melding his scientific knowledge with a keen interest in cooking. In 1969, he gave a talk to the Royal Institution in London titled "The Physicist in the Kitchen," in which he explained the science of microwave cooking and other culinary techniques.

In 1990, after he had retired from Oxford, Kurti began working with Elizabeth Cawdry Thomas, Hervé This, and Harold McGee to organize an international workshop on the science of cooking at the Ettore Majorana Foundation and Centre for Scientific Culture, in Erice, Sicily.

The first Erice workshop was held in 1992 and drew 30 to 40 participants, including university and food-industry scientists, as well as some chefs (notably Raymond Blanc and Pierre Gagnaire). Five more Erice workshops were held over the next 12 years. After Kurti's death in 1998, Hervé This named the next meeting of the Erice workshop in his honor: the International Workshop on Molecular and Physical Gastronomy "N. Kurti."

dream of having a conference at Erice that brought chefs and scientists together. Valdre introduced her to Antonino Zichichi, who ran the Ettore Majorana Foundation and Centre for Scientific Culture, in Erice. He liked her idea of a conference on food and science, but he prompted her to find a scientist to run it.

Thomas turned to Nicholas Kurti, whom she had known for years, and recruited him to sponsor the project. In early August 1990, Kurti wrote to Zichichi, saying he was writing at the suggestion of Valdre and Thomas, whom he described as a "mutual friend of ours," since Zichichi also knew her.

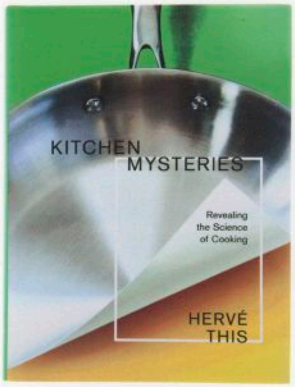
Kurti was tentative in his first letter to Zichichi, asking him whether the topic of science and cooking might be too "frivolous" for his prestigious center. Nevertheless, Zichichi scheduled the conference, provided that Kurti personally run it. In late September, Kurti replied, saying that since his August letter he had made progress in recruiting Harold McGee and Hervé This, who, with himself, would form a triumvirate to run the conference. In fact, it was Elizabeth Thomas who first called McGee and recruited him to the project; then Kurti followed up. Kurti acknowledged in another letter that Thomas was the one who "sparked" the conference, but she was not made part of the organizing group. Valdre was disappointed with that and took the issue up with Kurti. In letters to Thomas, Valdre explained it as being due to a rather odd concern of Kurti's that association with the Ettore Majorana center might appear to improperly benefit Thomas's private cooking school. Although not officially recognized as an organizer, Thomas attended each of the Erice conferences as an active participant.

Initially, Kurti proposed the conference be called "Science and Cooking." In February 1991, this was changed again to "Science and Gastronomy." At some point between then and early 1992, the name changed again to "Molecular and Physical Gastronomy." The first appearance of that term seems to be the poster advertising the first Erice conference, which occurred in August 1992.

Six of these workshops were held between 1992 and 2004. Each one attracted between 30 and 40 participants, who informally discussed their work and presented papers over the course of four days. No conference proceedings or papers were ever published. The majority of the attendees were scientists who were interested in cooking, but a number of notable chefs attended, including Raymond Blanc and Heston Blumenthal from the United Kingdom, and Pierre Gagnaire from France. Attendance was by invitation only.

The impact of these conferences is open to debate. They were interesting and informative

Kurti organized the 1992 Erice meeting with McGee and This. The 1995 and 1997 meetings were organized by Kurti and This. In 1998, Kurti selected Tony Blake, a flavor chemist, to take over his role in organizing the workshop as "program coordinator," working with Hervé This as director. The last workshops, in 2001 and 2004, were organized by Peter Barham and Hervé This.



There is little doubt that This's books, which are written for a popular audience, have brought more people in touch with the concept of culinary science. In that sense, they are part of the broad trend toward greater public recognition of the relationship between science, technology, and food.

Hervé This (on left) and Nicholas Kurti (on right). Photo courtesy of Hervé This.

events that the participants enjoyed, but there is no evidence they had any direct influence on innovations in modern cuisine. Adrià never attended, nor did any other chef from Spain. Gagnaire, a highly influential chef in the Nouvelle cuisine movement, participated in some of the conferences, but some of the attendees reported that he was quite ambivalent about the role of science and technology in the kitchen. (In his more recent work, he has collaborated with This and has been open to Modernist innovations.)

The only chef who both attended the Erice workshops and is clearly part of the Modernist revolution is Blumenthal, who went to Erice in 2001 and 2004. His role there, however, was primarily to report on innovations he had already implemented at his restaurant, The Fat Duck.

Indeed, McGee argues on his website and in personal communications to us that the conferences were, by themselves, not responsible for the explosion in Modernist cuisine.

> "Before Erice even happened, Ferran Adrià had decided that he was going to experiment. I think he is almost single-handedly responsible for this movement in experimental cooking, and it wasn't until 2000 that he decided maybe food science had some answers for him. The technological and scientific aspects of food, for all their prominence in magazines these days, are secondary to a larger trend: the globalization and generalization of food and cooking such that national traditions aren't as important as they used to be. People like Ferran are willing to use any tool, any technique, to create experimental cuisine. Blumenthal came to the last two [workshops], in 2001 and 2004, but had already begun to apply science to restaurant cooking. He memorably demonstrated that cooks outside the small Erice circle were using the ideas and tools of science with great imagination and creativity."

The conferences' impact on what chefs did was modest, but they proved to be a watershed event for Hervé This. He resolved to take the name "molecular gastronomy" and turn it into a new scientific discipline. He returned to graduate school and earned a Ph.D. in chemistry in 1996, with a dissertation that was also titled "Molecular and Physical Gastronomy." After Kurti died in 1998, This became the primary organizer of the workshop, and he started to promote the name "molecular gastronomy" far and wide.

According to This, molecular gastronomy is a new science dedicated to understanding the process of cooking. He views the new discipline strictly as a branch of academic science, and he dismisses the notion that molecular gastronomy is related to the cuisine at elBulli, The Fat Duck, or elsewhere. He calls that "molecular cooking" and argues forcefully that it is totally distinct from molecular gastronomy.

But that's not the opinion of the public at large. The way the story is told in countless articles, the proper name of all Modernist cooking is molecu-

BIOGRAPHY OF

Hervé This

Hervé This was an editor of *Pour la Science*, the French edition of *Scientific American* magazine, from 1980 to 2000. His interest in food led him to collaborate with Nicolas Kurti, Harold McGee, and Elizabeth Cawdry Thomas to create the first International Workshop on Molecular and Physical Gastronomy in Erice, Sicily (see previous page).

This is a prolific author and has written or coauthored many books, including *Kitchen Mysteries* (2007); *Cooking: The Quintessential Art* (2008); *Molecular Gastronomy: Exploring the Science of Flavor* (2008); *Building a Meal: From Molecular Gastronomy to Culinary Constructivism* (2009); and *The Science of the Oven* (2009).

For his part, This claims to care little for food, except as a topic for scientific inquiry. Although he grew up in a family of gourmands, he once told a journalist, "I have no interest in food." Apart from the necessity of food for survival, he said, "I wouldn't care if I ever ate again."

THE HISTORY OF

The Goals of Molecular Gastronomy

The discipline that Hervé This termed "molecular gastronomy" has had a slight shift in goals over the years. This says "the initial program of the discipline was mistakenly mixing science and technology." But he says he has corrected that mistake and removed technology from the definition. In a 2009 review article and subsequent personal communications with us, This describes molecular gastronomy as "the science of exploring the phenomena that occur during cooking, looking for their mechanisms."

This divides the "new program" for molecular gastronomy into four primary components:

1. Model "culinary definitions."
2. Collect and test "culinary precisions."
3. Explore scientifically the art component of cooking.
4. Scientifically explore the "social link" of cooking.

According to This, "culinary definitions" are the objectives of recipes—in other words, the parts of the recipe that tell the cook which ingredients to use and the basic outline of what to do with them. To study and codify these "definitions," This created the CDS/NPOS system of notation.

"Culinary precisions" are "useful technical information [that is] added to the definition but that is nonetheless not absolutely needed to make the dish; culinary precisions include old wives' tales, proverbs, tips, methods, etc."

He is careful to distinguish molecular gastronomy from what he calls "molecular cooking" (and what this book refers to as Modernist cuisine). He views these two pursuits as entirely separate disciplines, although he also says that "molecular gastronomy has led to molecular cooking."

lar gastronomy. Chefs such as Adrià, Blumenthal, Grant Achatz, Wylie Dufresne, and anyone else who practices what in this book we call Modernist cuisine are almost invariably labeled as practitioners of molecular gastronomy. They are often described as "disciples" or "followers" of Hervé This. Sometimes Adrià or Blumenthal is called the "dean" or "leading proponent" of molecular gastronomy.

It is an odd state of affairs. Hervé This argues that the work of those chefs is *not* molecular gastronomy. The chefs argue exactly the same thing. In fact, the food produced by Modernist chefs has very little, if anything, to do with the academic vision of molecular gastronomy espoused by This. Chefs also don't like the moniker because it seems too scientific. Many chefs also believe that it fails to capture the creative aspect of what they do. They view themselves as chefs, not scientists, and their interest in science is motivated primarily by their drive to invent new dishes, not the other way around. Finally, many chefs bristle at what they feel is Hervé This being unfairly credited with their innovations. They see his work as unrelated or even irrelevant to their cuisine.

Meanwhile, This often claims not to be very interested in Modernist food (or food of any kind, according to some quotes). Indeed, as of this writing, he has never dined at either elBulli or The Fat Duck, which would be strange if they really were his followers. The one thing both sides can agree on is that they are doing *different* things that should not be lumped together. Yes, they are both about food, and both involve some input from science, but that's about as far as any similarity goes.

Unfortunately, that's not the way the story has usually been told. Part of the reason for this miscommunication is that no one has been able to give a good name to the differing styles of modern cuisine represented by Adrià, Blumenthal, and others. Journalists generally don't take the time to appreciate the differences between these chefs' culinary styles. Once what they do starts to sound like science and cooking brought together, writers often jump for the only name out there—molecular gastronomy. And the more the term is used and disseminated, the more difficult it is to replace.

The difference between This's definition of molecular gastronomy and the media's is all the more pointed thanks to an underlying fact: This's research primarily addresses long-standing practices and old wives' tales in traditional cooking—quite the opposite kind of cooking that interests Modernist chefs. He has accumulated some 25,000 examples of these customs and traditions, which he calls "culinary precisions." He has investigated numerous claims from cookbooks, confirming some and refuting others. He often works by doing his own research; to test a claim from a medieval

In 1999, Heston Blumenthal heard of the Erice meetings and tried to contact Kurti, who unfortunately had died a few months before. Kurti's widow, Giana, sent Blumenthal an Erice poster, on which he found the name of Peter Barham, a physics professor. He contacted Barham and began a collaboration that proved fruitful for both of them.

We explore several techniques pioneered by This in this book, including chocolate or Camembert cheese blended into a whipped cream-style foam (see page 4·281), salt in oil (see page 330), and the now ubiquitous 65 °C egg (see page 4·78).

cookbook, This roasted whole suckling pigs and confirmed that cutting the head off after cooking keeps the skin crisp, because it allows steam trapped under the skin to escape.

In addition to examining "precisions," This created a formal notation for cooking called the CDS/NPOS system. (CDS stands for "complex dispersive system" and NPOS for "nonperiodical organization of space.") Similar in spirit to formal mathematical notation or chemical formulas, This's system serves as an abstract description of the processes and techniques used in cooking. He believes this notation will be useful to chefs in creating new dishes, although few chefs seem to agree. The notation is so abstract that it has not been widely adopted by either chefs or mainstream food scientists.

In some cases, however, This has invented or researched techniques that could be used as a point of departure for new dishes. This and Pierre Gagnaire have collaborated to come up with many new recipes, which are featured on Gagnaire's website (pierre-gagnaire.com), some of which are featured in this book.

In a 2010 paper in the journal *Chemical Reviews*, the physicist Peter Barham and his coauthors present an excellent summary of the key scientific findings of molecular gastronomy to date. They argue that it is an emerging scientific discipline. Whether that assertion is true is an intriguing question, but the answer is still unclear, at least to us. Conventional food scientists, not "molecular gastronomists," are responsible for many of the scientific findings reviewed in the paper.

Food science has origins that stretch back at least a century (see Food Science, below), and the discipline has been a major focus for thousands of researchers in recent decades. What distinguishes "molecular gastronomy" from other forms of food science? Is there something really new here, or is this just a case of applying a trendy new name?

The principal answer seems to be that what Barham and his colleagues call molecular gastronomy is focused on home and restaurant cooking. Previously, food science tended to be applied almost exclusively to large-scale commercial and industrial food processing. Indeed, the birth of food science as a discipline was driven largely by the emergence of the packaged- and canned-food industries in the early 20th century.

During most of its existence, food science was all but invisible to restaurant chefs and the general

THE HISTORY OF

Food Science

Agriculture and food preservation have been around for millennia (see page 6), but these disciplines were not widely studied as sciences until the 19th century, when canning and pasteurization were developed (see Louis Pasteur, page 148). Today, food science is made of several different disciplines, including food chemistry, food engineering, and microbiology. The closely related field of agricultural science often overlaps with food science.

Many food scientists work in the food-manufacturing industry, at universities, or in government to create new food products and to improve methods of processing, packaging, distributing, and storing foods. For some scientists, this means determining ways to get optimal results from traditional cooking and food-processing techniques such as baking, drying, and pasteurization. Others research and develop new methods of food production and processing.

Agricultural scientists study crops and livestock, and develop ways of improving quality and yield. They also may research methods of converting agricultural commodities into consumer food products.

There were roughly 17,000 people working in food and agricultural science in the United States in 2008. About 20% of these scientists worked for manufacturing companies, 15% in educational institutions, and 7% for the federal government (primarily the U.S. Department of Agriculture).

Research on food and agricultural science is published in dozens of academic journals around the world. These journals run the gamut of food science disciplines, from *Cereal Science* to *Meat Science* to *Dairy Science,* and from *Molecular Nutrition & Food Research* to *Food Hydrocolloids.*

public. That's because food science was mostly funded by industry or by government agriculture departments that wanted to boost the agricultural economy on a large scale. Most of the findings ascribed to molecular gastronomy were discovered in the course of those activities.

There are also many issues that food science has simply not investigated, because they are not important to large-scale food manufacturers. Nicholas Kurti is famous for saying, "It is a sad reflection on our civilization that, while we can and do measure the temperature in the atmosphere of Venus, we do not know what goes on inside our soufflés." Nobody in industry cared much about soufflés; you couldn't make them in bulk to put on supermarket shelves. And if nobody in industry cared, food scientists tended not to investigate. It's not like the U.S. Department of Agriculture or the National Science Foundation, both major funders of academic research, care much about soufflés either.

Starting in the mid-1980s, the situation changed dramatically, as McGee, This, Barham, and others shined the light of science on problems of home and restaurant cooking. The main distinguishing feature of molecular gastronomy is that it does care about all types of food, including home and restaurant food (and, yes, soufflés). In asking scientific questions about these foods, Barham, This, and their colleagues are performing a great service.

Heston Blumenthal and The Fat Duck

In 1982, a British family on holiday turned up at L'Oustau de Baumanière, a famous Michelin three-star restaurant in Provence. Like many tourists, the family had read about the restaurant and decided to seek it out. None of the party had ever been to a fine-dining restaurant, but since they were in France, it seemed like a good thing to try. It was by all accounts an excellent meal, which is to be expected of such a restaurant.

What was less expected was the effect it had on one of the diners—a 16-year-old boy—who decided that night to become a chef. The boy was Heston Blumenthal, and 22 years later his restaurant, The Fat Duck, would also have three Michelin stars and would be proclaimed by many food critics as the best restaurant on Earth.

Heston Blumenthal stands at the front door to his restaurant, The Fat Duck.

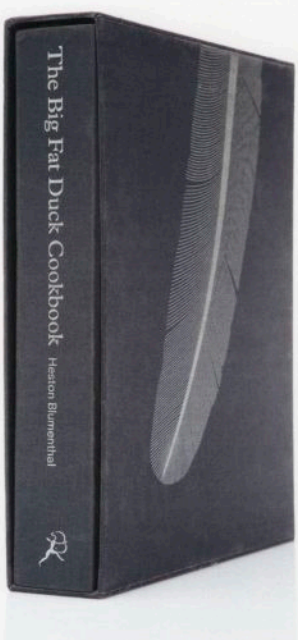
Aside from a weeklong *stage* in the kitchen of Raymond Blanc's Manoir Aux Quat' Saisons, Blumenthal had no formal culinary training. He was born in 1966 in Berkshire, England (where he still lives with his wife and children). After his eye-opening dinner at Baumanière, he spent a decade poring over Escoffier, *Larousse Gastronomique*, and the other classic texts on French cuisine, teaching himself to cook. When he could afford it, he traveled to France on culinary research missions. In 1986, he read Harold McGee's *On Food and Cooking*, an experience that he says "literally changed my life."

Blumenthal realized he could not accept what was written in the classic texts at face value. McGee's book showed that they might have gotten it wrong. Instead, Blumenthal came to question and challenge everything about cooking until it had been proved or demonstrated. That, of course, is the essence of the scientific method. Although Blumenthal is quick to argue that he is no scientist, his skeptical and fact-driven approach to cuisine is at its essence a form of scientific inquiry. This attitude of exploration is perhaps the greatest thing he learned from McGee.

In 1995, Blumenthal opened The Fat Duck, serving a menu of classic brasserie dishes. Although this menu featured radically different food than he would begin serving several years later, he was already using culinary science to perfect his dishes. His goal was to create perfect versions of the classics—such as the perfect fried potato—by using

Heston Blumenthal isn't the only chef who found his calling via a memorable teenage meal. For his sixteenth birthday, Jean-George Vongerichten's parents took him to the legendary Auberge de L'Ill, a Michelin-three-star restaurant in the town of Illhaeusern, located in Alsace. The boy was so taken with the experience that he, too, decided on the spot to become a chef. His first culinary job was as an apprentice at the same restaurant, under renowned chef Paul Haeberlin.

Hot and cold tea exploits the rheology of fluid gels, which have the properties of both liquids and solids, to keep its hot and cold sides separate. For a recipe, see page 4·182. For more on fluid gels, see page 4·176.



Heston Blumenthal's The Big Fat Duck Cookbook became a best-seller in the U.K.

science as a tool. He ultimately arrived at a recipe for triple-cooked chips (see page 3·322) that is a perfect rendition of crispy French fries. In addition, to learn more about the links between taste, smell, memory, and emotions, Blumenthal contacted McGee, Barham, and other scientists who were studying psychology and flavor chemistry.

Blumenthal attained his first Michelin star just three years after opening the restaurant. In 2001, when he was awarded his second Michelin star, his career as a celebrity chef was born. He became a columnist for the *Guardian* newspaper, made a six-part television series for the Discovery Channel, and published his first book, *Family Food*. He also received numerous accolades from publications both within the United Kingdom and outside it.

Meanwhile, Blumenthal's interest in culinary science was leading him to dream up radically new dishes, such as crab risotto with crab ice cream, white chocolate filled with caviar, and parsnip cereal with parsnip milk. As *Guardian* food columnist Matthew Fort wrote in 2001,"It isn't too much to claim that the approach that [Blumenthal] is taking represents the biggest shake-up to ideas about how we cook of the past 50 years."

The Fat Duck was awarded its third star in 2004, becoming only the fourth British restaurant to ever hold that distinction. The journey beginning with the meal at L'Oustau de Baumanière was now complete: Blumenthal had not only become a chef; he had reached the highest level of the profession.

That journey was anything but easy. When Blumenthal opened The Fat Duck, he had never worked in a restaurant before, apart from a one-week *stage* in Blanc's kitchen. It was a rude awakening, a sort of baptism by fire. Blumenthal rose to the occasion and overcame his own inexperience. With incredible drive, he persevered and created an establishment with top-caliber food and service.

As his cuisine matured and recognition grew, financial success did not always follow. During the week in 2004 when Michelin called to announce that the restaurant had earned its third star, there was so little business that Blumenthal worried he would not have sufficient funds to make payroll. In fact, on the very day the call came from Michelin, there were no reservations; not a single customer showed up that night. Of course, the next morning the news of the third star was out, and the phone rang off the hook.

To Perfection and Beyond

Perfection was Blumenthal's original goal when he opened his restaurant, and he still returns to that goal often today. He created several TV series with the BBC called *In Search of Perfection*, in which he sought to perfectly execute many culinary classics, from high-end dishes such as Peking Duck to more humble ones such as bangers and mash or fish and chips.

If Blumenthal had stopped at the perfect execution of old classics using modern techniques, he would have been a great chef, but one with limited impact. Instead, perfection was just the beginning. Soon he discovered that the scientific approach to food offered him the possibility to do things that are new and unique, and he began to branch out. In one early dish, his *pommes purées* (mashed potatoes) contained cubes of a heat-stable lime gel. Each bite included the foundation of creamy mashed potatoes punctuated by the clean, bright flavor of lime. It was still classic *pommes purées*, but it wasn't like any version that had come before.

Sensory science and its application to cuisine are of particular interest to Blumenthal, and he has collaborated with scientists studying human perception. Many of his more innovative dishes combine multiple sensory experiences. An oyster and abalone dish called Sound of the Sea, for example, engages not only taste but also sound: before serving the dish, the waiter brings each diner a conch shell with a set of headphones protruding from it. The shell, which contains a tiny MP3 player, seems to produce ocean noises. Blumenthal had a scientific reason for believing that the sound would add to the dining experience. He had conducted research with Oxford University and determined that listening to sea sounds while eating an oyster makes the oyster taste stronger and saltier than usual.

In a training manual written for the Fat Duck staff in 2003, Blumenthal described his approach at the time in an open letter to his guests:

> In all cooking there is science—some say much art—and sage traditions that must be understood in relation to the diner. Our challenge is to discover these relationships, demystify the culinary traditions and, with

that knowledge, create an experience that reaches beyond the palate.

This is the culinary cornerstone of The Fat Duck. Though it sounds Shelleyesque, in its truest sense the approach is fundamental. Every aspect of dining must be in harmony. This goes well beyond music choice or decor. For a dining experience to be full, it must ignite all senses and awaken the soul.

At The Fat Duck we enjoy challenging traditional techniques and theories, even those in place for centuries. We don't challenge these techniques because they are wrong. We look at the cause and effect of centuries of tradition; pair that with evolving knowledge and the overall effect of those things that make up you, our guest.

In an interesting reversal of Nouvelle cuisine and its emphasis on plated dishes, Blumenthal designs many of his recipes to be plated tableside by servers, adding to the drama of the dining experience. In a dish called Nitro Green Tea Sour (see photo on page 74), a whipping siphon is brought to the table and used to squirt a foam into liquid nitrogen. When diners take the first bite, cold air and condensed water vapor from the foam-nitrogen reaction rushes into their nasal passages. The result: it looks like smoke is coming out of your nose.

In another dish, Nitro Scrambled Egg and Bacon Ice Cream (see photo on page 54), the server goes through an elaborate charade in which he appears to be making scrambled eggs in a tableside chafing dish. He adds what appears to be oil to the pan (it's actually liquid nitrogen) and cracks eggs into it (the eggshells are filled with a custard base). When he "scrambles" the eggs, the custard freezes and becomes a rich, eggy ice cream. In one sense, this is the kind of tableside service Escoffier might have approved of, yet its shock value and unconventional use of liquid nitrogen make it clearly Modernist.

These dishes are obviously related to deconstruction, but with a twist all their own. In deconstruction, the flavor profile is that of a classic dish—but in a form that keeps you from recognizing what it is until you eat it. Here the opposite happens: something appears to be a classic dish, but it is actually very different in substance.

Another theme that runs through much of Blumenthal's cuisine is the role of memory and nostalgia. He tries to re-create tastes and aromas that will trigger childhood memories and evoke emotions. Unlike deconstructionist chefs, Blumenthal does not aim to provoke a double take as the diner recognizes the classic dish being referenced. Instead, he wants to evoke just enough of the memory to transport diners back in time, while at the same time engaging them in the present.

Blumenthal often plates dishes in ways that help to create this mood, as in his Flaming Sorbet (see photo at right), which is designed to look like a campfire. The dish is just what it sounds like—a sorbet made with gellan, a gelling compound that, unlike conventional gelatin, retains its solid form up to 90 °C / 194 °F. Whiskey is poured on and lit to create flames, which do not melt the sorbet. The bowl containing the sorbet is nestled in a bed of twigs that conceals a layer of dry ice beneath it. As the waiter ignites the sorbet, he simultaneously pours a perfume mixture (containing notes of leather, wood, tobacco, and whiskey) onto the twigs, where it reacts with the dry ice. Vapor cascades around the dish and releases the pleasant and perhaps nostalgic aromas of a campfire.

Blumenthal also aims to transport diners back in time by re-creating dishes from the distant past. In a dish called Beef Royal (1723), he reimagines a recipe published in 1723 that was served at the coronation of King James II. He has also explored antiquity in a TV series for the BBC's Channel 4, constructing new versions of Roman and Victorian feasts.

Blumenthal's influence on cuisine goes far beyond his work at The Fat Duck. He is extremely personable, and through his television shows, he has taken his enthusiasm to a much larger audience than could ever get a table in his restaurant. As an ambassador for Modernist cuisine, he has opened the door for a whole generation of young chefs, who will find a more receptive audience because Blumenthal blazed the trail for them.

Flaming Sorbet uses gellan gel to make a sorbet that can withstand high heat. The theatrical presentation of sorbet at the center of a bonfire both surprises and entertains guests. For more on gellan gels, see page 4·124.
Photograph by Dominic Davies

In 1999, Peter Barham, a physicist, took Tony Blake, a flavor chemist, to dinner at The Fat Duck. The dinner led to Blumenthal's invitation to the 2001 Erice meeting. More important, it put Blumenthal in touch with Firmenich, a Swiss food flavor company at which Blake worked as a senior scientist. The Firmenich contact gave Blumenthal both access to their flavors and also financial support, in the form of a consulting agreement.

THE MODERNIST REVOLUTION

Bits of a squid ink fluid gel float among dill spheres and sprigs in an "everything bagel" broth (above and next page). For recipes, see page 4·130.

As we have seen, the mid-1980s were the beginning of the most radical revolution in cuisine that the world has ever seen. Ferran Adrià began to create a new, intellectually motivated cuisine at elBulli. Harold McGee, later joined by Hervé This and others, started a trend toward general appreciation of the scientific basis for cooking. Researchers looking to improve institutional and commercial food developed new technology that expanded the range of what is possible for chefs to achieve. And a teenage Heston Blumenthal studied both culinary classics and McGee's book *On Food and Cooking* in his quest to become a great chef.

These four stories each contributed to the creation of what we call the Modernist revolution. There are doubtless other tales that were also important and whose threads are woven into the fabric of Modernist cuisine as we know it today. We have simplified and focused on these threads to give a flavor of the early days of the new cuisine and the factors that shaped it.

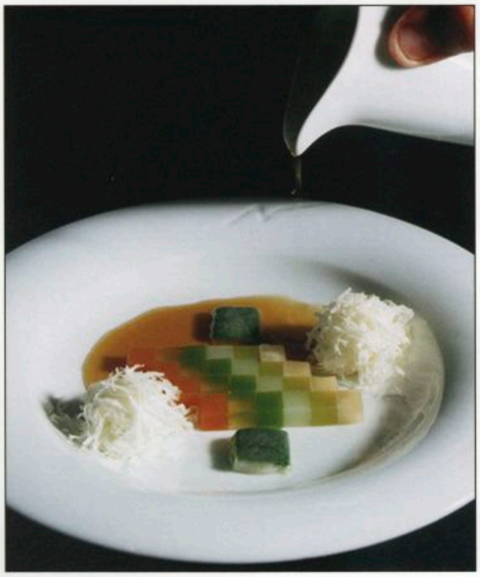
By the year 2000, the Modernist culinary movement was well underway, and a new generations of chefs started to join the revolution. Grant Achatz, a talented young sous chef working for Thomas Keller at The French Laundry (see page 68), yearned for something new. Keller arranged for Achatz to do a *stage* at elBulli. As luck would have it, his first night there coincided with the visit of Wylie Dufresne, another talented young sous chef who worked for another master of New International cuisine, Jean-Georges Vongerichten. Achatz and Dufresne were both enthralled with what they found that night at elBulli (see page 38), and the visit helped confirm that the new cuisine would be their future.

We call this shift the Modernist revolution for several very specific reasons. Art, architecture, and other aspects of aesthetic culture went through just such a revolution nearly 100 years ago. French Impressionism was among the first wave of artistic movements in what would become the Modernist avant-garde. These movements changed painting, sculpture, photography, architecture, typography, and just about every other cultural discipline.

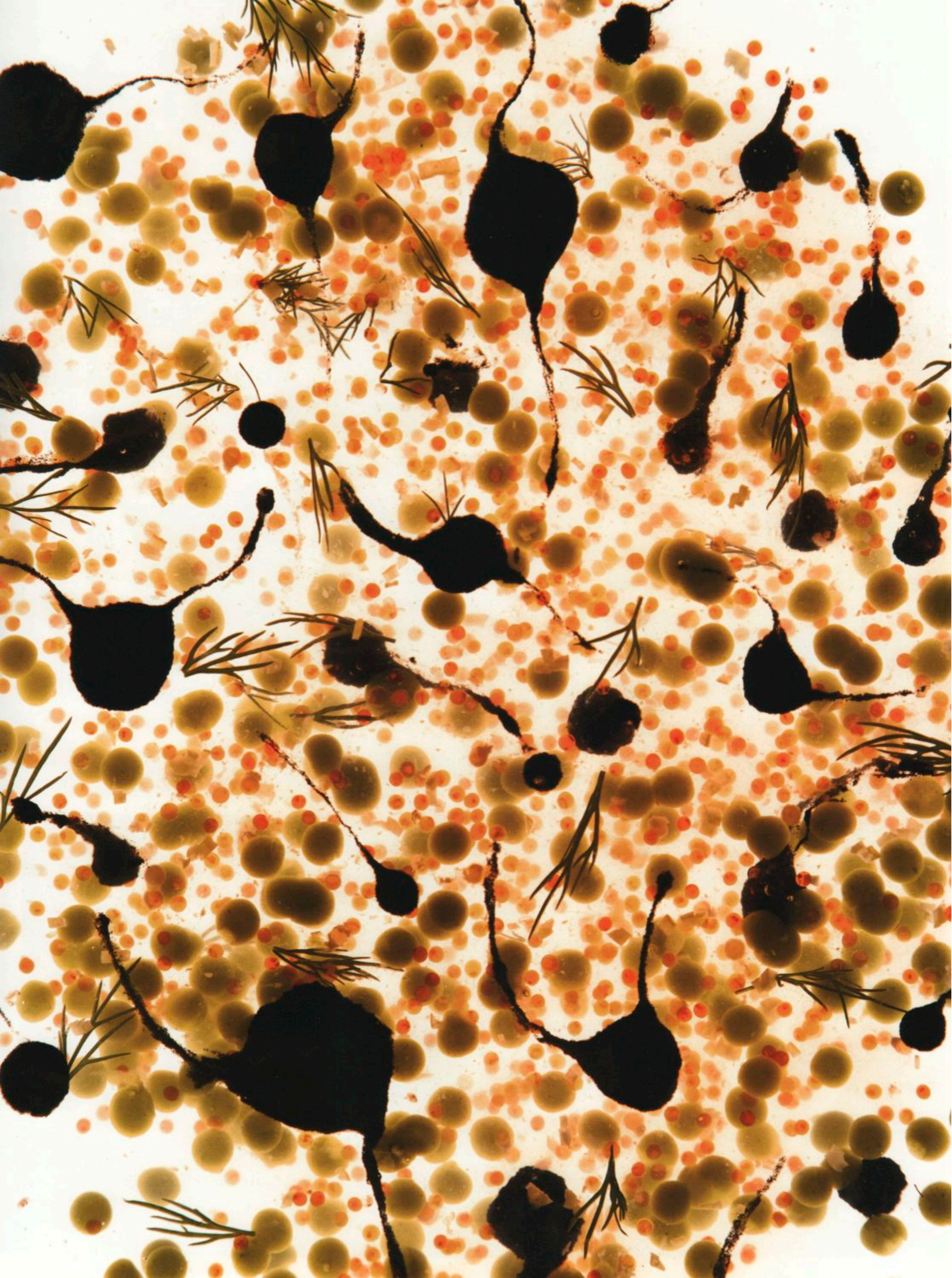
The Modernists of those movements received that name because they were clearly, avidly, and self-consciously seeking to replace old traditions with something new. The world was changing in profound ways. They felt the drumbeat of that change and sought to channel it into their creative endeavors. A break from the past was an explicit part of their goal. The concept of an avant-garde challenge to the old system was their method to achieve the goal.

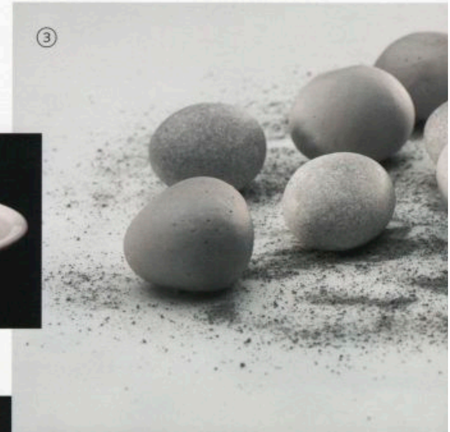
As we have discussed, the Modernist drumbeats that shook most other cultural institutions were not felt in the kitchen. The very people who sought to remake the style of the modern world somehow sat down to eat totally conventional food—and thought nothing of doing so. It wasn't until nearly a century after the Impressionists held their first salon that even a glimmer of revolution occurred within cuisine.

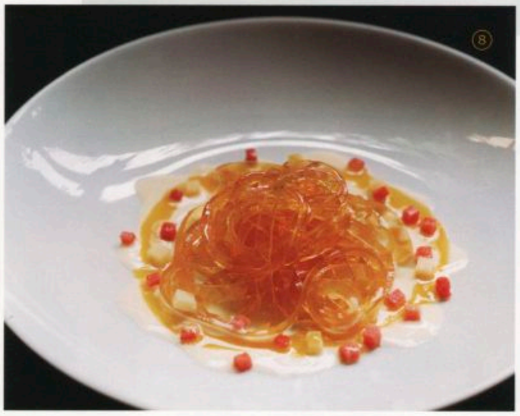
That was when Nouvelle cuisine emerged, but as we have seen, it was a limited, timid revolution compared to what would happen next. This is not to minimize it; Nouvelle was absolutely critical to the development of all future cuisine, both in France and in many other places. But the winds of change brought by Nouvelle soon dissipated, and most of the edifice of classical cuisine remained intact. Innovations in flavors and ingredients created delicious food, but the change was evolutionary rather than revolutionary. The aesthetics

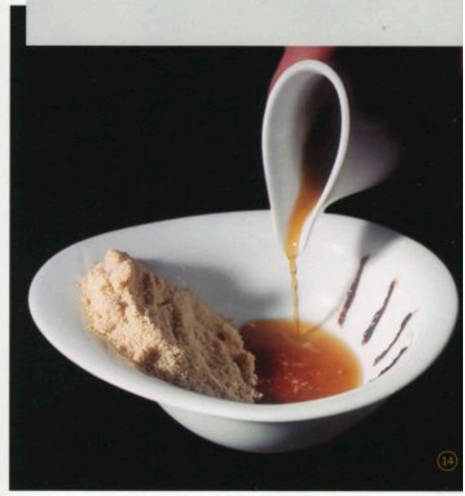


Inspired by a dish at Jacques Maximin's restaurant Chantecler, Ferran Adrià began in 1985 to serve soups in an unusual style. A shallow soup plate was set with food in a manner that suggested it was a complete dish. Then, just before the diner would tuck in, the waiter would pour in a soup or broth, drowning the food on the plate, ruining its careful composition and arrangement. What appeared to be a dish in its own right was turned into a garnish for the soup. The surprising twist was an early experiment in challenging the assumptions of the diner. Today you can find this style of soup service at almost any restaurant in the world. Photo courtesy of Franscesc Guillamet and elBulli





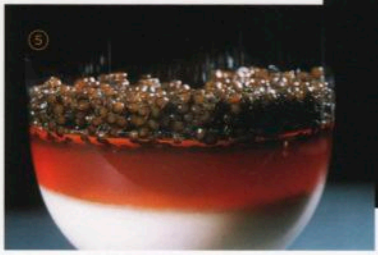




Modernist dishes take on many forms, reflecting the diversity of culinary visions at work among their creators. The appearance of the dish is often an integral part of the dialog between chef and customer. Surprise, drama, humor, and even misdirection are part of what makes Modernist cooking so unique—both to make and to eat.

Grant Achatz, Alinea: (9) Salsify, Smoked Steelhead Roe, Parsley Root, Radish (photo by Lara Kastner/Alinea)
Ferran Adrià, elBulli: (5) Hot Cauliflower and Lobster Jelly with Caviar; (6) Olive Oil Spring; (8) Consomme Tagliatelle Carbonara; (10) Fried Rabbit Ears; (12) Carrot Air with Mandarin and Bitter Coconut Milk; (13) Cepes in Amber; (14) Frozen Foie Gras Powder with Foie Gras Consomme; (15) Melon with Ham 2005; (16) Red Mullet Mummy with Sea Water Cotton Candy; (18) Cherries in Ham Fat Cream; (20) Pumpkin Seed Oil Candy (photos by Francesc Guillamet)
Andoni Luis Aduriz, Mugaritz: (1) Vegetable Coals with Scrambled Eggs and Crushed Potatos ; (2) Buttery Idiazabal Cheese Gnocchi with Ham Broth; (3) Potato Stones (photos by José Luis López de Zubiría—Mugaritz)
Heston Blumenthal, The Fat Duck: (4) Nitro Scrambled Egg and Bacon Ice Cream with Pain Perdu; (17) Snail Porridge (photos by Dominic Davies)

Wylie Dufresne, wd-50: (7) Eggs Benedict; (19) Foie Gras, Passionfruit, Chinese Celery; (21) Aerated Foie Gras, Pickled Beet, Mashed Plum, Brioche (photos by Takahiko Marumoto)
Quique Dacosta: (11) Stevia Sponge (photo by Carlos Rondón, www.carlosrondon.es)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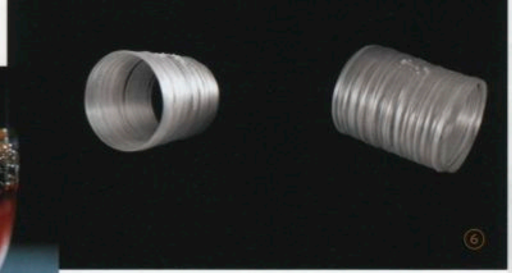
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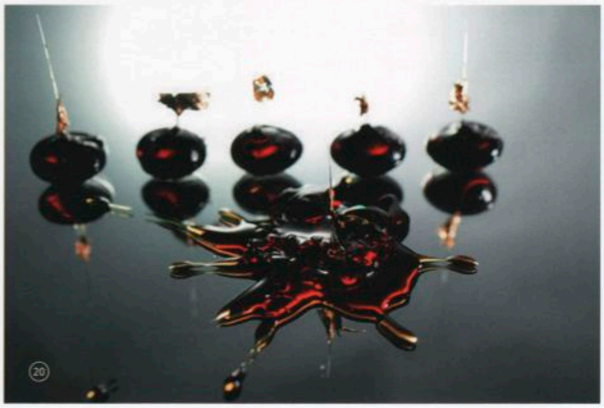
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of Nouvelle, and those of the New International movement that later supplanted it, basically stayed true to prior iterations of haute cuisine.

Perhaps the most significant failure of Nouvelle is that its chefs were still constrained by many rules, both written and unwritten. Those rules, assumptions, and constraints were precisely what Adrià and his Modernist brethren attacked. In effect, they asked the question: Why let anything get in the way of making the most creative food possible?

The true example of Modernism in cuisine is not Nouvelle; it is the revolution we are in now. We call it the Modernist revolution because its themes and driving forces are similar to Impressionism, the Bauhaus, and other Modernist avant-garde movements. The Modernist movement in cuisine is not afraid of breaking with tradition; on the contrary, that is one of its goals. The act of upending culinary conventions allows chefs to engage with diners in powerful ways. When tradition is found in the new cuisine, it is generally as a rhetorical foil, highlighting the contrast between the old and the new in deconstruction.

If you dug up and revived Auguste Escoffier and took him to dinner at a Nouvelle bastion like Maison Troisgros, circa 1980, or a New International venue like The French Laundry, circa 2010, he would notice much that was new and different, but the basic themes would be recognizable. The food would look like what he knew as food. The tasting menu would have a familiar structure. The meal would begin with appetizers, followed by fish, then perhaps an intermezzo or palate cleanser of some sort. This would be followed by meat, then cheese and dessert. Escoffier would note that the food was mostly plated, some of the flavors were unusual, and the sauces were not the thick, floury pastes he was used to, but the broad themes would be those of his haute cuisine.

Take the same reanimated Escoffier to dinner at

THE PRINCIPLES OF

Modernist Cuisine

Modernist cuisine is still young and evolving. Its direction has been determined by the vision of individual chefs, rather than by committee or consensus. Still, looking at the movement today, it is possible to discern some shared general principles. In much the same way that the *Gault Millau* guide outlined the "10 commandments" of Nouvelle cuisine (see page 27), here we offer 10 principles of the Modernist movement.

1. Cuisine is a creative art in which the chef and diner are in dialogue. Food is the primary medium for this dialogue, but all sensory aspects of the dining experience contribute to it.
2. Culinary rules, conventions, and traditions must be understood, but they should not be allowed to hinder the development of creative new dishes.
3. Creatively breaking culinary rules and traditions is a powerful way to engage diners and make them think about the dining experience.
4. Diners have expectations—some explicit, some implicit—of what sort of food is possible. Surprising them with food that defies their expectations is another way to engage them intellectually. This includes putting familiar flavors in unfamiliar forms or the converse.
5. In addition to surprise, many other emotions, reactions, feelings, and thoughts can be elicited by cuisine. These include humor, whimsy, satire, and nostalgia, among others. The repertoire of the Modernist chef isn't just flavor and texture; it is also the range of emotional and intellectual reactions that food can inspire in the diner.
6. Creativity, novelty, and invention are intrinsic to the chef's role. When one borrows techniques and ideas or gains inspiration from other chefs or other sources, that should be acknowledged.
7. Science and technology are sources that can be tapped to enable new culinary inventions, but they are a means to an end rather than the final goal.
8. First-rate ingredients are the foundation on which cuisine is built. Expensive ingredients such as caviar or truffles are part of the repertoire but have no greater intrinsic value than other high-quality ingredients.
9. Ingredients originating in food science and technology, such as hydrocolloids, enzymes, and emulsifiers, are powerful tools in helping to produce dishes that would otherwise be impossible.
10. Diners and chefs should be sensitive to the conditions under which food is harvested and grown. Whenever possible, they should support humane methods of slaughter and sustainable harvesting of wild foods such as fish.

THE HISTORY OF

Modernist Cuisine in Spain

In recent years, Spain has become a mecca for Modernist cuisine. By most accounts, the country has surpassed France in terms of culinary creativity. As chef David Bouley put it in 2003, "Something happened in France—they ran out of gas. The real explosion is with all the young guys in Spain." For anyone interested in innovative cooking, Spanish chefs are the ones to watch.

The most famous of these chefs is, of course, Ferran Adrià, the legendarily creative mind behind elBulli (see page 33). Adrià and his contemporaries, including Joan Roca (see next page) and Martín Berasategui, have been disseminating avant-garde techniques and training young chefs since the 1990s. Now, many of those chefs ("the young guys in Spain") are advancing this movement, taking the path charted by Adrià but also veering off in their own directions. The most prominent of these new stars are Dani García, Quique Dacosta, Sergi Arola, and Andoni Luis Aduriz.

García is the chef of Restaurante Calima in Marbella, Andalusia. He has become famous for his avant-garde take on classical Andalusian cuisine, including dishes like gazpachos and *frituras*. Like Roca, García sees memory as one of the most important aspects of his culinary philosophy. He received a Michelin star in 2007.

Dacosta, like Adrià, is a self-taught chef. At his restaurant in Denia on the coast near Valencia, Dacosta has made his name with his Modernist treatments of local produce and seafood, such as his now-famous Oysters Guggenheim Bilbao (designed to look like the museum, with a covering of edible titanium and silver that resembles the building's exterior). He has also published a number of books, including *Arroces Contemporáneos* (*Contemporary Rices*), published in 2005 by Montagud Editores, in which he demonstrated his approach to the regional staple. Dacosta received his first Michelin star in 2002, followed by another in 2006.

Arola, who initially wanted to be a musician, spent eight years in the kitchen of elBulli. There, he cooked alongside Adrià before leaving in 1997 and moving to Madrid; three years later, he opened his own restaurant, La Broche. Arola's high-concept menu earned the restaurant two Michelin stars. He now runs kitchens at four restaurants, including Sergi Arola Gastro (which he also owns) and Arola Barcelona.

Aduriz, another young protégé of Adrià, worked at elBulli for two years, then at Berasategui's eponymous three-star restaurant. Since Aduriz opened his own restaurant, Mugaritz, in 2000, he has become a world-renowned chef in his own right. His approach to food is naturalistic, even ascetic, yet still playful and modern. He grows produce and herbs in a garden behind the restaurant and forages other ingredients from nearby woods with the aim of creating food that puts diners into closer contact with the natural world. His potato "rocks," made by coating potatoes in white clay, are a prime example (for a related recipe, see page 3·398). Mugaritz was awarded its second Michelin star in 2005.

elBulli, and he might wonder what planet he was on. The meal would challenge all of his preconceptions about fine dining.

Some commentators, notably chef Homaro Cantu (see page 69), have suggested that this cuisine be called "Postmodern." The name might seem appropriate, given that in the past two decades, both art and architecture have experienced a reaction to the century-long domination of Modernist movements.

But the term "Postmodern cuisine" only makes sense if there is a clear body of Modernist cuisine to react to; and unlike art and architecture, there simply has been no previous Modernist phase. As a result, "Postmodern" as a culinary movement makes little sense—it is based more on simply copying the term Postmodern from other fields than accepting what Postmodern means. Someday, a Postmodernist cuisine will be developed as a reaction to the current Modernist revolution, but we have a long way to go before that happens.

Other terms have been proposed. Adrià calls the cuisine "technoemotional." This may be a good name for his culinary style and the cuisines of some of his closest colleagues, but we feel that another name needs to be coined for the movement as a whole, which incorporates broader themes and trends. Jeffrey Steingarten uses the term "hypermodern," which has a nice ring to it, but the problem is that it again raises the question of what was modern in the first place. McGee calls the cuisine "experimental cooking," and a good case can be made for that choice. But using the word "experimental" tends to devalue the explicit use of aesthetic theory in the cuisine that Adrià and others have developed.

The Cult of Novelty

One of the most interesting aspects of Modernist cuisine is the way in which it expands the realm of the possible. Novelty—the creation of new dishes and techniques—is its heart and soul. Modernist chefs pride themselves on breaking new ground and being fiercely original; indeed, they become famous for these achievements. Many of these chefs will not serve any dish they did not invent or develop (at least in part). They also bristle if other people reproduce their dishes without acknowledgment or credit.

This is a strange state of affairs compared to other cuisines. No one who runs a steak house claims that they have invented steak, or refuses to serve a baked potato with it because the steakhouse chef didn't invent the baked potato. In traditional cuisine, there is often an implicit philosophy that separates the design of the food (the recipes) from its execution (the actual dishes). A steak house is perhaps the most extreme example: the product, a steak, isn't unique to the chef or the restaurant, and therefore great steak houses fetishize every aspect of the execution (selecting the meat, dry-aging it, and so forth). Steak houses may also have some recipe variations—perhaps for their sauces or side dishes—but there is no expectation that these recipes evolve over time.

Much the same occurs in other forms of traditional cuisine. As we discussed above (see page 14), many Italian restaurants are proud of serving dishes that are based on "authentic" recipes from a particular region in Italy. Some of the most traditional-minded chefs proudly claim that their best recipes did not come from their own creativity but were passed down from their grandmother or somebody else's grandmother. In this view, the chef's role in the design of a dish is reduced to that of a curator: he chooses which of Grandma's recipes will most please his clientele and makes the best use of seasonal ingredients.

Granted, most high-end traditional restaurants, such as those in the Nouvelle or New International style, focus on both design and execution. Customers expect that the chef will have her own inventions on the menu, and her reputation rides on both execution and the uniqueness of the dishes. But even in this case, there is little mandate that her repertoire turn over quickly. As a result, a chef's signature dish—like Joël Robuchon's mashed potatoes—can stay on the menu forever.

The intense focus on novelty in Modernist

BIOGRAPHY OF

Joan Roca

One of the leading figures in modern Spanish cuisine, chef Joan Roca is known for his innovative take on traditional Catalan fare. Roca was steeped in that style of cooking from an early age, spending many hours in the kitchen with his mother and grandmother at his family's Restaurant de Can Roca in Girona, Catalonia. In 1986, Roca and his two brothers, Josep and Jordi, opened their own restaurant next door to their parents' place, with Joan running the kitchen, Josep as sommelier, and Jordi as pastry chef.

At El Celler de Can Roca, today a three-Michelin-star establishment, Joan Roca soon began applying new techniques and technologies to classic Catalan cuisine. His philosophy is to use technology in the service of creativity to convey emotions. Over the years, he has worked with sous vide, vapor cooking, smoking, distilling, and various other techniques. One of his most famous achievements was figuring out a method for distilling soil from a nearby forest to create a "dirt essence." He made a clear jelly from the liquid and put it on top of an oyster–a unique rendition of surf and turf.

Roca's 2005 book, *Sous Vide Cuisine,* cowritten with Salvador Brugués and published by Montagud Editores, was the first major cooking text to describe how to use this technique. The authors outlined a new system that would allow chefs to cook sous vide dishes to order during a restaurant's regular service. Despite being hard to find in the U.S., the book became a valuable resource for food professionals.

BIOGRAPHY OF

José Carlos Capel and Rafael García Santos

Two of the most influential food critics in Spain are José Carlos Capel, who writes for the daily *El País*, and Rafael García Santos, food critic for the Basque newspaper *El Correo* and founder of the annual *La Guía Lo Mejor de la Gastronomía* (Spain's answer to the *Michelin Guide*). Each of these men has played a key role in the spread of Modernist cuisine.

Capel has championed young avant-garde chefs in his articles and has written or cowritten several cookbooks that feature recipes from forward-thinking Spanish chefs, including Ferran Adrià (see page 33), Joan Roca (see previous page), Sergi Arola, Dani García, and others (see page 57).

In addition, Capel is the founder and president of Madrid Fusión, an annual international conference for chefs and food journalists that spotlights the work of culinary innovators and stars of the Modernist movement.

Santos is the founder and director of Spain's other prestigious international gastronomic conference, Lo mejor de la gastronomía, which also highlights Modernist cuisine and has included workshops with Adrià, René Redzepi (see page 70), Quique Dacosta (see page 57), and many more. Santos has also written extensively about Spanish Modernist chefs in his annual guidebook (whose inaugural 1995 edition gave top honors to elBulli) and in *El Correo*.

cuisine is a complete break from that philosophy. Designing new dishes is essential to a Modernist chef's livelihood. Execution is also important, because without good execution, customers can't properly experience the dishes as they were intended. But a Modernist restaurant that kept the same dishes on the menu for years would be strange indeed.

In 2002, Adrià published the first in a series of books that gave a comprehensive view of his cuisine. The books were meant to trace the evolution of elBulli's food over time, with explicit dates for every dish and every new development. These books helped cement a feeling that forward momentum is a cornerstone of Modernist cuisine.

The first three elBulli books covered the years 1983 to 2002; these were followed by volumes covering 2003, 2004, and 2005. The publication of the follow-up books set another interesting precedent: a chef publishing the secrets of his cuisine rapidly, only a year or two after the dishes were first served in a restaurant. This act underscored the urgency of moving forward and set a standard that other chefs could not ignore.

Adrià's approach was not universally popular. Some chefs complained in private that the pace of his publishing made it difficult for them to keep up. They were not keen to get on a treadmill of continually changing dishes and of disclosing their recipes so quickly.

Another target of chefs' ire was the growing number of restaurants that copied Adrià's food. As one chef complained about a rival, "Why can't he create his own dishes? He just copies Ferran, but the bulk of his clients think he is being creative on his own." Part of the reason that Adrià published his recipes was so that people could use and learn from them, but this inadvertently raised the bar for those who wanted to cook creatively. Ultimately, Adrià's books have engendered a dynamic that is very healthy for the field: a culture of rapid invention and openness.

The Internet has also stoked the fires of Modernist innovation. When a new dish goes on the menu anywhere in the world, the chances are very high that it will be the subject of postings on eGullet.org, Chowhound.com, or Twitter, complete with digital photos and detailed explanations. Indeed, people can (and do) post to these sites from their smart phones before they even get their dinner check. Once posted, the information then reverberates around the Internet on dozens, hundreds, or perhaps even thousands of food-related blogs.

Meanwhile, information about new techniques or recipe ideas is discussed on the same broad-based culinary websites or on more specialized Modernist blogs like IdeasInFood.com, khymos.org, CookingIssues.com, and a growing list of others. With this instant connectivity, there

is little point in trying to hide; it's much better to participate and be part of the community of people sharing ideas.

Culinary Modernism's focus on originality and constant evolution raises some interesting questions. What dishes were created when? How did the cuisine evolve? Who came up with the key ideas first? These questions consume a lot of discussion among Modernist chefs, in part because the answers are more elusive than they might seem.

The Culinary Life of a Cryogen

Consider the fascinating history of liquid nitrogen in cuisine. It might seem like a very straightforward thing to find out who first used this **cryogen** in the kitchen. In the late 19th century, several scientists, including Michael Faraday, were working on liquefying gases by cooling them to extreme temperatures. The first measurable quantities of liquid oxygen and nitrogen were made in 1883 at Jagiellonian University in Krakow, Poland.

Liquid gases might have stayed a scientific curiosity, but Agnes Marshall, the proprietor of a cooking school and a famous Victorian-era cookbook author, attended a demonstration of "liquid air" by James Dewar (inventor of the Dewar flask, the design still used to contain liquid nitrogen), held at the Royal Institution in London. Marshall wrote the following in 1901:

> Liquid air will do wonderful things, but as a table adjunct its powers are astonishing, and persons scientifically inclined may perhaps like to amuse and instruct their friends as well as feed them when they invite them to the house. By the aid of liquid oxygen, for example, each guest at a dinner party may make his or her ice cream at the table by simply stirring with a spoon the ingredients of ice cream to which a few drops of liquid air has been added by the servant; one drop in a glass will more successfully freeze champagne than two or three lumps of ice, and in very hot weather butter may be kept in better condition on the table and make milk free from any suspicion of sourness by adding a drop of liquid air to an outer receptacle into which a jug or butter dish is placed. Liquid air will, in short, do all that ice does in a hundredth part of the time. At picnics it would be invaluable and surely ought to be kept freely on hand in hospitals.

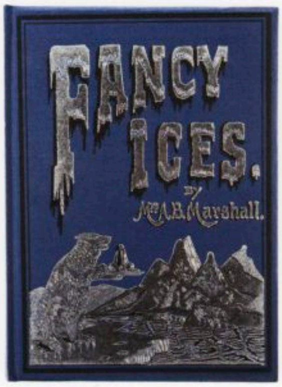
The amazing thing about this quote is that Mrs. Marshall (as she was known to her readers) clearly understood some key Modernist culinary principles more than 100 years ago. Unfortunately, the balance of evidence suggests that she never tried this ice cream trick. If she had, she might have discovered that using liquid oxygen is quite dangerous compared to using liquid nitrogen.

In 1957, William Morrison, an employee of the Union Stock Yard and Transit Company in Chicago, filed a U.S. patent for making ice cream by putting liquid nitrogen directly into the ice cream base and stirring. Morrison's method clearly implements at least part of Marshall's vision, but it is unclear when his patent was first put into use commercially—or whether it ever was. Like Marshall's idea, Morrison's invention seems to have been a dead end.

Our research indicates that the next milestone in the history of liquid nitrogen was in 1974, when Walter Chamberlin, an engineer working for Martin Marietta Corporation on a joint project with the Bendix Corporation in Ann Arbor, Michigan, took some liquid nitrogen home from work in a thermos bottle. He decided to try to make liquid nitrogen ice cream (see page 4·236); he says that the idea came to him as he was working with cryogenic material for his job. After a few failed attempts with a blender that left ice-cream mixture splattered on his ceiling, Chamberlin developed a method of using a kitchen stand mixer to make liquid nitrogen ice cream.

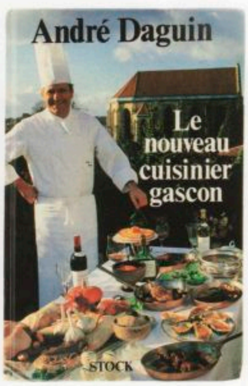
This technique was so successful that he started throwing liquid nitrogen ice cream parties. He held 6–10 of these parties every year for the next 36 years, many of them at or near the Los Alamos National Laboratory where he worked. Many engineers and scientists were exposed to liquid nitrogen ice cream over the years, and they then took the idea to the institutions where they worked.

As Chamberlin was hosting his first parties, thousands of miles away, the French chef André



Agnes Marshall ran a cooking school, authored several cookbooks, and sold her own line of cookware and ingredients, which made her a celebrity chef in late 19th-century England.

Technical terms set in boldface, like "cryogen" at right, are defined briefly in the Glossary of Technical Terms, near the end of volume 5.



André Daguin was the first chef to use liquid nitrogen tableside in 1974 and the first to describe it in a cookbook in 1981.

Dippin' Dots, invented by biologist Curt Jones, are made from ice cream base that is cryopoached, freezing it into spheres.

Daguin was starting to experiment with liquid nitrogen. Daguin was the founding chef at the restaurant Jardin des Saveurs at the Hôtel de France in the small country town of Auch in southwestern France. At the time, Daguin's restaurant held two Michelin stars and was a leading example of the regional cuisine of Gascony. Around 1976, the chef visited a facility in nearby Aubiet that did artificial insemination of cattle. Part of the tour included a demonstration of liquid nitrogen, which was used to keep bull semen in cold storage. This visit inspired Daguin to try using liquid nitrogen in the kitchen.

He made a number of novel ice creams and sorbets and served them at his restaurant, where he mixed liquid nitrogen into the ice cream base tableside with great drama, just as Marshall had suggested. Daguin also prepared liquid nitrogen-cooled dishes at dinners around the world, including a banquet for the prestigious international gastronomic society Chaîne des Rôtisseurs at The Pierre hotel in New York City. Daguin was the first chef to write about the cryogen: he included a recipe for liquid nitrogen ice cream in his 1981 book *Le Nouveau Cuisinier Gascon*.

Daguin's work with liquid nitrogen attracted considerable notice at the time. It is mentioned in many reviews of his restaurant, including one by influential food critic Gael Greene that appeared in *New York* magazine in 1980. Greene wrote, "Now Daguin appears, armed with a jet-spewing liquid nitrogen to turn white Armagnac into a granité before our eyes ... a snowy palate refresher."

The stunning thing about this part of the story is that Daguin was a famous French chef, yet his role in the history of cooking with liquid nitrogen has been underappreciated to the point that it is virtually unknown. Even more surprisingly, he does not seem to have influenced any other French chefs of the era to use liquid nitrogen.

In 1979, I (Myhrvold) entered graduate school in physics at Princeton University. I recall discussions about using liquid nitrogen to make ice cream or frozen whipped cream as a classroom demonstration or a trick at parties. I never attended such a demonstration or party, but the story was passed along by word of mouth. We have not been able to find any journal articles or other written evidence referencing liquid nitrogen ice cream in that period. It is possible that this oral tradition started with Chamberlin's parties.

Liquid nitrogen chills ingredients quickly, even at a rolling boil.

At the University of Bristol, Peter Barham had been looking for a new way to explain the concept of entropy to his physics students, when in 1982 he hit upon the idea of making liquid nitrogen ice cream for them. He thought at the time that he was the first to do this, but later colleagues at government research laboratories in the U.K. told him that it had been done as a stunt since the 1950s. Barham tried (and failed) to find any written documentation of this; it seems to be part of the oral tradition, just as it had been at Princeton.

In 1987, Curt Jones, a biologist who was familiar with liquid nitrogen in scientific applications, discovered a method for creating miniature frozen spheres of ice cream. A year later, he launched the company Dippin' Dots and began producing and selling this ice cream. Dippin' Dots are simply ice cream base dropped into liquid nitrogen, which freezes the base into solid spheres—a process we call cryopoaching (see page 2·460). This is very different than the other approaches, which create churned and aerated ice cream.

Note that Dippin' Dots—which is now a successful ice cream franchise in the U.S.—uses liquid nitrogen as a preparation technique, but this is done in a factory. The performance aspect of the customer witnessing the creation is not part of the process.

In 1994, Barham demonstrated the technique to Nicholas Kurti and Hervé This. Barham reports

Greene began her article in *New York* magazine with the provocative statement, "The Nouvelle cuisine is dead. Finie. Morte. Tombée." She then proceeded to discuss the virtues of "La Cuisine Bourgeoise." Despite Greene's high profile as a food critic, both her description of Daguin's liquid nitrogen and her proclamation that Nouvelle cuisine was dead have largely been forgotten.

Ariane Daguin, the daughter of André, later became CEO of D'Artagnan, a New Jersey-based company that played a crucial role in bringing fresh foie gras and other delicacies to the American market.

Ice cream and whipped cream were the first culinary uses for liquid nitrogen. They taste good, and they make for theatrical tableside presentations (or class demonstrations or party tricks). But if you look in Modernist kitchens today, you'll find that liquid nitrogen can be applied to myriad ingredients beyond cream. Mostly it is used in the kitchen, not at the table, as a convenient way to chill ingredients quickly. For more on the culinary uses of this cryogen, see page 2·456.

that Kurti, who devoted his career to low-temperature physics, had never heard of liquid-nitrogen ice cream before seeing Barham's demonstration. So the oral tradition appears to be spotty.

Later that year, Kurti and This wrote an article in *Scientific American* that briefly mentioned liquid nitrogen ice cream. At the time, This was an editor of the magazine's French edition. Amazingly, This had no knowledge of Daguin's liquid nitrogen work and only became aware of it much later. Instead, This says, he was inspired by the oral tradition of "laboratory folklore."

The *Scientific American* article inspired chemistry professor Brian Coppola and colleagues to write a paper for the *Journal of Chemical Education*, which gave detailed instructions to academics about how to perform liquid nitrogen ice-cream demonstrations for classrooms. It is unclear how widespread the demonstrations had been before the publication of that paper in 1994—but they became common soon thereafter.

What appears to be the first web page dedicated to liquid-nitrogen ice cream was created in 1996. Since then, the page has been viewed more than 34 million times. The same year, This gave a demonstration of liquid-nitrogen ice cream on a French TV show, which Adrià happened to see, although he says it had no impact on him or his cooking at elBulli at the time. Michel Bras also appeared in the same show but seems not to have used liquid nitrogen in his kitchen.

In 1999, Iowa State University chemical engineering students William Schroeder and Thomas Paskach invented a liquid-nitrogen ice-cream machine and demonstrated it at the university's spring festival. The next year, they launched a company called Blue Sky Creamery and sold liquid nitrogen ice cream at the Iowa State Fair, then opened a shop in Ankeny, Iowa. Blue Sky appears to have been the second company

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Critical Responses to Modernist Cuisine

According to many critics and rankings, the two best restaurants in the world are elBulli and The Fat Duck. Both are temples of Modernist cuisine. The chefs of these restaurants, Ferran Adrià (see page 33) and Heston Blumenthal (see page 49), have built wildly successful careers by serving inventive food that flouts culinary conventions and challenges diners' expectations. Adrià's and Blumenthal's intellectual heirs in the U.S.—including Grant Achatz, José Andrés, and Wylie Dufresne—are among the top chefs in the U.S. And yet they are also among the most controversial. Much like the Impressionist painters (see page 19), Modernist chefs have faced a good deal of criticism—in their case, from other chefs as well as the public.

Although Adrià and Blumenthal have been media darlings since early in their careers, they have also been criticized or mocked for their nontraditional approaches to food. The prominent Catalan writer Josep Maria Fonalleras has accused Adrià of "talking about dishes as if he were discussing mathematics rather than cooking" and has said that "those who watch how ... Adrià uses a screwdriver to coil a thread of sugar to make it into a ring will split their sides with laughter." Adrià is also frequently and cruelly lampooned in cartoons and on the Catalan TV show *Polonia* (in one episode, for example, he is shown gleefully wrapping a live Mickey Mouse in plastic wrap to make mortadella).

Blumenthal has also been excoriated by critics and fellow chefs. Nico Ladenis, the British chef who gave back his three Michelin stars when he decided to concentrate on "simpler food," said in 2004 that Blumenthal was not a genius and that he "debases himself by cooking [his egg-and-bacon ice cream]." And Germany's most famous restaurant critic, Wolfram Siebeck, wrote a scathing review of The Fat Duck in the influential *Die Zeit* newspaper in 2005. He called Blumenthal's mustard ice "a fart of nothingness" and compared his cooking techniques to something out of Frankenstein's lab.

Outright hostility toward these chefs' styles of cooking is not as common a cause of controversy, however, as is favorable but misinformed media coverage. In the late 1990s, Blumenthal, Adrià, and other creative chefs working in the finer restaurants of Europe started to borrow ingredients and techniques from the realm of industrial-scale food manufacturing. As a result, these chefs were labeled practitioners of "molecular gastronomy"—a term that many of them say is erroneous or misleading (see page 42). The molecular gastronomy label, along with the pervasive idea of these chefs as "mad scientists" wielding beakers full of mysterious chemicals, provoked hostile reactions from some diners who felt alienated by the idea of science being applied in the kitchen.

in history to sell liquid-nitrogen ice cream made-to-order for a paying customer (Daguin's restaurant being the first). The Blue Sky machine used an automated process, so it was a somewhat different experience than watching servers at the Jardin des Saveurs prepare it by hand.

In 2001, Heston Blumenthal started serving his famous nitro-poached green tea and lime mousse. Barham had shown him liquid nitrogen a year or two prior. Originally the dish was served as a liquid cocktail that arrived at the table in a soda glass with a straw, but later that year Blumenthal began serving it as a foam, which was frozen tableside in liquid nitrogen. By the end of 2002, the mousse became a regular menu item, served as an amuse-bouche to all customers.

Meanwhile, in the U.S., several parallel developments were taking place. In 2002, Rob Kennedy, of the tiny town of Rock Island in Washington's Cascade Mountains, began making liquid nitrogen ice cream. He soon decided to invent his own machine, which he planned to sell to ice cream shops. Kennedy's machine appears to be the first commercially available piece of liquid nitrogen cooking equipment. It makes ice cream to order, but in relatively large batches. His company, NitroCream LLC, still produces each machine by hand, selling them mostly to cafes and ice cream shops.

The next milestone belongs to Jerry Hancock of Orem, Utah. Starting in 2004, he sold single-serving scoops of liquid nitrogen ice cream in his restaurant, New York Burrito, and then in his ice cream shop, SubZero Ice Cream. Hancock made his ice cream by hand rather than with an automated machine. His method, along with Daguin's, stays truest to Marshall's original vision of made-to-order single servings of ice cream.

In 2003, Theodore Gray, a computer scientist and cocreator of the Mathematica scientific

When a few chefs in the U.S. first began experimenting with Modernist cuisine, the American press further disseminated the "mad scientist" characterization. As William Grimes wrote in *The New York Times* in 2000, "Spanish foam has finally washed ashore on Manhattan Island. It was only a matter of time. For much of the past year, the food press has been enthralled with the mad experiments of Ferran Adrià, ... who delights in turning traditional recipes inside out and, in a kind of culinary alchemy, presents flavors in foams, gels, and even puffs of smoke."

But the American practitioners of avant-garde cooking didn't initially garner the high praise that Adrià did. In 2005, Frank Bruni wrote in the *Times* of Alinea (Achatz's Chicago restaurant) and Minibar (run by Andrés in Washington, D.C.) that "the efforts of these restaurants paled beside those of Adrià's El Bulli, where carnival flourishes more often had a payoff of pure pleasure. His American acolytes more frequently lose sight of the line between purposeful improvisations and pointless flamboyance."

Bruni nevertheless conceded that these American Modernist chefs also create "transcendent moments" of culinary delight. In the years that followed, the *Times* published several positive articles about Achatz, Andrés, and other Modernist chefs. In 2008, Bruni gave Dufresne's New York City restaurant, wd~50, a four-star review. These days, the food media generally tends to cover avant-garde cooking favorably.

Some traditionalist chefs have grown increasingly critical, however. One of the most vocal of these critics is Santi Santamaria, the chef at Can Fabes, which was the first restaurant in Spain to attain three Michelin stars. He has condemned Modernist cuisine and its practitioners, specifically Adrià; as he said in 2009, "I really think that this style of cooking will destroy the brains of the people. It's not honest to take a chemical powder and put it in food that people eat. It's not a natural ingredient. This is a big mistake. You don't need chemical gimmicks to make good food."

In response to these attacks, Adrià told the BBC that "it's the biggest madness in the history of cuisine. Lies, lies, lies!... The additives under debate account for just 0.1% of my cooking." The safety issues Santamara has raised are discussed on page 258.

Other chefs have been slightly less vocal in their negative reactions to Modernist cooking, but they have concerns. Gordon Ramsay, who has since become a fan of Adrià's cooking, said in 2000, that "food should not be played with by scientists. A chef should use his fingers and his tongue, not a test tube." In a 2007 interview with Bloomberg News, Alain Ducasse said of Adrià's culinary style: "I prefer to be able to identify what I'm eating. I have to know. It's 'wow'-effect food, virtual food. If we were surrounded by these restaurants, we would be in trouble."

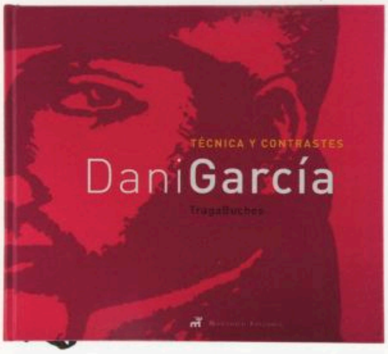
software package (used extensively in the creation of this book), wrote an article in *Popular Science* magazine in which he described in detail how to make liquid nitrogen ice cream.

Another event in 2003 had a more direct impact on the food world. Adrià ate the nitro foam dish at The Fat Duck. He also saw Blumenthal give a series of liquid nitrogen demonstrations at the Madrid Fusión conference in early 2004.

These experiences prompted him to add liquid nitrogen to the elBulli menu for the 2004 season. Spanish chef Dani García had also been experimenting with liquid nitrogen (at the restaurant Tragabuches) and gave a liquid nitrogen demonstration at the San Sebastián conference in late 2003. García's cookbook Dani García: *Técnica y Contrastes*, published in 2004, is the first book to have an extensive section devoted to cooking with liquid nitrogen. In it, he credits Blumenthal as his inspiration. García was also assisted by Raimundo García del Moral, a serious gourmand who is also a professor of pathology at the University of Grenada. Unlike previous chefs, García does not focus primarily on ice cream or even on tableside presentations. Instead, he uses liquid nitrogen for many other purposes—like freezing olive oil, then shattering it and using the glasslike shards as a garnish.

So whom do we credit with bringing liquid nitrogen into the world of cooking? Marshall was clearly the visionary who published the idea of using cryogenic liquids for myriad cooking tasks, including making ice cream tableside in front of diners. It is hard to give her all the credit, however, for several reasons.

First, she never seems to have actually made it. Second, and far more important, her visionary ideas were so far ahead of their time that they became a dead end. Marshall does not seem to have influenced any of the future developments in



Dani García's book was the first cookbook to devote an extensive section to liquid nitrogen, showing multiple techniques.

THE HISTORY OF

Modernist Cuisine in France

Spain may be the world leader in Modernist cuisine (see page 57), but innovative French chefs, including Marc Veyrat, Pierre Gagnaire, Thierry Marx, Pascal Barbot, Alexandre Gauthier, and others, have broken through the boundaries of traditionalism.

Veyrat, who opened his first restaurant in 1978, was an early trailblazer. Before his retirement in 2009, he pushed the culinary envelope with dishes like "yesterday's, today's, and tomorrow's vegetables cooked in a clay pot" and "caramelized frogs, wild licorice, strange salad, and orange vinaigrette." His thoughts about the French culinary establishment were, in the words of *Food & Wine* magazine, "unprintable." In 2003, he was awarded the *Gault Millau* restaurant guide's first-ever perfect score (20/20) for his two restaurants, L'Auberge de l'Eridan and La Ferme de Mon Père.

Gagnaire, meanwhile, has been called "the most out-there Michelin three-star chef in France." In 1980, he opened his eponymous restaurant in St. Étienne, his hometown, and quickly distinguished himself with a provocative, modern, ever-changing menu. Today, Gagnaire has a small empire of restaurants around the globe, from Southeast Asia to the Middle East.

Marx is also known for shaking up French culinary traditions. At his restaurant, Château Cordeillan-Bages, outside of Bordeaux, he creates whimsical dishes like liquid quiche Lorraine, "virtual sausage," sweetbread spaghetti, and bean-sprout risotto. While this food is not an everyday experience for most people, Marx nonetheless says that one of his goals is to democratize cuisine in France. "Much of what I do is about trying to set French cooking free from its bourgeois cage," he told Gourmet.com in 2009.

Barbot's style of cooking is perhaps simpler than Marx's or Gagnaire's, but he shares their emphasis on creativity and culinary reinvention. In the tiny kitchen of his Paris restaurant, L'Astrance, Barbot produces minimalist dishes like tomatoes with white chocolate and wild sorrel and vacherin with figs and green-tea whipped cream. Reservations at L'Astrance have become so sought after that it's nearly impossible to get one. Gauthier represents the new generation of French chefs and is famous for dishes such as shellfish with seawater and "a handful of sand" parsley cream with banana powder. His style echoes that of his Danish contemporary, René Redzepi. His creativity thrives while showcasing local products in unexpected combinations of flavors and textures, and an insightful ability to juxtapose the familiar and the exotic.

BIOGRAPHY OF

Jeffrey Steingarten

Every avant-garde movement has its critics, whose job is to explain, interpret, clarify, and chronicle as much as to attack. Jeffrey Steingarten, one of the most influential American food writers, played all of these roles for Modernist cuisine (he calls it "hypermodern"). He has covered this culinary movement in scores of articles for *Vogue* magazine and elsewhere, and in his books, including *The Man Who Ate Everything* (1997).

Steingarten, a graduate of both Harvard College and Harvard Law School, worked as a lawyer before becoming the food columnist for *Vogue* in 1989. His articles are informed by tireless research and kitchen experimentation, characterized by *The Wall Street Journal* as "obsessional, witty and authoritative ... brisk and self-mocking ... unrivaled in the completeness of its basic research."

Steingarten's articles in *Vogue* have discussed many of the influential ideas and figures in the Modernist movement. From nearly the beginning, Steingarten participated in the Molecular and Physical Gastronomy conferences in Erice, Sicily (see page 45), and he was the first journalist to write about the event's co-organizer, Hervé This. Steingarten has written extensively about Heston Blumenthal (see page 49), Grant Achatz (see page 68), Wylie Dufresne, and José Andrés (see page 67), and contributed an essay to Achatz's groundbreaking cookbook. Steingarten has known Ferran Adrià, whom he described as "the Catalan genius and pioneer of hypermodern cooking," before Adrià became famous beyond the borders of Spain.

Steingarten's role is more than that of a writer; his research and experimentation have also made him a participant. In one early *Vogue* column, Steingarten achieved a breakthrough in the preparation of the perfect mashed potato, which has since found its way into the cooking of Blumenthal and Dufresne. In a 2006 column devoted to sous vide cooking, Steingarten revealed his technique for preparing sous vide salmon using a bathtub. With Blumenthal, he has prepared vanilla ice cream in a continuous process from udder to cream separator to a bowl of liquid nitrogen. He is probably the only food critic who keeps a large Dewar of liquid nitrogen in his home kitchen.

The Chicago Tribune has referred to Steingarten as "our most original investigative food writer." In a marked contrast, London's *Independent* newspaper has called him "the world's wittiest food writer." For our purposes here, we can say that more than any other food critic, Steingarten has become an integral part of today's culinary avant-garde.

culinary applications of liquid nitrogen. In retrospect, her idea was a brilliant mental exercise, but ultimately, it did not make much of a difference—like the proverbial tree falling in the forest with no one there to hear it.

Within the world of serious cuisine, Daguin clearly seems to have been the first chef to use liquid nitrogen—at least as far as we know. He deserves enormous credit for independently coming up with much the same vision as Marshall, with only bull semen as his inspiration. Yet it is striking that neither he nor the rest of the haute cuisine world seems to have grasped the myriad other ways in which liquid nitrogen could be used in the kitchen.

The world was not ready to accept the idea, it seems. Indeed, much the same thing occurred in 1996, when Adrià, Bras, and likely many others were first exposed to culinary uses of liquid nitrogen via the Kurti and This article or the French TV show featuring This and Bras. Even Adrià, who at that point was already more than 10 years into his program of reinventing cuisine, did not immediately see a use for liquid nitrogen.

Ultimately, it was Blumenthal's use of liquid nitrogen that seems to have struck a chord in the culinary world. Perhaps this was because it seemed to be an integral component of his unique approach to cuisine rather than an isolated parlor trick. Or maybe it was simply that the Modernist revolution had advanced enough that the time was finally ripe. Whatever the reason, Blumenthal's use of liquid nitrogen directly inspired García and Adrià to use it in their cuisine, which started a trend among other Modernist chefs.

It is equally possible that there are other unsung

Some people have speculated that James Dewar might have demonstrated liquid nitrogen ice cream and that Mrs. Marshall was just writing down what she saw. In the course of our research, we uncovered a book on cryogenics published in 1899 that describes in detail the demonstrations that Dewar and others did in that era. The only food item frozen was whiskey. Seeing whiskey frozen solid was likely enough to inspire Mrs. Marshall.

heroes in the liquid nitrogen story. A bit of research has uncovered the facts presented here, including the role of some surprising players—but we may have overlooked others.

This tangled web of developments is typical of what you find whenever you ask the question "Who was first?" As discussed above, the histories of sous vide cooking and of "molten" chocolate cake have similar twists and turns, including false starts and parallel invention. Many of the techniques and ingredients in Modernist cuisine have very similar stories. This is particularly true when the technique evolved first in the context of science or industrial food production.

The most unusual aspect of the liquid nitrogen story is that someone had the deep insight to understand the technique in the abstract first and then the technology caught up. In most cases, the reverse is true—a technique or ingredient is used unwittingly, and only later does someone conceptualize what it is and what it could become.

A good example of this latter pattern is the egg-based fluid gel. For centuries, chefs have been stirring eggs (whites, yolks, or whole eggs) into sauces while heating them, with the knowledge that thickening would result. Michel Bras took the process one step further by lightly poaching eggs before mixing them into sauces. We now understand that eggs can form fluid gels that have a number of interesting properties. Once you realize that eggs can create fluid gels, it broadens the possibilities enormously and helps you understand what else they can be used for. But it is also possible to use eggs to create **fluid gels** without ever knowing that you are doing so. Usage can precede full understanding; indeed, in the kitchen, this happens more often than not.

In this case, I have a personal perspective because I realized that eggs could form fluid gels while learning about hydrocolloids in 2004. I have discussed this idea with many Modernist chefs, including Adrià, Blumenthal, Achatz, and Dufresne, and it was news to them. We have not found any other references to it in the academic literature; as far as we know, this book is the first publication of the idea. But it's entirely possible that there are food scientists or chefs who discovered this property of eggs much earlier and either

THE HISTORY OF

Ideas in Food

In late 2004, while working at Keyah Grande, a remote hunting lodge in Colorado, chefs H. Alexander Talbot and Aki Kamozawa launched their food blog, Ideas in Food (IdeasInFood.com), to chronicle their explorations in Modernist cuisine. The lodge was an inauspicious place to launch anything. It was deep in the wilderness, miles from the nearest town. It had only eight rooms, which were mostly used by elk hunters who viewed dinner as a time to refuel rather than as a gastronomic adventure. These guests were more often looking for familiar comfort food than spectacular Modernist cuisine. Many of them were shocked to sit down to a table, often in camouflage gear, only to be served dishes like smoked trout roe over parsnip ice cream.

Nevertheless, Talbot and Kamozawa were committed to Modernist food, and they saw their blog as a way to communicate with kindred spirits across the globe. They used the website to catalog their experiments in the kitchen and took turns jotting down their thoughts in this new online notebook.

The premise was simple, but the subject matter was radical: Talbot and Kamozawa wrote about working with ingredients like methylcellulose, transglutaminase, and liquid nitrogen, and with equipment like dehydrators and Pacojets. The pair also openly discussed recipes and techniques that would have been trade secrets in many restaurants.

Alongside the main blog entries, they published PDF files with additional notes about current and future projects. No one had done this before—at least not in a way that emphasized the *ideas* that undergird Modernist cooking as much as the novel techniques. Ideas in Food quickly developed a cult following among Modernist chefs, both amateur and professional. The power of the Internet to connect people let Talbot and Kamozawa reach an audience that they never could have otherwise. Today, in addition to maintaining the blog, the team runs Ideas in Food, LLC, a consulting business based in Levittown, Pennsylvania. They also wrote a column called "Kitchen Alchemy" for the *Popular Science* web site. Their cookbook, *Ideas in Food: Great Recipes and Why They Work*, was published in 2010.

THE HISTORY OF

Modernist Cuisine in America

Compared to Spain and France, the U.S. discovered culinary Modernism relatively recently. This budding American movement has been spurred by innovative chefs, including José Andrés, Grant Achatz, Wylie Dufresne, Homaro Cantu, David Kinch, Daniel Patterson, Sean Brock, and Sam Mason.

Andrés is probably the best known of these American Modernists (though he was actually born and raised in Spain). He apprenticed at elBulli under Ferran Adrià for two years before moving to the U.S. In 1993, Andrés opened his first restaurant, Jaleo, in Washington, D.C., and helped popularize Spanish cuisine in the U.S.

His major contribution to American Modernism is his fifth restaurant, minibar, also in D.C. *The New York Times* dubbed the tiny, six-seat spot "a shrine to avant-garde cooking." Andrés's latest project, called The Bazaar, has introduced this taste to Los Angeles on a larger scale. With minibar and Bazaar, he runs both the smallest and the largest Modernist restaurants in the world.

At Alinea in Chicago, Grant Achatz (see next page) creates some of the most inventive food in the U.S. Alinea frequently tops lists as the best restaurant in the country. Both Achatz and Homaru Cantu—another chef in Chicago's flourishing Modernist culinary scene (see page 69)—are keenly interested in design and food technology, and both men have made major breakthroughs in these areas.

Cantu and his restaurant, moto, became famous for his "printed food": edible paper on which images of dishes or other objects are printed with food-based inks. His company, Cantu Designs, has filed patent applications for printed food and many other dining and cooking implements that he and his colleagues have created. He also stars in *Future Food,* a reality TV show that shows the moto team in the process of coming up with new Modernist dishes.

David Kinch, who runs the Silicon Valley-area restaurant Manresa, focuses less on equipment and more on ingredients, while still using Modernist techniques. He often combines seemingly dissonant flavors, such as broccoli and foie gras, or turnips, plums, and vanilla. The signature amuse-bouche at Manresa is his take on Alain Passard's soft-boiled egg with sherry vinegar and maple syrup.

But the American Modernist movement's real "egg man" is Wylie Dufresne, who is famous for his obsession with eggs (and his signature deconstructed eggs Benedict, which includes deep-fried hollandaise sauce). Dufresne's New York City restaurant, wd~50, was perhaps the first major fine-dining establishment in that city to focus so singularly on Modernist cuisine. As he told *Esquire* in 2005, "I might be the only chef in Manhattan who can tell you what methylcellulose does."

Well, perhaps the only chef except for Sam Mason, Dufresne's former pastry chef. In 2007, Mason opened his own New York City restaurant, Tailor, where he created a daring menu full of unexpected flavor combinations, like pork belly with miso butterscotch. Mason closed Tailor in the summer of 2009. But he continues to showcase Modernist cuisine on his TV show, *Dinner with the Band,* where he invites musicians into a kitchen and builds a creative menu around their tastes.

Sean Brock, the chef at McCrady's in Charleston, South Carolina, is probably the only chef in his city who regularly uses methylcellulose. He told *Food & Wine* that he believes hydrocolloids (including gellan gum, carrageenan, and pectin) should be in every pantry. But the young chef is equally committed to fresh, locally grown ingredients—in fact, he owns a one-hectare (2.5 acre) farm, where he grows 90% of the produce used in his restaurant. "I want to be completely respectful to in-season ingredients and elevate them with science and knowledge," he says.

Daniel Patterson has a similar sensibility. Located in San Francisco, his two-Michelin-star restaurant, COI, showcases California's bountiful produce, often in unexpected and playful ways. "We brine, cure, and smoke, as cooks have been doing for thousands of years," the COI website explains, "but we also embrace modern cooking methods, like sous vide." And in his frequent columns in *The New York Times Magazine,* Patterson explains basic food science to the home cook.

Other influential figures in American avant-garde cuisine include Will Goldfarb, who sells specialized equipment and ingredients through his website, WillPowder.net; and H. Alexander Talbot and Aki Kamozawa, who have done much to disseminate Modernist techniques through their blog, Ideas in Food (see previous page).

didn't publish it or published it somewhere that we have not yet found.

It is important to distinguish between several different roles that innovators play in new culinary creations. One role is to conceptualize the idea. Another function is to be the first to put the idea into practice (for chefs, this generally means using it in a dish that you serve to customers). A third role is to popularize the idea and spread it to others. And a fourth role is to scientifically understand the phenomenon of interest. All of these roles are important.

As much as we like science, we would argue that the fourth role is actually the least important. It is quite possible for a new technique to burst on the scene and become popular long before anyone has a good scientific understanding of why it works.

The most important role is that of conceptualizing the technique, which includes understanding its impact on cuisine. Daguin came up with the idea before any other chef, but he seems to have treated it as a clever trick rather than as something fundamental. Adrià and Bras were both exposed to the idea of using liquid nitrogen in 1996, but they,

BIOGRAPHY OF

Grant Achatz

By the time he was 35, Grant Achatz had already become one of the most respected chefs in the U.S. The Modernist master got his start working for Thomas Keller at The French Laundry in California, where he became sous chef within two years. In 2000, Achatz went to Spain and spent a brief period working at elBulli under Ferran Adrià (see page 33), and experience that greatly influenced Achatz's culinary philosophy. He returned ready to leave The French Laundry and strike out on his own.

In 2001, Achatz took over the kitchen at Trio, a restaurant in the Chicago suburb of Evanston. He faced some difficulties there—the restaurant was poorly funded and not terribly busy—but he nevertheless took chances with the menu and experimented with avant-garde techniques. It paid off. Achatz attracted critical acclaim for his unexpected dishes, such as his signature Black Truffle Explosion (ravioli that "exploded" with hot truffle broth when bitten into). He also developed a following of devoted regulars.

One of those regulars was Nick Kokonas, a derivatives trader who had become a multimillionaire by his early 30s. He was a big fan of Achatz's cooking. As Achatz remembers, Kokonas said to him, "If you want to do your food justice and open a restaurant worthy of your food, just let me know."

In 2004, Achatz took him up on the offer. The two men lined up a group of investors for their restaurant, Alinea, in Chicago. They worked together on every detail, collaborating with architects and designers to build a unique space. Neither of them had ever owned a restaurant before, so it was a big risk, and the type of food Achatz planned to serve was ambitious.

In 2005, they opened Alinea, and it quickly garnered critical acclaim. The positive reviews came from local publications, including the *Chicago Tribune,* and national ones, including *Gourmet*, which named it the best restaurant in America.

Things seemed to be going swimmingly for Achatz until 2007, when he received a devastating diagnosis of tongue cancer. Rather than having much of his tongue removed, as most oncologists recommended, Achatz underwent an experimental treatment program of radiation and chemotherapy at the University of Chicago. While he was unable to taste anything for several months during the treatment, he continued working long hours at the restaurant, creating new dishes that drew praise from Alinea regulars. His cancer went into remission, and he recovered his sense of taste, saying that the ordeal helped him understand flavors in a new way.

In addition to cooking and overseeing the daily operations at the restaurant, Achatz became a prolific writer. He blogged regularly for *The Atlantic,* and in 2009, he and Kokonas self-published a book of recipes, essays, and photography, called simply *Alinea*. In 2010, the duo wrote a memoir of Achatz and the restaurant called *Life on the Line*.

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Chicago as a Modernist Mecca

Despite its lingering reputation as a steak-and-potatoes town, Chicago is home to more Modernist restaurants than all other American cities put together. In fact, Chicago has more restaurants of this kind than any other city in the world—the only one that comes close is San Sebastián, Spain, but only if you count the surrounding suburbs. Chicago's list includes Alinea, moto, Tru, L2O, Avenues, and Schwa. Many others have Modernist touches on their menus.

Nick Kokonas of Alinea argues that the reasons for Chicago's lead position are at least partly economic. "It's easier to take risks here," he argues, noting that the city is big enough to have a critical mass of adventuresome diners with the income to eat well, yet small enough that the rent is low and start up costs are perhaps half what they are in New York.

Credit for the city's status as a Modernist mecca also goes to Chicago chef Charlie Trotter and his influence on high-end fine dining. Trotter built enthusiasm for fine cuisine in Chicago when he opened his eponymous restaurant in 1987. Although he does not specialize in Modernist cuisine, Trotter's culinary philosophy shares some elements with Modernism. He emphasizes dining as an emotional and intellectual experience, for example, and uses classic dishes as starting points for improvisation. Several of today's Modernist stars, including Homaro Cantu (of moto) and Rick Tramonto (of Tru), worked for Trotter early in their careers; Grant Achatz did his first *stage* in Trotter's kitchen.

In 1993, Tramonto and his culinary partner, Gale Gand, opened Trio, the restaurant where Achatz later made a name for himself. In 1999, Tramonto and Gand opened Tru, creating a critically acclaimed menu that emphasized playfulness and fun. Several years later, Tramonto promoted Tim Graham, who has a background in food science, to executive chef. (Tramonto remains chef-partner of Tru.) Graham used sous vide cooking, steam distillation, and other high-tech methods but also classic techniques in creative new ways, such as simmering butter and water to make "butter water" that contains the flavor of butter without the fat.

Graham's mentor was another of Chicago's Modernist masters, Laurent Gras. Raised in France, Gras worked for Alain Ducasse and Guy Savoy before coming to the U.S. Gras's classical French training is evident in the menu at his Chicago restaurant, L2O, which opened in 2009. L2O also showcases his love of technology—it boasts a formidable arsenal of specialized cooking tools, from a distiller to a Hawaiian ice shaver, which Gras deploys to achieve a high standard of culinary exactitude.

Perhaps the most technologically advanced wizard on Chicago's culinary scene is Cantu, who is known for breakthrough inventions such as "printed food" (see page 74), carbonated fruit (see page 2·469), and laser-smoked aromatic ingredients (made with surgical-grade lasers). Cantu's pastry chef, Ben Roche, also worked for Trotter early on.

Avenues, run by chef Curtis Duffy, an alumnus of Alinea, is yet another superb Chicago Modernist restaurant. Duffy, who took over Avenues in 2008, soon received perfect four-star ratings from both of Chicago's major newspapers.

Michael Carlson, the chef at Schwa, has been inspired both by Modernist chefs like Achatz and Heston Blumenthal (see page 49) and by traditional Italian chefs such as Paul Bartolotta. The dual influence is reflected in his menu, which includes inventive dishes like ravioli filled with liquid quail egg and truffles, and pad Thai made with jellyfish noodles. Unlike Alinea or moto, Schwa's service and wine program are remarkably laid back: Carlson and his kitchen staff double as servers, and the restaurant is B.Y.O.B.

In contrast with Chicago, New York City is generally considered unfriendly to Modernist food. In that city, Wylie Dufresne's wd~50 was the first major fine-dining establishment to focus so singularly on Modernist cuisine (see page 67). Today, a few other New York chefs, including Paul Liebrandt at Corton, are experimenting with Modernist techniques, but the movement is a long way from taking root as it has in Chicago.

too, did not see a use for the technique.

In some cases, all of these roles are played simultaneously by one person. That is a rarity, however; the development of ideas is messy, and these various phases can occur in any order. With this messiness in mind, we have assembled a timeline of some of the major developments in Modernist cuisine—see page 78. Like the story of liquid nitrogen or sous vide, the story of how any culinary idea evolves is complicated, and we can't analyze each case exhaustively. The timeline is based on our own research, which included an informal survey of chefs.

Ideas with Owners

Being the first person to achieve a culinary milestone has reputational advantages, but there is another potential source of value: ownership of intellectual property. In the ancient Greek city of Sybaris, chefs who invented a new dish were allowed to make it for a year without any competition. In the modern world, similar (albeit longer) periods of exclusivity are conferred by intellectual property laws, but unfortunately in most cases, not for chefs or their dishes.

From a legal standpoint, there are three primary branches of intellectual property law: trademark, copyright, and patent law. The first one isn't much help to most chefs, because trademark law is primarily about names. For example, you can brew your own brown-colored soda, but you can't call it Coca-Cola, because that name is a registered trademark. Trademarks can only protect your product's name and other branding devices (such as symbols and phrases), not the recipe or cooking techniques used to make the product.

The second branch of intellectual property law is only slightly more useful to chefs. In general, copyright laws in most countries are about the artistic expression of an idea. Classic examples of copyrighted works include music, writing (both fiction and nonfiction), and graphic art. The content of this book is protected by copyright law—you're not supposed to reprint it or copy text or photographs from it without permission from the copyright holder. But you could write your own book, even on the same topic. The legality of that book would hinge on whether it included any literal copying. Reexpressing

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Modernist Cuisine Elsewhere

Chefs around the world have embraced Modernist techniques. We have had Modernist meals in remote mountain lodges in Patagonia and other far-flung places. We can't possibly list every Modernist chef, but here is a sample of the leading proponents worldwide.

In Japan, Yoshiaki Takazawa produces his own take on Modernist food with strong Japanese influences at his restaurant Aronia de Takazawa in Tokyo. It is a very personalized experience—the restaurant only has two tables. Koji Shimomura is the chef at Edition Koji Shimomura, another Modernist restaurant. Seji Yamamoto has a more traditional Japanese restaurant, Nihonryori RyuGin, that includes a few Modernist touches.

Alvin Leung Jr. of Bo Innovation in Hong Kong cooks what he calls "X-treme Chinese cuisine." Anatoly Komm at Varvary in Moscow uses Modernist techniques to reimagine Russian classics like borscht and pelmeni. Claudio Aprile of Colborne Lane in Toronto is one of the leading Modernist chefs in Canada. In Italy, Modernist-inspired interpretations on Italian themes can be found at several restaurants, including Osteria La Francescana (chef Massimo Bottura), Le Calandre (chefs Max and Raf Alajmo), Combal.Zero (chef Davide Scabin), and Cracco (chef Carlo Cracco).

Belgium has L'Air du Temps (chef Sang-hoon Degeimbre), Le Postay (chef Anthony Delhasse), and Restaurant Apriori (chef Kristof Coppens). The Netherlands has Oud Sluis, with chef Sergio Herman. In Germany, restaurant Maremoto, run by chef Cristiano Rienzner, produces what he calls "metaphoric cuisine." Chef Juan Amador operates l'Amador, featuring Modernist cuisine in a Spanish style.

In Austria, chef Martin Schneider produces Modernist food at the Landhotel Kirchdach, as does Heinz Hanner of Restaurant Hanner. Chef René Redzepi's restaurant Noma has recently been named the best in the world by at least one survey. Located in Copenhagen, it features a new approach to Nordic cuisine.

similar ideas with different words does not, as a general rule, violate copyright.

As a result, copyright laws (in most of the countries we are familiar with) don't protect the ideas behind a recipe—the particular combination of ingredients or ways they are assembled. Nor do they prevent others from preparing the dishes described by the recipes. These laws generally only restrict people other than the copyright holder from reprinting the recipe as it is published in a book or other copyrighted work.

So it's illegal to copy a recipe verbatim but not illegal to pinch the idea and recast it in your own style. Even relatively minor changes can be enough to turn someone else's recipe into your own (at least as far as copyright law goes). And there's no legal obligation to cite the source of inspiration for that recipe, though ethical writers generally do so out of professional courtesy.

The third type of intellectual property law is patent law. In some sense, it is the opposite of copyright—it is designed to protect the fundamental idea rather than the exact instantiation. Patents only cover certain things; you can patent machines, chemical compositions (including recipes), software, and many other technological inventions.

Patent law applies to numerous aspects of food preparation. Many food ingredients and techniques are patented. At various points in this book, we discuss patented techniques such as espresso making (see page 4·372), pressure fryers (see page 2·120), cheese emulsifiers (see page 4·218), Spam (see page 20), and methods of carbonating whole fruit (see page 2·469). Most of these patents have already lapsed into the public domain, which happens roughly 20 years after the

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Copying in Modernist Cuisine

Arguably, the phrase that ignited the Modernist movement was chef Jacques Maximin's pronouncement, "Creativity is not copying." When Ferran Adrià heard these words in 1986 (see page 33), he vowed to stop using cookbooks and began developing his own recipes. Over the years, his style evolved to place an ever greater emphasis on creativity. Today, Adrià has inspired countless other chefs and, ironically, now has many imitators.

So what is the role of imitation in Modernist cuisine? Is true creativity antithetical to copying? Since novelty is so important in this style of cooking, many Modernist chefs are especially bothered by copycats.

Perhaps the most famous example of copying in Modernist cuisine is the case of the Australian chef Robin Wickens, who completed *stages* at Alinea, wd~50, and other Modernist establishments, then produced exact replicas of a dozen or so of their dishes at his Melbourne restaurant, Interlude. In 2006, the online forum eGullet.com exposed the uncanny similarities between Wickens's dishes and those served at the American restaurants. "He copied them so well I was almost impressed," Alinea chef Grant Achatz said. Following the incident, Wickens wrote to Achatz and wd~50 chef Wylie Dufresne to apologize.

A few weeks after blowing the whistle on Wickens, eGullet exposed another case of copying, this time in Tokyo. Tapas Molecular Bar, in the Mandarin Oriental hotel, was serving a tasting menu that seemed to be identical to one originally served by José Andrés at his Washington, D.C., restaurant, minibar. Like Wickens, the chef at Tapas Molecular Bar had worked at the restaurant from which the dishes were apparently copied. When Andrés learned of the similarities, he called his lawyer and attempted to get the Mandarin Oriental to pay him a licensing fee or change its menu.

Unfortunately, chefs have little legal recourse in cases such as this, because in most countries copyright laws restrict only the *publication* of cookbooks or recipes elaborated with commentary or detailed guidance; neither copying the simple list of ingredients nor making the dishes themselves is covered. Most artists retain the copyright to individual works: writers own their short stories, photographers own their images, and composers own their songs, even when these works appear on the Internet. Chefs do not have the same kind of ownership of their recipes. Thus, copying in cuisine is mostly a question of professional ethics.

Chefs can, however, patent their recipes or technological innovations if the U.S. Patent and Trademark Office agrees that the idea is truly novel. Getting a patent can be costly and may take years, but some Modernist chefs, notably Homaro Cantu of moto in Chicago, have applied for such patents. Cantu's famous "printed food" even contains a legal notice: *"Confidential Property of and © H. Cantu. Patent Pending. No further use or disclosure is permitted without prior approval of H. Cantu."*

patent is first filed (the actual rules on patent lifetime are more complicated, but that range is the gist of it). That is the whole point of patent law: in return for filing a patent that discloses the secret of how to do something, you get two decades of exclusive access to the technique. After that, the idea becomes fair game for anyone who wants to use it.

There are also hundreds of patents on food techniques that are currently in effect. Of the many pieces of equipment and distinctive ingredients discussed in this book, some are covered by patents. We have highlighted certain cases where patents are in place, but it would not have been practical to discuss all patents on all items featured in this book. We take no responsibility for ensuring that the technologies discussed here are not subject to patents. On the other hand, essentially any cookbook, magazine, or website that features cutting-edge techniques faces the same issue.

Diners at Homaru Cantu's famous Modernist restaurant moto (see page 69) are sometimes surprised to see a patent notice on the bottom of the menu that warns that many of the techniques used in the restaurant may be patented by the chef's company, Cantu Designs. Part of his business strategy is to patent technologies that he develops for use in the restaurant.

This brings up a question that we are often asked: can Modernist chefs patent new dishes and techniques? I am an inventor by profession; as of this writing, I have received 115 patents on my own inventions across a number of technological fields, and I have applications pending for more than 500 others—and thousands more indirectly through the inventions created by my company. But so far very few of these are related to cooking.

As much as I love to cook and to invent, it is actually quite difficult to come up with a genuinely new invention in cooking that is patentable. The first reason is novelty: in order to qualify for a patent, a technique has to be truly new. The reality is that most ideas in cooking aren't new in the sense required by the patent office.

The next hurdle is economic. It costs money to get a patent; between legal fees and fees to the patent office, you're looking at $10,000 to $25,000 or more to obtain a U.S. patent, and fees in most other countries are similarly high. This investment typically gives you patent rights only in a single country—it costs that much again if you want rights in another country.

Of course, getting the patent is only part of the battle; you then need to license the patent to someone or to start a company to produce the product yourself. A cooking technique that is relevant to high-end, low-volume Modernist restaurants almost certainly has too little economic value to make it worth the cost of the patent.

If the idea works on a large scale and would be relevant to industrial food production, that is a different story—then it could be very worthwhile to file a patent, as it was for Curt Jones with Dippin' Dots. But then your competition is the processed-food industry with its inventions of the past century, so creating something truly new and patentworthy is difficult. The year of exclusivity that ancient Sybaris gave its chefs was, in hindsight, much simpler and more practical than the protection intellectual property law gives chefs today.

What Next?

The Modernist revolution is still in its infancy. The Fat Duck and elBulli have traded positions on various lists as the best restaurants on Earth, but most cities still don't have a Modernist restaurant. Indeed, there are a comparative handful of restaurants practicing a fully Modernist style, and most of them are listed in sidebars in this chapter.

Over time, that will change, and the Modernist movement will expand in new directions. We can already see that happening, as young chefs take up the cause and seek to apply their skills in new ways. The future for the Modernist movement seems very bright.

The next stages in the Modernist revolution will have several aspects. At the high end, a set of talented chefs are marching forward with ever bolder and more novel creations. At this point, there are no signs of the revolution slowing or of chefs running out of creative new ideas.

This doesn't mean all Modernist cooking will look like today's examples. The first generation of Modernists chefs have their own distinctive styles, much as the Impressionists had theirs. But Impressionism didn't last forever; subsequent generations of artists created their own movements under the umbrella of "modern art." The same thing will happen with Modernist cuisine.

New schools and movements will emerge, with their own aesthetic principles and styles. It may be quite different from today's Modernist food, but we think it will still be Modernist in spirit.

Meanwhile, other ambitious chefs are adopting the Modernist approach in their cuisine. Foams, gels, and other inventions of the Modernist movement are appearing on more and more menus as a bright spot of innovation in an otherwise more conventional setting.

This second group of chefs may not be expanding the scope of Modernist cuisine with utterly novel techniques, but they are creating exciting food that is stylistically Modernist and helps introduce the approach to a wider group of people outside the lucky few who can visit the restaurants of Modernist masters. Over time, many of these early adopters will themselves rise to master status.

An interesting phenomenon is that many New International restaurants begin their experimentation with new techniques via the pastry chef. Pastry has always been a more technically oriented discipline than savory cooking. To pastry chefs, Modernist techniques and methods don't seem so foreign. Pastry chefs like Johnny Iuzzini of Jean Georges, Michael Laiskonis of Le Bernardin, and many others like them help bring techniques of the Modernist revolution to the more conservative New International kitchens in which they work.

Home chefs are part of the arc of adoption, too. Sous vide machines designed for home use are now on the market, and eGullet.org and other Internet forums are giving people access to information that was previously almost impossible for nonprofessionals to come by (see Sous Vide at Home, below). A few pieces of equipment, like centrifuges and freeze dryers, may remain out of reach to the home cook, but virtually all of the most important techniques in the Modernist repertoire can be executed in a well-equipped residential kitchen.

Finally, the Modernist movement has had some important trickle-down benefits for chefs cooking in other styles. The path that Blumenthal started out on—using the latest scientific knowledge and technology to perfectly execute classic dishes—is now being followed by many chefs.

Sous vide got its start this way at Maison Troisgros. It has since been adopted by Thomas Keller, whose book, *Under Pressure,* made the technique accessible to cooks in the English-speaking world. If Keller's impeccable cuisine can be made sous vide, what excuse is there for other chefs not to apply the method to their own?

The trickle-down effect won't stop at sous vide. Techniques like centrifugation, vacuum filtering, dehydration, and many others also have a role in a New International kitchen. So do ingredients like xanthan gum. Over time, we will see more and more cooks and chefs using these Modernist approaches to create food that may not appear to be overtly Modernist in style. Indeed, in volume 5 of this book, you will find Modernist recipes for familiar-looking hamburgers, Southern barbecue,

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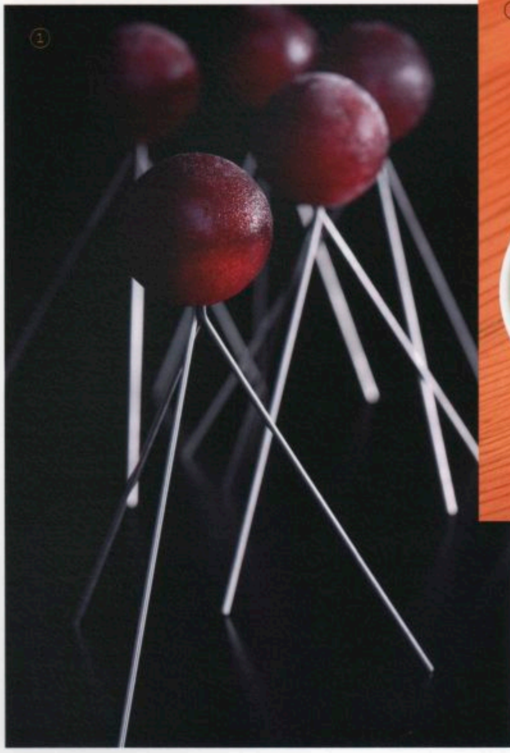
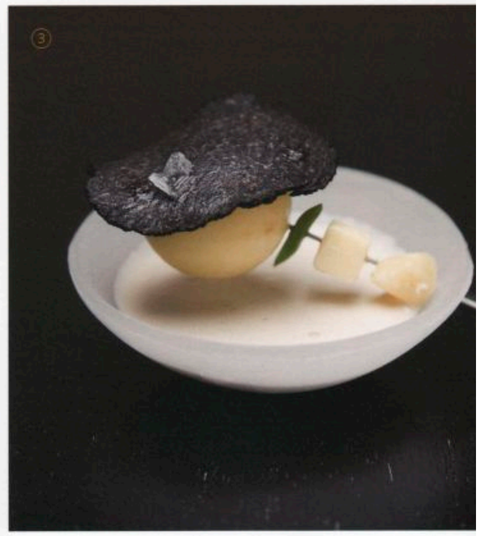
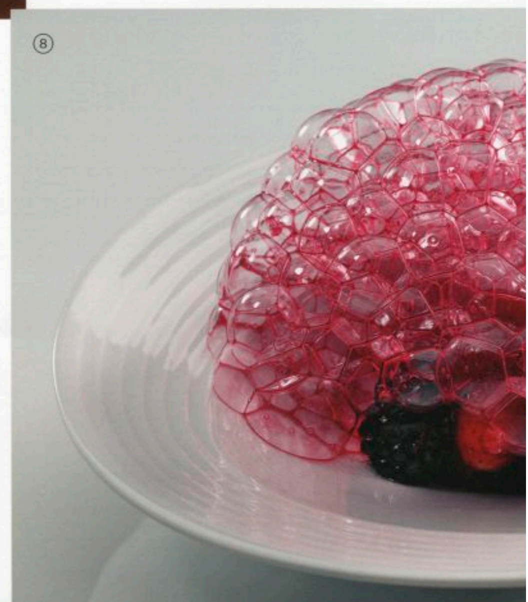
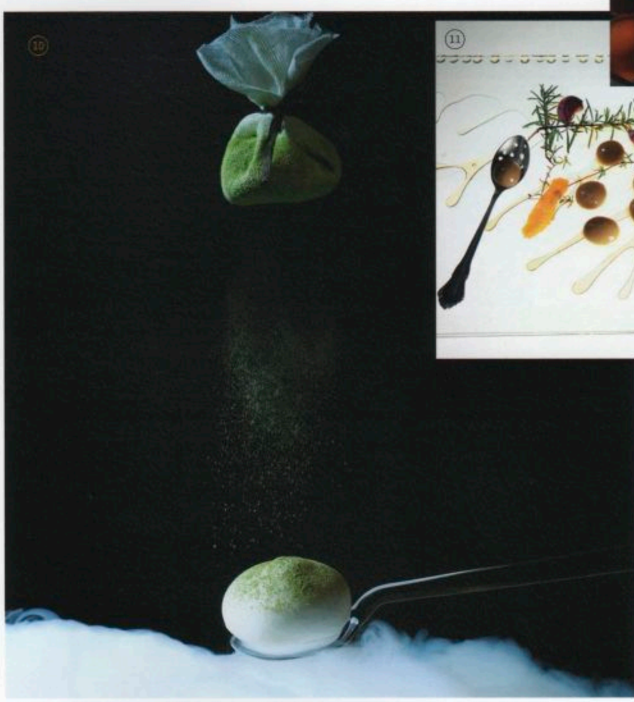
Sous Vide at Home

Home chefs were largely excluded from the first phase of the sous vide revolution. In the early 1980s, Canadian researcher Pierre de Serres developed a sous vide-like system for home cooks. De Serres's system included a SmartPot that was similar to a conventional crock pot or slow cooker and acted like a simplified water bath. Instead of using a vacuum packer, de Serres advocated using open plastic bags that hung in the water from clips at the top. This technique kept the open end of the bag out of the water. The system was sold in Canada but never caught on broadly.

Amateur sous vide largely began in 2004, when I posted a request for sous vide recipes and guides to cooking sous vide at home on the Internet site eGullet.org. This thread soon became a central point of communication between professional chefs (many of whom use the site) and amateurs. Both groups learned a lot; indeed, a great deal of technical information on sous vide first appeared on eGullet instead of in books or articles. As of this writing, the thread contains about 3,700 postings on sous vide by hundreds of contributors. It has been viewed more than 550,000 times and is a major clearinghouse for information on sous vide.






Innovation in how food is presented, served and eaten is another hallmark of Modernist cuisine. Shown above are just a small sample of some of the new and interesting utensils and plating styles found in Modernist food today.

Grant Achatz, Alinea: ① Tripod Hibiscus; ③ Hot Potato, Cold Potato; ④ Applewood, Muscovado Sugar, Fenugreek; ⑥ Granola in a Rose Water Envelope; ⑫ Sweet Potato, Brown Sugar, Bourbon, Smoking Cinnamon; ⑮ Pheasant, Shallot, Cider, Burning Oak Leaves; ⑯ Raspberry Transparency, Yoghurt, Rose Petals (photos by Lara Kastner/Alinea)
Ferran Adrià, elBulli: ⑦ Spherical Ravioli of Tea with Lemon Ice Cube; ⑨ Caramelized Pork Scratchings; ⑪ Spherical Green Olives; ⑭ Frozen Parmesan Air with Muësli (photos by Francesc Guillamet) ⑰ Pea Sphere (photo by Nathan Myhrvold)
Andoni Luis Aduriz, Mugaritz: ⑧ Sun-Ripened Red Fruit with Beet Bubbles (photo by José Luis López de Zubiria—Mugaritz)
Heston Blumenthal, The Fat Duck: ⑩ Nitro Green Tea Sour (photo by Dominic Davies)
Homaro Cantu, moto: ⑤ Edible Menu
Quique Dacosta: ⑬ Sprouts 2000 (photo by Carlos Rondón, www.carlosrondon.es)
Wylie Dufresne, wd~50: ② Miso Soup with Instant Tofu Noodles (photo by Takahiko Marumoto)

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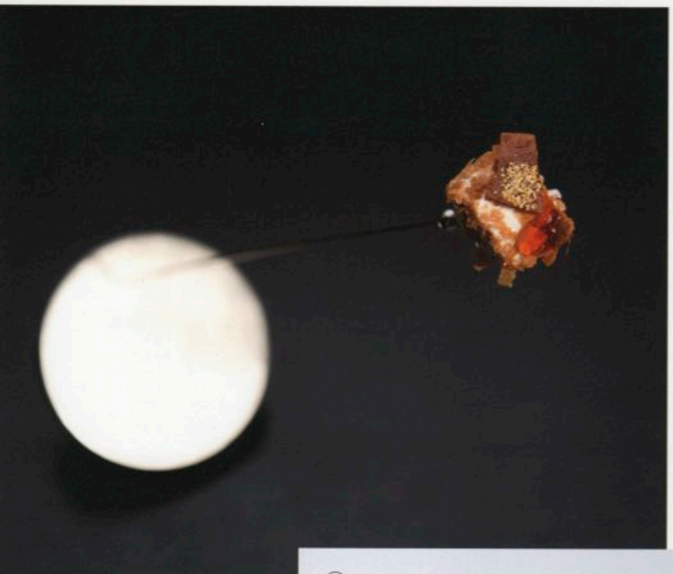

NITRO sushi rice
ITALIAN food
RED/YELLOW beets
GINGER BEER
GOAT CHEESE
CARAMEL APPLE
GREEK salad
BOUILLABAISSE
WASABI & hamachi
BLUEFIN & gumbo
SMOKED PORK
QUAIL & white
LAMB & eggs
CD-2 fruit
3 COTTON
FROZEN
CARROT
CHICAGO
PINA
CHILI-CHE

5

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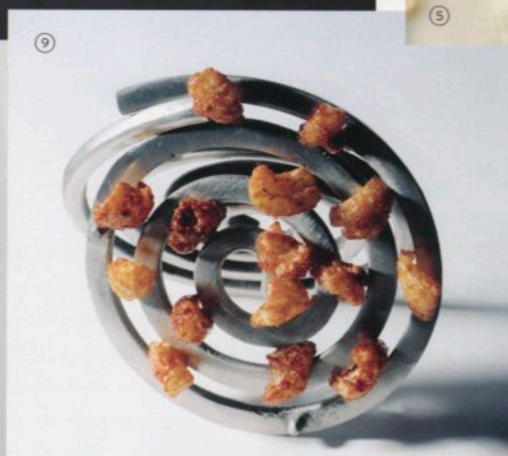

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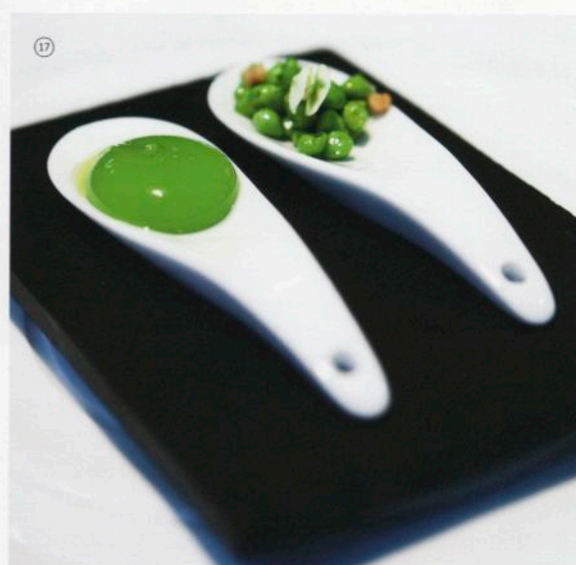

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and Indian curries. We hope that this book will play a role in the dissemination of techniques to a wide array of chefs who can use them as basic building blocks in forging their own culinary vision.

The restaurants at the forefront of Modernist cuisine—elBulli, The Fat Duck, Alinea, Mugaritz, wd~50, and many others—each follow their own styles and culinary vision. In the future, we will see chefs develop more new styles and develop new movements dedicated to them. Modernist art got a kick start from the Impressionists, but the movement surely did not end there. In the same way, we think Modernist cuisine has a future that includes a broad application of creativity beyond anything we have seen so far.

Of course, controversy over the new cuisine will continue to erupt as the movement becomes part of the culinary mainstream. People from the old order will (quite naturally) feel threatened by it. In reality, the Modernist revolution does not threaten traditional food and will never make it obsolete. But many lovers of traditional cuisine will surely continue to feel threatened and worry, just as traditionalists did when Modernist painting and architecture emerged.

Indeed, architecture is probably a closer analogy to cooking than painting or other art forms are, because architecture has a strong utilitarian aspect. People must have buildings for shelter, and as a result, most buildings on Earth

THE HISTORY OF

Trade Secrets

In addition to trademarks, copyrights, and patents, there is a fourth branch of intellectual property law: trade secrets. A trade secret is a method, recipe, or approach that is hidden from public view. In that sense, it is very different from patents, copyrights, or trademarks, which are registered with the government and thereby disclosed to the public.

It is up to the owner to keep a trade secret. If someone else does her own research and re-creates the secret recipe or technique, she has every legal right to use it. The only protection provided by the law is a prohibition against outright theft of the secret.

Colonel Sanders's recipe for fried-chicken batter, which famously contains "a blend of 11 herbs and spices," is a trade secret, as is the recipe for Coca-Cola. Like many companies, KFC and Coca-Cola opted to use trade secrets instead of patents because trade secrets are forever, whereas patents typically last for about 20 years before becoming part of the public domain.

Coca-Cola has maintained the secrecy of its soft-drink formula for more than 100 years, at least in principle. Of course, the reality is that the formula has changed over the years: high-fructose corn syrup has replaced sugar, and there have been many adjustments to the other ingredients.

Another advantage of trade secrets is that they apply to things that would not be eligible for patent or copyright protection. Most recipes fall into that category.

Critics point out that many companies use their "secret" formula primarily as marketing hype. Although they do keep the formula secret, it is unlikely that disclosing that formula would dramatically change the company's sales. This is particularly true now that the tools of modern analytical chemistry make it easier than ever to reverse engineer a formula or recipe.

There is little doubt that the Colonel's 11 herbs and spices could be identified and quantified by any competitor who spent enough time in the lab. Indeed, the Internet is rife with people's best guesses about secret recipes and formulas. A recent product called OpenCola even promotes itself on the basis of having a published, open-source recipe.

Despite the limitations, large food companies do engage in legal fights over trade secrets. Bimbo Bakeries USA, the makers of Thomas' English Muffins, filed a lawsuit in 2010 to block one of its executives from taking a job with Hostess Brands, a rival commercial baked-goods company. In a court brief, Bimbo's lawyers argued that at Hostess, the executive "could produce an English muffin that might look a bit different, but that would nevertheless possess the distinctive taste, texture, and flavor character that ... have been the foundation of the product's success."

Most serious chefs don't see much value in secrets and have a tradition of being open with their recipes. They know that it is hard to keep secrets, with sous chefs and *stagiers* coming and going. Modernist chefs, in particular, tend to be quite willing to share what they have learned with others. Gaining credit as an innovator makes more sense than trying to keep secrets. That philosophy doesn't apply to some areas of cooking, which are steeped in secrecy–for example, chili or barbecue in the American South, bouillabaisse in Marseille, or cassoulet in southwestern France. With these foods, it's typical to find people jealously guarding their secret recipes.

are quite mundane; warehouses, office buildings, shopping malls, and homes all need to exist for very prosaic reasons. Yet architecture can also be an exhilarating art form. The work of architects like Frank Gehry, Renzo Piano, Santiago Calatrava, and Tadao Ando (to name just a few) can serve both artistic and functional purposes. They are works of high art that also give us shelter.

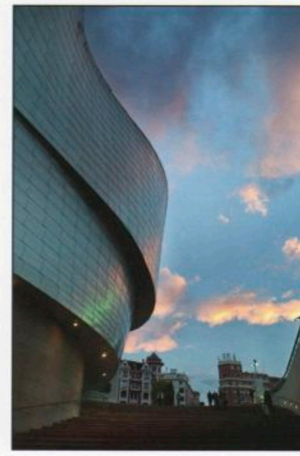
Yet the styles of the great masters of architecture are in no way the same. A museum or bridge by Calatrava is instantly recognizable to anyone who has even a passing familiarity with his work. Gehry or Piano, if given the same commission, would create totally different structures. We see these distinctions in competitions, where many architects present proposals for a major new building.

Of course, most of the world's buildings weren't created by famous architects—cutting-edge architects only design a tiny fraction of them. Many architects don't aspire to artistry; others do, but they have a traditional aesthetic that does not push the boundaries. Most buildings are still constructed in a very traditional style.

In the same way, most food isn't meant to be high art. It is made to satisfy people's hunger and, one hopes, to give a bit of pleasure along the way. Chefs on the line at a steak house and short-order cooks at a diner serve an important role in society, much like the architects who design buildings that are not at the cutting edge of architecture, but still serve a functional purpose.

Food can also be high art. Some of that can be art that falls within a traditional culinary aesthetic, but the scope of art is much broader than that.

The Modernist revolution is perhaps the purest expression of food as art. Stripped of rules and conventions, and with dishes that provoke thought and engage the diner in a culinary dialogue, Modernist cuisine is the first major culinary movement that self-consciously sets out to be art. Much like great architecture, Modernist food generally isn't for everyday consumption, and because it is intellectually demanding, it may not be for everyone. Like many artistic movements, Modernist cuisine has a theoretical framework for achieving its goals. And when it succeeds, it does so magnificently, creating dining experiences that could not exist in any other way.



Extreme architecture, like Frank Gehry's magnificent Guggenheim Museum Bilbao coexists with far more conventional and traditional buildings around it.

Further Reading

For a list of cookbooks by chefs mentioned in the chapter, see the further reading list near the end of volume 5, on page 5·II.

Barham, P. *The Science of Cooking.* Springer, 2001.

Blumenthal, H. *Family Food.* Penguin Global, 2006.

Brillat-Savarin, J. A. *Physiologie du Goût.* Echo Library, 2008.

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Daguin, A. *Le Nouveau Cuisinier Gascon.* Stock, 1981.

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Fernandez-Armesto, F. *Near a Thousand Tables: A History of Food.* Free Press, 2003.

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Kamozawa, A., Talbot, A. H. *Ideas in Food: Great Recipes and Why They Work.* Clarkson Potter, 2010.

Marshall, A. *Fancy Ices.* Marshall's School of Cookery, 1885.

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Montagne, P. *Larousse Gastronomique.* Crown Publishers, 1961.

Pegge, S. *The Forme of Cury.* BiblioBazaar, 2006.

Poggioli, R. *The Theory of the Avant-Garde.* Harvard University Press, 1981.

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Sokolov, R. *Why We Eat What We Eat: How Columbus Changed the Way the World Eats.* Touchstone, 1993.

Steingarten, J. *The Man Who Ate Everything.* Vintage, 1998.

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This, H. *Cooking: The Quintessential Art.* University of California Press, 2010.

This, H. *Kitchen Mysteries: Revealing the Science of Cooking.* Columbia University Press, 2007.

This, H. *The Science of the Oven.* Columbia University Press, 2009.

Varenne, F. *La Varenne's Cookery.* Prospect Books, 2006.

Wrangham, R. *Catching Fire: How Cooking Made Us Human.* Basic Books, 2010.

Timeline of Modernist Recipes and Techniques

The trajectory of Modernist cuisine is arguably best captured by the innovative dishes it has produced. The culinary chronology below is a time-ordered table of contents of the key milestones covered in this book. For each recipe, the initials of the inspirational chef or inventor are given (see the key below), as well as a general indication of the ingredient or technique that was used in a new way. Page references to the recipe or procedure are also given, in brackets. The list also includes a small selection of seminal achievements that are not illustrated by recipes or step-by-step procedures appearing in the book.

KEY TO THE CHEFS AND INVENTORS:

AA	Adoni Luis Aduriz
AD	André Daguin
AK, AT	Aki Kamozawa and H. Alexander Talbot
AM	Ambrose McGluckian
CC	Carlo Cracco
DA	Dave Arnold
DC	David Chang
DK	David Kinch
DP	Daniel Patterson
FA	Ferran Adrià
GA	Grant Achatz
GP	Georges Pralus
HB	Heston Blumenthal
HC	Homaro Cantu
HT	Hervé This
JA	José Andrés
JC	Jordi Cruz
JFP	Jean-François Piège
JGV	Jean-Georges Vongerichten
JI	Johhny Iuzzini
JMA	Juan Mari Arzak
JR	Joan Roca
MB	Michel Bras
MC	Modernist Cuisine Team
ML	Michael Laiskonis
MSR	Miguel Sanchez Romera
MT	Michel Troisgros
MV	Marc Veyrat
NM	Nathan Myhrvold
NN	Nils Norén
PB	Pascal Barbot
PG	Pierre Gagnaire
PL	Paul Liebrandt
QD	Quique Dacosta
RA	Rational AG
SB	Sean Brock
SHD	Sang-Hoon Degeimbre
TK	Thomas Keller
WD	Wylie Dufresne
WM	Wilhelm Maurere
WS	Winston Shelton

1970

AM: first sous vide in a restaurant [1·40]

1974

GP: sous vide foie gras terrine [3·176]

1976

AD: liquid-nitrogen ice cream [1·311]

RA: invention of combi oven [2·154]

Early 1980s

WM: invention of Pacojet [2·406]

WS: invention of Cvap [2·154]

1987

Green Asparagus and Morels with Asparagus Jus [2·341] ***JGV:*** juices

Spiced Chili Oil [2·330] ***JGV:*** oil infusion

1988

FA: aromatic oils [2·328]

1989

FA: plated soups [1·52]

1990

FA: juices [2·332]

Salmon Tartare in Cornets [3·68] ***TK:*** salmon tartare in ice cream cone

1991

FA: infusions [2·310], service on a skewer

Smoked Pasta [3·362] ***NM:*** smoked pasta

1992

FA: cold jelly as a sauce [4·140], herb jus, nut milk [4·59], service on a spoon

1993

Parmesan Water [2·310] ***FA:*** cheese infusion

1994

FA: clear vegetable juice [2·350], ham consomme [4·48], herb water [2·310], liquid ravioli

Corn Foam [4·273] ***FA:*** first savory cold espuma

1995

FA: deconstruction [1·37]

NM: Pacojet savory ice creams [2·406]

Chocolate Chantilly [4·281] ***HT:*** whipped chocolate

1996

FA: egg yolk as sauce [4·180], squeeze bottle

Pacojet Pea Soup [2·410] ***NM:*** Pacojet soup

1997

FA: coal oil [2·328]

HB, JR: sous vide cooking [2·192]

1998

HB: crab ice cream

Blood Orange Foam [4·272] ***FA:*** gelatin-stabilized espuma

FA: hot espuma [4·283], hot jelly as a sauce, agar [4·160], puffed grains and cereals [4·307], tomato water [2·366]

1999

FA: frozen Pacojet powder [1·54], [2·406]

Agar Carbonara [4·160] ***FA:*** hot agar noodles

Tomato Powder [3·312] ***TK:*** microwave dehydration

2000

QD: edible landscapes [1·74]

Squid Ink Bean Sprout Risotto [3·397] ***FA:*** faux risotto

Foie Gras Soup with Bomba Rice and Sea Lettuce [3·151] ***AA:*** foie gras cooking

Soy Sauce Sponge [4·299] ***FA:*** gelatin set foam

Hot Egg Mayonnaise [4·227] ***FA:*** hot siphoned emulsion

FA: Microplane grater [3·388], microwave oven [2·182], solid sauce [4·140]

Egg Blossom [4·80] ***JMA:*** molded poached egg

HB: popping candy

2001

GA: Black Truffle Explosion

DP: essential oils [2·325]

Passion Fruit Jelly [4·180] ***HB:*** gelatin fluid gel

HB: gellan

FA: ice sheets

Green Tea Sour [4·291] ***HB:*** liquid-nitrogen set foam, tableside

JR: smoked fat [3·362]

FA: soda siphon [2·468]

2002

HT: 65 °C egg [4·78]

Corn Custard [4·122] ***DK:*** cornstarch gel

Topic

Name of recipe or procedure — Volume and page number — Initials of the chef or inventor

FA: coal oil [2·328]

Initials of the chef or inventor — Topic — Volume and page number

Molasses Butter [2·331] ***MB:*** butter infusion

Corn Custard [4·122] ***DK:*** cornstarch gel

HB: essential oils [2·325]

Lemon Strips [4·61] ***HB:*** flavored film

HT: foie gras chantilly [4·281]

Quinoa and Idiazabal with Bonito Stock Veil [4·168] ***AA:*** gel veils

Soft-Boiled Egg and Garlic Emulsion [4·227] ***MB:*** poached egg emulsion

How to Triple-Cook Chips [3·322] ***HB:*** vacuum drying

2003

HB: Activa, Mackerel Invertebrate [3·250]

Oyster with Mignonette Foam [4·265] ***FA:*** airs as sauces, soy lecithin

GA: aromatic utensil [1·74]

Melon Caviar [4·189] ***FA:*** basic spherification

JR: blown-sugar spheres

Hot Butter Foam [4·283] ***FA:*** butter siphon foam

Green Olive Meringue [4·298] ***PG:*** constructed meringue, vacuum oven

FA: cotton candy machine [1·54], dehydrator [2·434], milk skin [4·114]

WD: foie gras with liquid center [1·54]

Salmon Poached in Licorice [4·155] ***HB:*** gellan coating gel

Truffle Jus [4·53] ***MV:*** konjac gum

Sweet Pea Clusters [4·173] ***FA, AA:*** Methocel binding

Instant Tofu Noodles [4·172] ***WD:*** Methocel noodles

Black Sesame Rice Crisps [4·304] ***FA:*** puffed rice chips

Mushroom and Bacon Cappuccino [4·275] ***MV:*** siphon agar fluid gel foam

Honey Glass [5·123] ***FA:*** sugar, isomalt glass

Cappucino Foam [4·266] ***FA:*** Texlavazza foam

Two-meter Parmesan Spaghetto [4·143] ***FA:*** tube molding

2004

FA: centrifuge [2·362], teppan-nitro (liquid nitrogen plancha) [3·124]

Lemon egg yolk fluid gel [4·180] ***NM:*** egg fluid gels

GA: gelation inside water balloon to create a sphere [4·135]

WD: gellan [4·42]

NM: hot gellan cauliflower foam [5·283], hot whipped cream [4·278], Jaccarded meat juicier [2·50]

Crimini in Amber [4·154] ***FA,*** **Popcorn Pudding** [4·181] ***WD:*** kappa carrageenan

Mozzarella Balloons [4·110] ***GA:*** siphon, mozzarella curd

Microwaved Pistachio Sponge Cake [4·294] ***FA:*** siphon, microwave

Smoked Octopus [3·214] ***JR:*** smoke gun

How to Vacuum Compress [3·390] ***TK:*** vacuum compression

2005

Beet Meringue [4·295] ***FA:*** albumin set foam

GA: Anti-Griddle [3·124], edible table centerpiece [1·74]

Fizzy Grape Fluid Gel [4·183] ***HB:*** carbonated gellan fluid gel

HB: centrifuge [2·362]

Steamed Blanc Manger [4·296] ***JFP:*** combi oven

Bacon Chip with Butterscotch, Apple and Thyme [3·191] ***GA:*** dehydrator, suspended serving dish

Olive Oil Noodles [4·146] ***JC:*** emulsion gel

FA: freeze-dried products [2·444], pressure-cooked nuts [5·65]

Freeze-dried Carrot Foam [4·300] ***FA:*** freeze-dried set foam

How to Filter with Gelatin Ice [2·370] ***HB, WD***: gelatin clarification

Hot and Cold Tea [4·182] ***HB:*** gellan fluid gel

"Sunny-side Up" Egg [4·148] ***WD:*** gelling agent blend

Ferran Adrià's Melon Caviar

Dungeness Crab and Peach Roulade [4·169] ***FA:*** high-acyl gellan and agar veil

NM: hyperdecanting [4·344]

Clay Potatoes [3·398] ***AA:*** kaolin clay coating

Microwave Fried Parsley [3·312] ***HB:*** microwave

WD: modified starch [4·30]

Bacon Powder [4·34] ***GA:*** N-Zorbit M compressed powder

Vanilla Olive Oil Powder [4·35] ***GA:*** N-Zorbit M powder

Pineapple Glass [3·370] ***GA:*** Pure Cote B790 film

Liquid Pimento Olive [4·193] ***FA:*** reverse spherification

JR: rotary evaporator [2·384]

Crispy Halibut Cheek [3·334] ***HB:*** siphon batter

Suckling Pig Shoulder with Shallots and Orange [3·110] ***JR:*** sous vide cooking

NM: sous vide time–temperature tables [2·276]

Mussels in Mussel Juice [4·191] ***FA:*** spherification with solids

Black Olive Puree [4·230] ***FA:*** sucrose esters and mono- and diglycerides

Aerated Chocolate [4·313] ***HB:*** vacuum set foam

Ham Consommé with Melon Beads [4·48] ***FA:*** xanthan gum suspension

Oyster with Cava Foam [4·277] ***JR:*** xanthan siphon foam

2006

NM: cold plunge does not stop cooking [2·254]

How to Make Bacon and Eggs in a Combi Oven [2·174] ***NM:*** combi oven, egg

FA: encapsulator (spray dryer) [2·438]

AK, AT: freeze-thaw "blanching" [3·374]

GA: frozen sauce sheet

Halibut in Verbena Bubble [4·156] ***MV:*** gel coating as cooking vessel

Edible Wrapper [4·62] ***HB:*** gelatin film

Idiazabal Gnocchi [4·123] ***AA:*** kuzu gel

Steamed Cod with Cod Roe Velouté [4·32] ***MSR:*** micri thickener

Corn Pebbles [4·36] ***WD:*** N-Zorbit M pebbles

Joan Roca's Oysters with Cava Foam

Parmesan Nuggets [4·35] ***FA:*** N-Zorbit M powder nuggets

Eggless Citrus Curd [4·234] ***PB:*** propylene glycol alginate curd

Sous Vide Rare Beef Jus [2·349] ***NM:*** rare beef jus

HC: shucking oysters with liquid nitrogen [2·459]

Uni with Whipped Tofu and Tapioca [4·285] ***DC:*** siphoned tofu foam

Hanger Steak Tartare [3·65] ***WD:*** sous vide tenderizing

Barbecued Eel with Whipped Caramel [4·283] ***WD:*** Versawhip foam

2007

Mozzarella Noodle [4·116] ***AK, AT:*** Activa YG noodles

Umami Seasoning Fluid Gel [4·183] ***GA:*** agar fluid gel

Bacon Dashi [2·308] ***DC:*** bacon infusion

Seafood Paper [3·190] ***CC:*** book of seafood paper, table side

Monkfish with Constructed Skin [3·132] ***AA:*** constructed skin

Eggs Benedict [4·86] ***GA:*** egg droplets

Honey Bubbles with Edible Soap Bar [4·266] ***AA:*** fish tank bubbler

Knot Foie [4·144] ***WD:*** flexible gel

Mackerel with Spicy Tomato Skin [4·175] ***HB:*** Methocel skin

Cheese Puffs [4·305] ***WD:*** modified starch puffed snack

Gruyère Spheres [4·190] ***WD:*** pectin spherification

DP: poached scrambled eggs [4·93]

HT: salt crystals in oil [1·330]

HB: sound of the sea [1·74]

2008

Edamame Sheets, King Crab, Cinnamon Dashi [4·118] ***WD:*** Activa RM pasta

Goat Cheese Dumpling [4·119] ***AK, AT:*** Activa YG dumpling

Foie Gras Torchon with Beet and Hibiscus Glaze [4·158] ***PL:*** agar gel coating

Beet Juice-Fed Oysters [3·206] ***NN, DA:*** aquarium salt

Crispy Beef Salad [3·184] ***MC:*** beef jerky strands, deep fried

Carbonated Mojito Spheres [4·188] ***JA:*** carbonated spherification

Centrifuged Carotene Butter [2·365] ***MC:*** centrifuge, butter infusion

Hazelnut Cream [4·236] ***MC:*** constructed cream

Sea Urchin Bottarga [3·186] ***MC:*** cured sea urchin

JR: extraction of essential oils [2·388]

Beet Flexicurd [4·219] ***JI:*** flexible emulsion gel

Freeze-dried Beef Gravy Granules [2·454] ***FA:*** freeze-dried essences [2·444]

Freeze-dried Lobster [2·454], **Freeze-dried Onion Powder** [3·373] ***MC:*** freeze dryer

Deep-fried Hollandaise [4·228] ***WD:*** fried emulsion gel

Chili Pearls [4·145] ***ML:*** gel beads in oil

Heat-Stable Beurre Blanc [4·219] ***MC:*** heat stable emulsion

Crispy Cream Cheese [4·63] ***WD:*** Methocel crisps

Liquid Pimento Olive [4·193] ***FA:*** molded spherification [4·193]

Onion Rings [3·342] ***MC:*** Methocel, tapioca starch

Shaved Frozen Foie Gras [3·177] ***DC:*** Microplane

Frozen White Truffle [3·400] ***QD:*** mimicry, mannitol, liquid nitrogen

Almond Polenta [4·36] ***WD:*** N-Zorbit M polenta

Compressed Melon Terrine [3·392] ***AK, AT:*** pectin and calcium lactate, vacuum impregnation

Cocoa Nib Curd [4·105] ***MT:*** rennet

Egg Salad Sandwich [4·90] ***WD:*** sous vide molding

Chorizo French Toast [4·98] ***MC:*** vacuum chamber impregnation

Prune Coals [4·314] ***MC:*** vacuum-set sugar-glass foam

Watermelon Meat [3·394] ***AA:*** watermelon, vacuum compression

2009

How to Clarify Liquids with Agar [2·372] ***AK, AT, DA, NN:*** agar clarification

Salt Gel [5·9] ***MC:*** agar seasoning gel

Autoclave Onion Soup [3·302] ***MC:*** autoclave

Lychee and Lime Soda [4·268] ***SHD:*** baking-soda effervescence

Pressure-Cooked Egg Toast [4·97] ***NN, DA:*** baking soda, egg yolk, pressure cooker

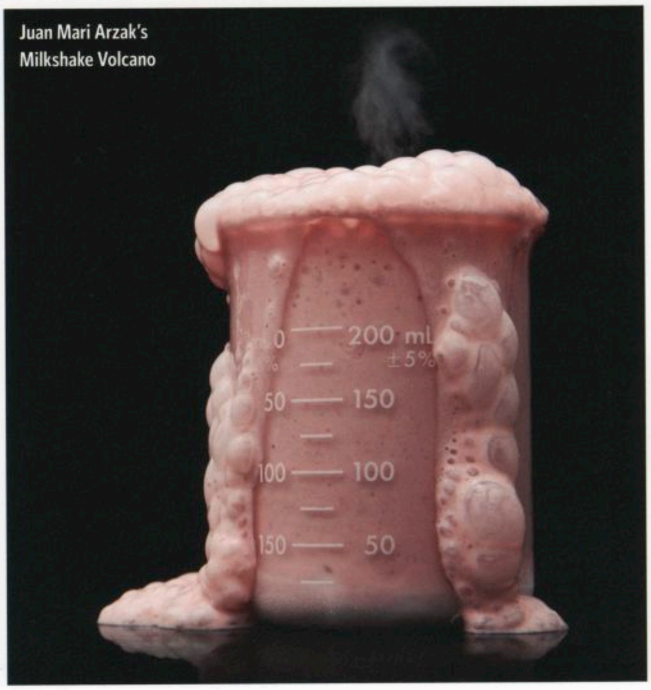
Fossilized Salsify Branch [3·399] ***AA:*** calcium hydroxide

Centrifuged Roasted Hazelnut Oil [2·367] ***NN, DA:*** centrifuge

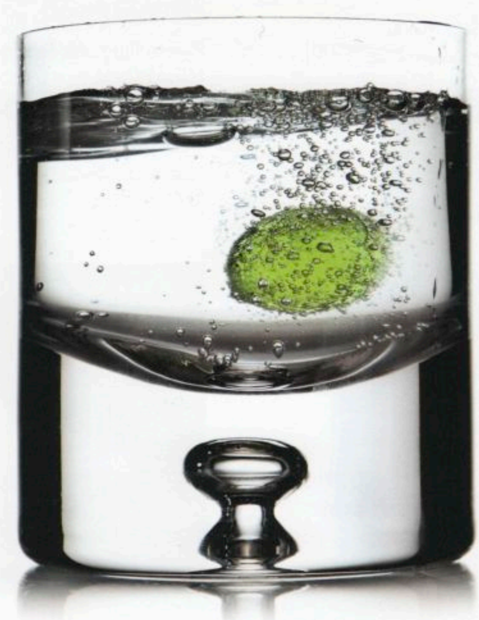
American Cheese Slice [4·224] ***MC:*** cheese, melting salts and gelling agents

GA: chocolate menthol coconut (served on silicone tablecloth) [1·74]

Juan Mari Arzak's Milkshake Volcano



José Andrés's Carbonated Mojito Sphere



Parmesan Polenta [4·181]
NN, DA: coarse gellan fluid gel

Foie Gras Cherries [4·152]
MC: complex gel formula coating

Strawberry Milk Shake [2·473]
JMA: dry-ice bubbles

How to Ripen on Command [3·285]
MC: ethylene gas, sous vide

House Barbecue Sauce [4·49]
MC: freeze-dried tomato thickener

Scallop Mochi [4·308] ***MC:*** freeze-dried scallop powder

Chestnut Puffs [5·20] ***MC:*** gelatin, konjac gum, iota carrageenan, whipping siphon

Mock Turtle Soup [2·394] ***HB:*** Genevac rocket

AK, AT: hot spring eggs for 13 min at 75 °C [4·78], plastic wrap to "decork" Methocel [4·171]

How to Crysoshatter Meat [3·64]
MC: liquid nitrogen

Sean Brock Shrimp and Grits [3·377]
SB: liquid nitrogen milling

Green Tea Cake [4·292] ***JI:*** Methocel, microwave sponge cake

Microwaved Beef Jerky [3·184]
MC: microwave jerky

Spinach Paper [3·369] ***MC:*** N-Zorbit M crisp

MC: Pacojet meat powder [3·62]

How to Puff the Skin on a Pork Roast [3·126] ***MC:*** pork skin, Methocel

Pasta Marinara [3·386]
AK, AT: presoaking

Broiled Tuna Belly with Montpellier Butter [4·220] ***MC:*** sodium caseinate, fluid melting butter

Coffee Butter [4·371] ***MC:*** sous vide infusion

Watermelon Chips [3·328] ***MC:*** starch impregnation

Black Truffle Concentrate [2·427]
MC: ultrasonic bath extraction

How to Make Stock Sous Vide [2·302]
MC: ultrasonic bath, sous vide

Aerated Foie Gras [4·311]
JI, WD: vacuum set gel foam

Blown-Up Gruyère [4·312]
AK, AT: vacuum set gel foam, mason jar

2010

Chawanmushi [4·96] ***MC:*** Activa

DC: bacon katsuobushi

Constructed Red Wine Glaze [5·221]
MC: berry juice, tartaric acid, enocianin powder

Ham and Cheese Omelet [4·95]
MC: combi oven omelet

Jus de Roti [4·54] ***MC:*** constructed jus

Olive Oil Margarine [4·235]
MC: constructed oil spread

Dairy-free Whipped Cream [4·283]
MC: constructed whipped topping

Pistachio Gelato [4·236]
MC: constructed nut cream

Whipped Butter [4·286] ***MC:*** delta-decalactone, whipping siphon

Olive Oil Spread [4·51]
MC: deodorized cocoa butter

Striped Omelette [5·215]
MC: egg, pastry comb, combi oven

Eggless Mayonnaise [4·232]
MC: emulsifier blend

Everything Bagel Broth with Dill and Squid Ink [4·130] ***MC:*** gellan fluid gel suspension

Chicken Noodle Soup [4·238]
MC: gum arabic emulsion

Instant Crème Fraîche [4·57]
MC: lactic acid, carrageenan

How to Marinate with Nitrous Oxide [3·207] ***NN, DA:*** nitrous infusion

Frozen Cheddar Cheese Powder [2·411]
MC: Pacojet gel powder

Apple Consommé [2·377]
NN, DA: Pectinex Smash XXL juice clarification

Crispy Boiled Peanuts [3·303]
MC: pressure-cooked fried nuts

Modernist Béchamel [4·31]
AK, AT: pressure cooker, thickener blend

Invincible Vinaigrette [4·231], **Jus Gras** [4·237] ***MC:*** propylene glycol alginate

Gruyère Cheese Souffle [4·301]
MC: instant souffle

Soft Tofu [4·113] ***MC:*** soft tofu, glucono delta-lactone

Cauliflower Crème Anglaise [4·89]
MC: sous vide custard

Sous Vide Vegetable Jus [2·347]
MC: sous vide jus

Sous Vide Fish Stock [2·303] ***MC:*** sous vide stock

Bergamot Sabayon [4·274], **Instant Swiss Meringue** [4·284] ***MC:*** sous vide, whipping siphon

Tomato Spheres with Basil Oil [4·192]
MC: spherification, oil injection

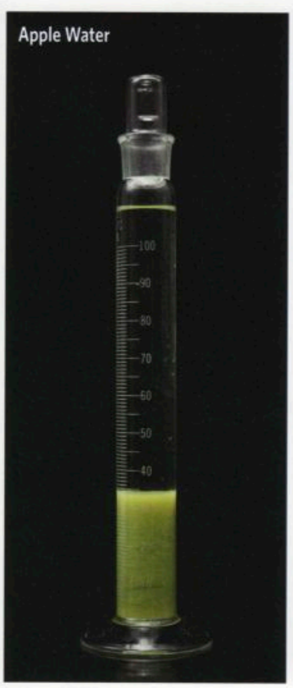
"Poached" Egg [4·195]
MC: spherification, plastic molding

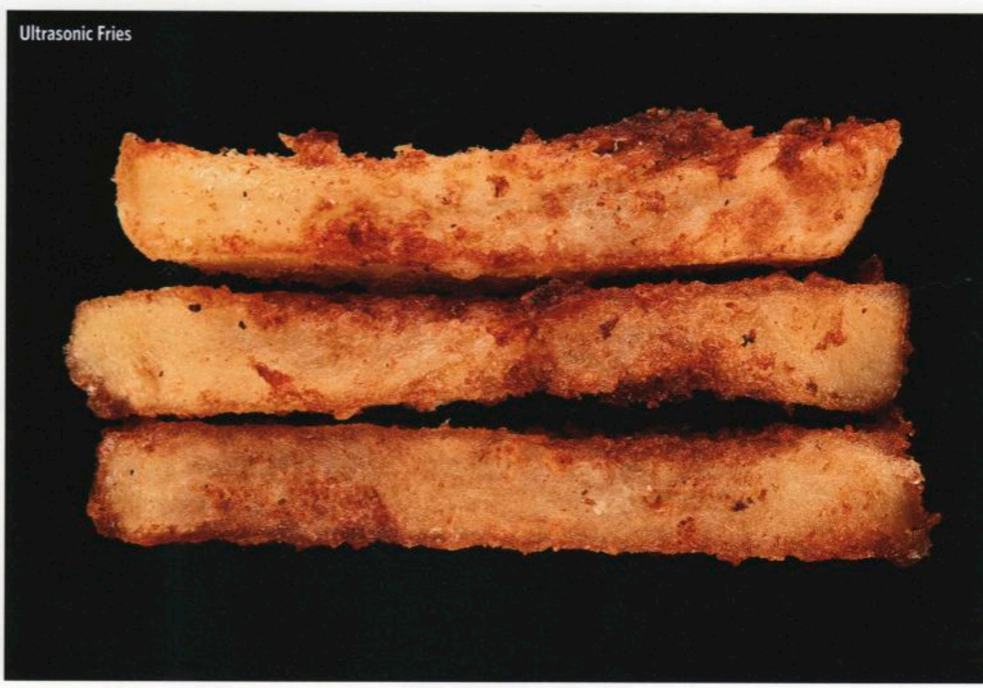
French Fry Variations [3·324]
MC: ultrasonic bath

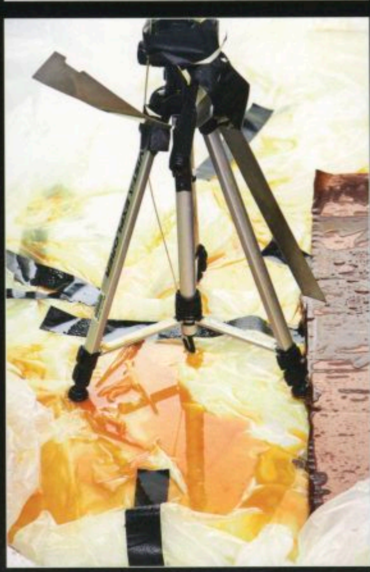
Hazelnut Oil Extract [2·321]
MC: vodka (or ethanol)

Mustard Vinaigrette [4·231]
MC: xanthan gum, polysorbate 80

MC: explaining the barbecue stall [3·211]


Apple Water


Ultrasonic Fries



THE STORY OF THIS BOOK

Browse any bookstore, online or brick-and-mortar, and you'll find a large selection of culinary reference books that offer step-by-step instructions for preparing classic French cuisine. Many of these books are wonderful, and we highly recommend a number of them for any cook's library. Unfortunately, although these texts often encompass Nouvelle and New International methods, they include few (if any) of the exciting new techniques that have been developed in the last 30 years.

Many Modernist chefs have written their own books, and these generally do a great job of elucidating aspects of each chef's personal culinary style. Chefs don't usually aspire to write a book that is more comprehensive than their own vision—after all, a chef operating a restaurant probably doesn't have the time to produce a lengthy reference text like those that exist for French cuisine. Chefs are too busy running their kitchens and creating new dishes.

In a sense, cookbook writers face similar barriers. Many of the greatest cookbooks are written by people who write for a living, like Paula Wolfert, Patricia Wells, Michael Ruhlman, Mark Bittman, James Peterson, Wayne Gisslen, and dozens of others. Authors such as these tend not to write large-scale reference books, which require large staffs working full-time for a matter of years. For context, consider that the production of these five volumes required the combined efforts of several dozen people over the span of three years. That level of effort is the norm for a major reference work or college textbook. Resources on this scale are generally not available to independent food writers, however.

Of course, Julia Child is one notable exception to this rule, but she had two coauthors, and even then, they undertook an arduous nine-year journey to the publication of *Mastering the Art of French Cooking*. In addition, Child's masterpiece was mostly text—it originally contained no photos and only minimal illustrations. That kind of book worked in 1961, but it wouldn't be competitive in today's market, where numerous visual elements are expected in a book of this size. Child's story is a cautionary tale to writers who would attempt a book on a similar scale. Indeed, for people who write for a living, it makes more sense to publish less comprehensive, more specialized cookbooks on a regular basis.

Who, then, would spend the time, energy, and money to create a large-scale culinary reference book? Certainly not mainstream publishers, because such a book would be extremely expensive to produce and would not have any proven market. Who would be foolhardy enough to step forward? We decided it would be us.

The origins of this book date back to 2004, when I started exploring and explaining sous vide cuisine in eGullet's online forums (see page 59). As a result of that experience, I resolved to write a book on sous vide. At the time, there was no book in English about the technique, and the only recent text on the subject was Joan Roca's excellent *Sous Vide Cuisine,* which I struggled through in Spanish (before the English version came out and before Thomas Keller published his book *Under Pressure: Cooking Sous Vide*). There was clearly a need for a comprehensive book on sous vide in English, so I decided to write it.

But as I worked on the book, I kept seeing reasons to expand its scope. Food safety is intricately linked to sous vide; misunderstandings about the safety of the method have long prevented its widespread adoption. So, with the help of several research assistants, I dug into the scientific literature and discovered that much of what chefs are told about food safety is wrong. Mostly it is wrong in a way that ruins the taste of food without providing any meaningful improvement in safety. Sometimes it is wrong in the other direction, producing results that could be unsafe. It became clear to me that cooks need some guidance.

This idea was driven home when the chef Sean Brock contacted me for help convincing his local food inspector that it would be safe to serve food prepared sous vide at his restaurant, McCrady's, in Charleston, South Carolina. A few days later, the local food inspector also contacted me. He was fascinated by the data I passed along to Brock and wanted to learn more. Brock got approval to go ahead, and I resolved that my book would cover microbiology and food safety as well as the core aspects of sous vide techniques.

For references to recommended culinary books, including books by Modernist chefs, see the Further Reading section near the end of volume 5.

The creation of this book required years of effort by a large team. Most of the photography, research, and recipe development and testing took place in the team's kitchen laboratory in Bellevue, Washington. Scenes shown on the previous page include (clockwise from top left) coauthor and head chef Maxime Bilet tossing stir fry for the photo on page 2·50, instrument maker Ted Ellis sawing equipment in half for a cutaway image, chef Grant Crilly arranging sausage for a cutaway image of a grill (see page 2·14), author Nathan Myhrvold adjusting a rotary evaporator, Maxime arranging up a plate-up for a photo shoot, Grant getting splattered while running an immersion blender upside-down to get a dramatic picture, researcher Christina Miller mixing it up, the photo studio floor after one especially messy shoot (see page 4·196), chef Johnny Zhu putting the final touches on a tilapia (see page 2·189), and coauthor Chris Young working with Grant and chef Sam Fahey-Burke to prepare a pig for cooking sous vide—whole.

Throughout the book, we use cutaway images to communicate the science of cooking in an accessible way. Here, we cut a Weber grill (and a couple of hamburgers) in half for our annotated explanation of grilling on page 2·7.

Next, inspired by the questions that people had posted in the eGullet thread on sous vide, I decided that my book would also include information about the basic physics of heat and water. Chefs hailing from many of the best kitchens in the world, as well as amateurs of all sorts, had questions about heat transfer.

When making traditional cuisine, you don't need to understand precisely how heat moves into and through food—you just need to know that you turn the burner to medium-high, for example, or set the oven to 175 °C / 350 °F and roast your food until it's golden brown. Unfortunately, this approach gives you little intuition that's any help when you try to use a technique like sous vide, in which a more precise knowledge of the heating process is required to achieve consistently good results. For the most part, experience from conventional cooking does not apply.

But this raised a question: wouldn't people like to understand how traditional cooking actually works? Aside from its intrinsic interest, the science of cooking would also help chefs apply Modernist techniques. Before long, I was sliding down a slippery slope toward a book of epic proportions. Why not add a section on hydrocolloids? What about foams? At that stage, my ideas were more daydreams than practical reality, so it was easy to convince myself that it all made sense.

How could such a technical book be made accessible to readers? I decided that photography—another passion of mine—could make the difference by presenting technical concepts in a highly visual manner. My hope was that seductively beautiful and clear photos would both draw readers in and provide a clear demonstration of what the text told them. This decision made the book much more challenging to create but also that much more compelling if it was successful.

What I wound up with was what you see now, a multivolume book with three main goals: to explain key aspects of food science in a new way; to show how traditional cooking really works; and to provide detailed, step-by-step photos and instructions for every major technique and ingredient in Modernist cooking. A saner man might have treated that as three distinct projects, but to me they seem to hang together as a unit.

This account of the book's history has been written in the first person singular, because in the beginning it was just me, Nathan. But it couldn't become a reality until I had a team. I had been very lucky to have met Chris Young at The Fat Duck (see page 49), and when I heard he was moving back to the U.S., I jumped at the chance to hire him for the project.

Chris quickly recruited Maxime Bilet, another Fat Duck alumnus, as head chef, and from there we were off. Initially, I had planned to take all of the photos myself. Ryan Matthew Smith joined the team as digital photo editor and photo assistant. Soon Ryan was taking most of the pictures, and we hired an assistant for him (Melissa Lehuta).

At first, the work was done in my home kitchen, but soon we decided to move to part of a science laboratory and invention workshop that my company was building. This allowed us to work all hours of the day and night, which we promptly proceeded to do.

In those early days, very little of our work was devoted to developing recipes. In most cookbooks, recipes make up 90% or more of the content—but that is possible only because almost all of the techniques and equipment discussed in such books are old hat. People know what sauté pans and ovens are, so writers don't need to spend pages describing these tools. But people may not have the same basic knowledge about combi ovens, water baths, or freeze dryers, so we knew we had to explain what they are and, more important, to discuss why you'd use them. As a result, this book devotes more pages to discussing new tools and technologies than a traditional book does; recipes make up a much smaller fraction of our text. Indeed, we had not planned initially on including recipes at all. Over time, however, we decided that we needed to provide some recipes as examples, since theory alone would be too hard to apply.

But then we got carried away. We developed not only small examples but also numerous plated dishes. The style of these dishes is eclectic, and that is a deliberate choice. The goal of most cookbooks is either to showcase a chef's personal style or to explore a certain type of cuisine (Korean, New American, vegetarian, etc.). In contrast, our goal is to showcase the techniques and technologies of Modernist cuisine across all of their potential applications.

As a result, there is no single style represented in this book. We explain how to use Modernist techniques to create the ultimate cheeseburger (see page 5·11), sunny-side up egg (see page 2·174), and Indian curries (see page 5·89). But we also discuss highly technical dishes and processes, such as constructed creams (see page 4·236), reverse spherification (see page 4·186), and spray-drying (see page 2·438). Many of the leaders of the Modernist movement were kind enough to give us recipes to use as examples. In some cases we developed our own examples using the work of other chefs as an inspiration or point of departure.

These volumes are dedicated to the Modernist revolution in cuisine discussed in this chapter, but many readers will be more traditionally minded. That's fine—our mission is to teach techniques, not proselytize for Modernism. People interested in traditional food will still find much here of value. We explain how traditional techniques work in chapter 7, and we have many recipes and techniques that involve purely traditional ingredients. Want to make perfect omelets for a crowd? See page 5·215. Would you like to make your own tofu or mozzarella? Check out page 4·110.

For traditional chefs who are ready to take a walk on the wild side and experiment with some new ingredients, we have recipes for an invincible beurre blanc that can be made ahead of time and held without coagulating (page 4·200), a meringue that can be made to order with a whipping siphon (page 4·284), and a perfect risotto that can either be made largely ahead of time or prepared rapidly in a pressure cooker (page 3·304).

This book, in five volumes plus a kitchen manual, is enormous by nearly any standard. Yet I am certain that there will be people who think we left something out. I am sure that we have! There is no way, even in books of this size, to cover every issue, or even every important issue. If your favorite technique, ingredient, or recipe is not covered, I apologize. We'll try to do better next time.

One omission is deliberate: we have no treatment of pastry, dessert, or baked goods. We expect to cover these topics in the future, but we had to draw the line somewhere, so we limited ourselves to savory cuisine.

Conversely, there will be people who argue we have put in too much. Indeed, a chef friend asked me, "Do you really *need* all that material in there?" My answer was to throw the question back at him: "Tell me, do you really *need* that many courses on your tasting menu?" The point is, what does *need* have to do with any of this? High-end cooking is about delighting both the chef and the diner; it's not about delivering the minimum daily requirements of nutrition. Similarly, books like these are meant to provide far more than the basics of culinary technique.

A strange phenomenon seems to occur when many top chefs publish books. These chefs have made their reputations by refusing to make compromises with their food, yet for their cookbooks they choose paper that isn't terribly nice, with limited photos and relatively low-quality printing. The recipes are often dumbed down and oversimplified. The no-compromise chef winds up with a book that has compromises on every page. How can that make sense?

Often the reason this happens is that publishing executives tell chefs they have to compromise, and the chefs believe them. That's because publishers want to make low-end to midrange books; they think these are what will sell best.

Maybe the publishers are right, but one has to wonder—it's like saying that cheap restaurants are more popular. The publisher is trying to make a book that is analogous to McDonald's or, at best, to a steakhouse chain. If publishers suggested that the chef change her restaurant in the same way—aim for lower quality, drop prices, eliminate expensive ingredients—they'd get thrown out on their ears.

Rightly or wrongly, we have taken the no-compromise approach with this book, believing that if we create something we love and are proud of, at least some people will value it the way we do. Maybe we're making a big mistake, but only time will tell.

Our book has plenty of extras, such as historical information, which isn't necessary in a strict sense. This information is like a garnish on the plate—it adds something of interest to the dish even if it isn't the primary focus. Yes, you can serve food without a garnish, and we could have omitted the history to make the work a bit smaller, but as you can clearly see, smaller was not high on our list of goals.

Indeed, the size of this book, the number of pictures it contains, and the labor that went into it, force it to carry a high price tag—at least compared to other books. Unfortunately, most people have been trained to expect books to be very cheap, and this colors how they view the price of a book.

But look at it this way: this book is likely to cost about as much as dinner for two at a top restaurant. At the very best restaurants, its price would probably only cover the food, without wine, tip, or tax; for restaurants that are a little less expensive, that price might buy dinner for four.

To me, that doesn't sound like a bad value. After all, by the next morning, dinner is just a fond memory. Don't get me wrong; I love dinner at a great restaurant. But like a concert or a play, it lasts only so long. Its most enduring legacy is probably a bit of weight gain, as in the old saying: "a minute on the lips, a lifetime on the hips."

This book, in contrast, teaches techniques that can be used to make an enormous variety of different recipes and dishes. You can refer to it again and again for years. (Indeed, it may take you years to get through it.) Why isn't the knowledge and information in it just as valuable as the transitory (albeit wonderful) experience of dining once in a great restaurant?

Continuing with the restaurant analogy, if all you are used to paying for is a McDonald's Extra Value Meal, then a night at Per Se or L'Arpège seems extremely pricey. Because publishers so often end up compromising quality to hit a price point, most cookbooks are priced somewhere between the Extra Value Meal and dinner at a midrange restaurant chain. Most cookbooks published in the U.S. cost from $15 to $40, with a few at $50 and virtually none over $75.

The perception in the publishing world is that the market won't support anything more expensive, but that is largely a self-fulfilling prophecy. It's like surveying restaurants and saying, "Look, most establishments are fast-food joints or strip-mall diners; therefore, nothing else is possible."

That pricing philosophy is perfectly appropriate for publishers and authors who truly embrace it. We decided that we could not create the book we wanted on that kind of budget—just as Per Se and L'Arpège have decided that to achieve the level of quality they are interested in, they need to charge more than McDonald's or the strip-mall diner.

Another criticism people may have of this book is that the material is too complicated for readers to understand. We made a rule that we wouldn't dumb down the content. We have tried to make the text as easy to understand as possible, and we have gone to great lengths to illustrate the content with photos and to lay out the key information in an accessible and engaging way. We hope you'll agree. Of course, you can always skip the science and go right to the step-by-step techniques and recipes. We have tried to make the material self-contained enough that you can either take the full-Monty approach and learn it all or cherry-pick the techniques you want to use.

The no-dumbing-down rule means that some techniques shown in this book require equipment not found in the average kitchen. Indeed, no restaurant in the world owns the full set of tools and technologies we show; there are few kitchens in the world other than research laboratories that would have all the equipment to make everything.

We chose to cover this specialized equipment for two reasons. First, there are plenty of other techniques and recipes that can be done without a centrifuge, freeze dryer, spray dryer, or other exotic gadget. Second, we think that people are curious about how these tools work and will enjoy learning about them, even if they don't have them at home.

You might wonder whether this book is meant for professional chefs or for home chefs. My reply is, *I am a home chef!* And yes, I have used almost all of the techniques we discuss in my home kitchen at one point or another. Admittedly, mine is a rather special home kitchen, but many of our recipes can be used with little or no unusual equipment.

The word "amateur" comes from the Latin root *amare,* which means to love. Amateurs cook for the love of food and the process of preparing it, but the truth is that most professional chefs also cook for the love of it. Anyone who loves food will find much to like in this book, regardless of whether or not they cook for a living. We pull no punches in explaining how to create both high-end and highly

Photographer Ryan Matthew Smith with a fiber optics strobe light used to light some of the pictures in the book.

The photography for Modernist Cuisine left us with a boneyard of cutaway tools.

technical food. But we are confident that home chefs will be able to execute the majority of the techniques and recipes in this book.

The Photographs

There are about 3,700 color photographs in the book. We took over 140,000 of our own shots to generate these. We also used photography from other sources.

One of the founding principles of this book is our decision to use graphics and photography to make the technical processes of food preparation approachable and understandable, and maybe even intriguing and compelling. Most existing books about the science of cooking are based on text and diagrams; we wanted a book that was far more visual.

That's tricky, because some important food-science concepts are not easy to visualize. A key development was the idea of the cutaway photo that would show what was happening inside food as it cooked. Initially I thought of doing it with illustrations, but that would lack the sense of verisimilitude that would draw people in. The cutaways had to be photos to show what was happening and make it seem real.

We have 36 annotated cutaway photos in the book.

So we cut stuff in half. An abrasive water jet cutter, an electrical discharge machining system, and other machine-shop tools let us cut apart our pots, pans, and other gear. Food was cut in various ways, including with meat-cutting band saws.

The cutaway photos are all real. We arranged food in our cut-in-half equipment and then took the pictures. In most cases, the food really is being cooked as shown or was cooked in an identical uncut pan, then swapped in. The pad thai shown on page 2·50 is cooked in a cutaway wok (with about one-third of one side removed so the pan could still hold some oil), which is sitting on a wok burner that is also partially cut away (but with enough left to burn gas).

It turns out there is a reason people don't cut their woks like this! We had problems with oil falling into the burner and the whole thing catching fire, so it was a bit dangerous and very messy. But the picture really is a shot of what it looks like to stir-fry noodles in a wok that's been cut apart.

In a few cases, we couldn't actually cook in the cutaway—for example, the whipping siphon shown on page 4·261, the pressure canner on page 2·90, and the microwave oven on page 2·186 couldn't function after we bisected them.

A technique we used to create many of the cutaways was to glue a piece of heat-resistant borosilicate glass to a cut pot with silicone caulking. Then we digitally edited the image to remove evidence of the caulking and the glass. It's somewhat like the technique used in Hollywood movies to make people look like they're soaring through the air: film them "flying" while supported by wires, then digitally remove the wires.

Creating cutaways to illustrate the process of deep-frying was a particular challenge. We built a special frying tank out of Pyrex borosilicate glass so we could photograph food as it was fried. Twice we burned up or shattered the tank, but ultimately we were able to get the shots (see page 2·118).

We often created composite shots by editing multiple images together. For example, when making the photo of hamburgers sizzling on a cutaway grill, Ryan had difficulty finding a photographic exposure to capture the coals and the meat simultaneously; camera sensors capture a far smaller range of brightness than human eyes do. So for each image of this kind, we took multiple shots with different exposures and combined parts of them together to make the final image.

In other cases, we did this using a technique called high-dynamic-range imaging, but in most cases we created the composites directly in software. As a result, purists will argue, each of these is a "photo illustration" rather than a single photograph. That comes with the territory—a magical view that shows you what is happening inside a pressure cooker as if it were cut in half is technically not a pure photo, nor can it be. Nevertheless, the cutaway photos are as close to real as we could make them.

Aside from the cutaways, the other images are all real photos of real food. Food photography and styling are well-developed arts that often make appetizing photos by using tricks—like mixing up fake ice cream that won't melt, using plastic ice cubes instead of real ones, or faking a roast chicken by painting a browning compound on a nearly raw bird. We generally did not use these techniques in the book. Our goal was to show how cooking works, in as realistic a way as we could. In a few cases we did have to resort to some extra work to achieve the effects we wanted.

One of the questions we get is "Who was your food stylist?" The answer is, nobody. Or, alternatively, one could say that everyone on the team was a stylist. Part of the art of Modernist cooking is styling and presentation; we see it as an integral aspect of cooking this type of cuisine. We also want to focus more on the food than on the table settings, so our shots are generally made without plates or silverware in the frame.

We shot the photographs primarily with Canon digital cameras, including the EOS-1Ds Mark II, EOS-1Ds Mark III, and EOS 5D Mark II, outfitted with a variety of lenses. Broncolor studio flash units were used for most of the photos, with a variety of soft boxes or other light modifiers. We used Nikon microscopes for the microscopy shots, along with custom-made servomotors and computerized controls for taking shots with extensive depth of field. We also used a number of objective lenses and condensers, including bright field, dark field, differential interference contrast, and Hoffman modulation contrast.

For a few shots, we used a Vision Research Phantom V12 video camera that shoots high-definition resolution video at up to 6,200 frames per second, with shutter speeds as fast as one millionth of a second; an example is on the next page. We also used Adobe Photoshop extensively, as well as other digital photography software, including Helicon Focus.

Digital photography made a huge difference to this project, because we could see what worked, and what didn't almost immediately. The quality level is higher than 35 mm film, but it is the immediacy that really sets it apart.

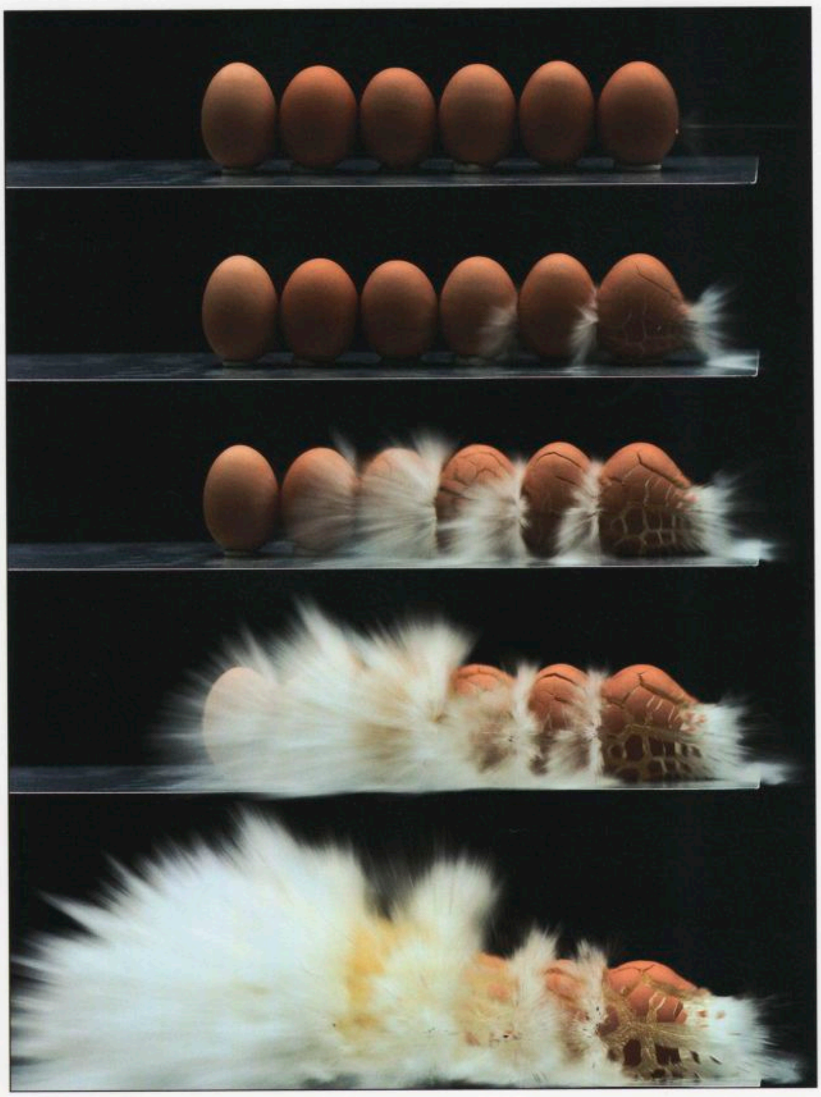
A Guide to *Modernist Cuisine*

The first volume is about the fundamentals—foundations for an understanding of the techniques described in the other volumes. This first chapter covers the history and philosophy of Modernist cuisine and the techniques used in it.

The next chapter, Microbiology for Cooks, addresses the way microbes interact with food. So much of food safety revolves around microscopic pathogens that it is valuable to understand the basic science of microbiology. For example, many chefs can't tell you why a common foodborne malady is called "food poisoning" or explain the differences between viral, bacterial, and parasitic infections. Chapter 2 demystifies these things.

Chapter 3 addresses food safety itself. Our analysis is likely to be controversial, because we point out how much of the conventional wisdom commonly presented to chefs is just plain wrong. First, we found that many food-safety guidelines taught to both home and restaurant chefs are out of date compared to the latest official regulations. For example, today there is no food-safety reason to cook pork for any longer than you cook beef or other meats. In addition, the official government regulations have their own problems. We found a number of errors in the U.S. Food and Drug Administration regulations, but perhaps worse, we also found that government food-safety regulations take positions that are based as much on politics and lobbying as on science.

We used high-speed photography and video to capture cooking processes that occur in the blink of an eye—as well as some events that are simply visually stunning, such as a bullet passing through a half dozen eggs.



That controversy pales in comparison to what we're likely to stir up with chapter 4 on Food and Health. People have strongly held beliefs about which foods are good for you and which are not. These beliefs are usually justified by scientific research—studies linking particular foods to heart disease and certain kinds of cancer, for example. Unfortunately, it turns out that the actual scientific results from the latest research contradict most of the conventional wisdom.

Recent large-scale, rigorously controlled studies have, for example, failed to link the consumption of fiber to the incidence of colon cancer. These investigations, which produce the most reliable kind of evidence available, have not uncovered any strong association between saturated fat—the predominant kind in butter, bacon, and foie gras—and heart disease. Nor have they found that antioxidants like vitamins C and E reduce the risk of cancer; in fact, the latest studies show that avid consumption of these micronutrients can actually increase some people's chances of developing certain forms of cancer.

What seems to have happened is that nutrition "experts" made claims based on preliminary results from small-scale studies. But better-designed, more reliable trials have failed to replicate the earlier results. This new information hasn't been nearly as widely disseminated as the older, now discredited claims were, so it is likely to come as a great surprise to many people.

The remainder of volume 1 covers the basic science of cooking, with an emphasis on the two most important players. The first is heat (chapter 5). So much of cooking is about heating food that it seems invaluable to really understand the basics of heat transfer. When heat flows into food, what happens next depends a lot on the physics of water. Most of our food, after all, is composed primarily of water. So that is the subject of chapter 6, the final chapter in this volume.

Volume 2 covers techniques and equipment, starting with chapter 7 on Traditional Cooking, which explains visually how the various processes long used to prepare food in the traditional kitchen work. Next, Cooking in Modern Ovens (chapter 8) covers combi ovens and water-vapor ovens that cook with low-temperature steam. These are very important pieces of kitchen equipment that are widely available but not widely understood. Chapter 9 on Sous Vide Cooking covers that invaluable technique in detail.

The last and largest chapter in the second volume, The Modernist Kitchen (chapter 10), offers an in-depth look at the equipment—much of it repurposed from science laboratories—that Modernist chefs use to work their magic in the kitchen. These special tools include centrifuges, rotary evaporators, freeze dryers, and many more gadgets and appliances.

Volumes 3 and 4 are about food ingredients. In Volume 3, Meat and Seafood (chapter 11) covers all aspects of using animal flesh—whether fish or fowl, mollusk or mammal—in cooking. Plant Foods (chapter 12) discusses the biology and preparation of all manner of vegetables, fruits, grains, and other plant-derived products. These two large chapters include both visual explanations of the ingredients and numerous recipes.

Volume 4 addresses the most important new ingredients in Modernist cooking. Our chapters on Thickeners (13), Gels (14), Emulsions (15), and Foams (16) all explore the ways in which Modernist techniques can be used to create new forms of food that would be impossible to produce with conventional ingredients. Eggs and dairy ingredients are also covered in this volume.

The two final chapters of volume 4, on Wine (17) and Coffee (18), cover the two most important beverages in a meal. In each case, we take a different approach from most cookbooks. In Wine, we discuss some of the latest research on flavors and *terroir,* and we offer new techniques for using wine, including "hyperdecanting." The Coffee chapter discusses both how to brew great coffee and how to make outstanding espresso drinks, both of which are often neglected arts in restaurants as well as in home kitchens.

Volume 5 contains our recipes for plated dishes. In that sense, this volume is more like a traditional cookbook than any of the others. As discussed above, these recipes run the gamut from hamburgers and barbecue to Indian curries to multicomponent, restaurant-style Modernist dishes. Each of these recipes combines multiple smaller recipes to create an entire plated dish or set of related dishes.

We hope you enjoy reading this book as much as we've enjoyed writing it, and we look forward to your feedback. Visit www.modernistcuisine.com to share your thoughts, ask the authors questions, see videos of selected techniques (as well as the exploding eggs shown on the previous page), and much more.

The Modernist Cuisine chefs worked in our research kitchen to develop and test the recipes in the book.

Tender hamburger bun, made from scratch and toasted in beef suet

Hamburger glaze of suet, pureed tomato confit, beef stock, and smoked salt

Maitake mushroom, sautéed in beef suet

Romaine lettuce infused sous vide with liquid hickory smoke

Vacuum-compressed heirloom tomato

Cheese single made from aged Emmental, Comté, and wheat ale

Short-rib patty ground to vertically align the grain

Crimini mushroom ketchup with honey, horseradish, fish sauce, ginger, and allspice

ABOUT THE RECIPES

Modernist Cuisine, both the culinary movement and this book, is dedicated to looking at cooking from new angles. We cover topics ignored by other culinary books, so it stands to reason that our recipes look somewhat different from those in other cookbooks. Our goal is to break down recipes in such a way that you can better understand not just the *what* (ingredients) and the *how* (methods), but also the *why.* To accomplish this, we needed a new format for presenting recipes.

The compact, modular form of our recipes makes them a broader resource for instruction and inspiration. They're meant to help you both understand the practical applications of culinary principles and visualize how you might apply those principles in other contexts.

In these five volumes, you'll find a huge variety of recipes and foods. Although we are telling the story of Modernist cuisine, our recipes are not limited to cutting-edge dishes—we cover everything from American regional barbecue to innovative flavored gels. The point is not to tout modern approaches or science for their own sake but to illustrate how the principles of Modernist cooking can be applied across a wide range of recipes.

An important thing to consider when following recipes in this book is that details matter, often to a great degree. In traditional cooking, there's a common precept that exact measurements don't matter much (at least in savory dishes): a handful of this, a few drizzles of that, a pinch of something else. Fundamentally, much of this kind of cooking is done "to taste," following the cook's experience.

That is not the case with pastry, where precision counts. You don't add yeast or baking powder to taste, and proportions of leavening to flour aren't left to creative impulse. Modernist cuisine tends to lean more toward the pastry chef's approach. In Modernist cooking, carefully measuring ingredients ensures consistent results.

In part, that is because the specialized ingredients used in this form of cuisine can be quite powerful. A little too much of a gelling agent, for example, can result in a tough, rubbery product, while too little will not produce the desired gelling effect. So measuring is a critical factor, at least if you'd like to attain the end result that we intended.

Ingredients and Equipment

You might be surprised to learn that although many people equate Modernist cooking with something akin to laboratory science, the majority of recipes here can be made with tools available in most standard kitchens. Even the recipes that involve sous vide techniques can be made without specialized gadgets; you can just use a simple pot on the stove and a thermometer (see page 2·240).

At the other end of the spectrum are recipes that do require a centrifuge, combi oven, freeze dryer, or other specialized tool. If you're interested in investing in such equipment, there are many places to find it, from eBay and other purveyors of secondhand equipment to scientific-equipment catalogs and a growing number of cooking stores.

Very few kitchens on Earth have all the equipment featured in this book (I know of only two: one at my house and another at our cooking lab). Our recipes were designed under the assumption that the optimal tools and equipment are on hand. If you don't have those tools at your disposal, those particular recipes will be more informational than practical, but they will still serve their purpose as an educational medium. Indeed, many recipes in cookbooks end up functioning primarily to provide information and inspiration. Not everyone who owns a copy of Auguste Escoffier's *Le Guide Culinaire* has made all his triple stocks and complicated forcemeats, for example, but there remains great instructional value in seeing his examples and reading the recipes.

What you won't find in our recipes is much attention to the most basic equipment, such as bowls and sauté pans. We presume that you'll know what equipment you need to use when we call for blending or simmering or sautéing.

Recipes here use a number of unusual ingredients, like xanthan gum, sodium alginate, gellan, essential oils, and glucono delta-lactone. Our glossary of cooking terms at the back of volume 5 describes each of these ingredients, and you may be surprised at how easy they are to acquire. Well-stocked supermarkets and health food stores sell many of them, because they are used in certain regional dishes or as substitutes for more routine products. People with wheat allergies, for instance,

Most of the laboratory equipment we use for cooking came from eBay, other Internet auction sites, second hand dealers or bankruptcy auctions of biotech firms. If you look hard, you can get bargains this way.

For more on where to purchase items mentioned in these volumes, see Sources of Equipment and Ingredients, page 5·XXX.

often use xanthan gum to replace the gluten protein found in wheat flour. Agar is often available where you'd find other Asian specialty products. The rise of the Internet has made finding such items much easier, and they are available from a number of online stores.

Seeing things like propylene glycol alginate in an ingredient list may take some getting used to, but it should be no stranger than a meringue recipe that calls for cream of tartar, a quick bread recipe that calls for baking powder, or a recipe for a regional specialty that calls for distinctive herbs and spices.

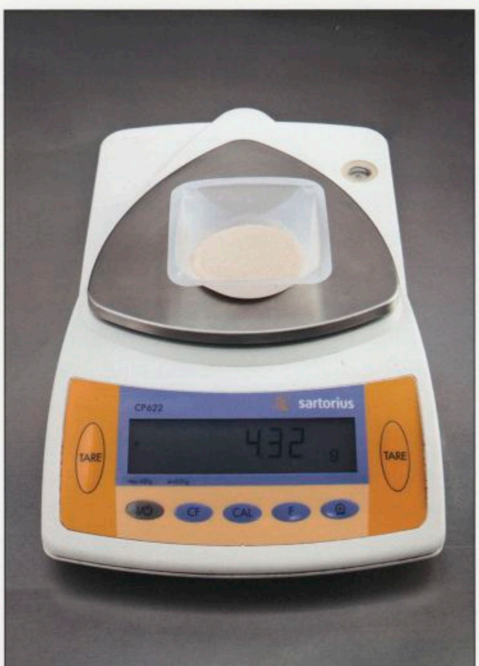
In a few cases, there may be local legal issues with some of the equipment we use. For one example, in the state of Texas there are laws requiring a government permit to own laboratory glassware, including the Büchner funnels and flasks that we recommend for vacuum filtration (see page 2·353). It may seem a bit odd to regulate a device we use for clarifying consommé, but there is a method to the madness: the laws are aimed at curbing production of methamphetamine and other illegal drugs. Whether one can do so by outlawing glassware is questionable, but that's the law—at least there. Other places may have similar issues.

Salting "to taste" is fine, but for most foods, and most people's taste, the proper salt level is 1%–1.5% salt by weight. A few salty foods may reach 2%, and some people might prefer a bit less than 1%, but the range is actually quite small.

Another touchy area is distillation, which is regulated in the United States at both the federal and state levels. One piece of equipment we use in this book, the rotary evaporator, is made for distilling; if it is used to distill and concentrate alcohol, it may be subject to regulation. Some states in the U.S. consider any and all alcohol distillation to be illegal, and they devote law enforcement resources to punishing moonshiners who make their own whiskey. At the other extreme, Oregon has a state-funded program dedicated to *promoting* artisanal craft distillers, which the state sees as businesses it wants to encourage.

Countries other than the U.S. have a wide range of regulations covering alcohol production. So find out what is appropriate for your area before you distill alcohol. Of course, rotary evaporators also have uses other than alcohol production.

For more on weight-to-volume conversions for common foods, see the reference tables provided near the end of volume 5.



A digital gram scale is a must-have for any serious cook. For more on digital scales, see page 4·41.

Weights and Measures

You'll see in these recipes that we measure ingredients by weight. Most cookbooks sold in America use U.S. weights and volumes for ingredients: ½ cup of sugar, one teaspoon of salt, two cups of milk, etc. We find that these volume measurements are not sufficiently accurate in many instances.

Modernist recipes often require great precision in measuring ingredients. If you use a fraction of a percent more or less of certain gelling agents or thickeners—for example, one extra gram of the compound per liter of liquid—that imprecision will ruin the recipe. So rather than using more general volume measures in some cases and precise gram weights in others, we chose to use gram weights for all ingredients in the book.

We even list water by its weight rather than by its volume, unless the quantity needed is undefined. Salt is usually relegated to the vague notion of "to taste," but where practical, we provide measurements for salt by weight. Obviously, if you like more or less salt, adding it to taste is always your prerogative, but we believe it's important to maintain as much precision as possible so that you achieve the same textures and flavors that we did when developing these recipes.

Ingredients that come in distinct units, such as eggs or allspice berries, are an exception to this rule. We usually still measure these by weight, but we also list the rough equivalent units for reference. And some ingredients are called for "as needed," when there simply is no single correct amount to use.

Digital gram scales are widely available in cooking stores around the world. They're common enough now that a good basic model is not an expensive investment. If you've measured ingredients only by the cup and teaspoon until now, this is a great time to buy a good scale and begin applying a bit more precision to your recipe measurements.

In fact, you might want to consider getting two different scales if you're committed to cooking a range of recipes from this book. One would be your general-purpose scale, good for measuring weights from one gram to 1,000 grams or more. The second scale would be for finer measurements, accurately weighing items down to 0.01 gram. Such scales often max out at 100 grams or so and thus are not as widely applicable as the first type of scale.

Keep in mind that the final yield of a recipe will not necessarily be a simple sum of the weights of the ingredients. Some things get trimmed along the way, liquids evaporate, and unmeasured ingredients come into play (for example, the water used to soak dry beans will add weight to the finished dish). We provide yield information based on the real weight of the final results, as measured in our test kitchen.

Temperatures in the book are given in both Celsius and Fahrenheit. In general, where precise temperature is less critical, we do some rounding. It doesn't help much to know that 57 degrees Celsius equals 134.6 degrees Fahrenheit; 135 °F will work fine. Kitchen thermometers typically don't operate well at more than one to two full degrees of accuracy anyway (see page 269), and the controls of ovens and deep-fryers often jump by five-degree intervals.

But one of the central themes of Modernist cooking is that exact temperature control is called for under certain circumstances. Water baths used for sous vide cooking (see page 2·236) are a means of precisely controlling temperature. Combi ovens and water vapor ovens can do this, although not quite as accurately (see page 2·156). Accuracy is particularly important in the lower range of cooking temperatures. Typically, the higher the temperatures, the less critical it is that they be precise.

But when you're cooking salmon *mi-cuit* (literally "partially cooked"), the color of the flesh shouldn't change from the raw state, which requires careful temperature management. You need to cook the fish within a very narrow range, to no more than 40 °C / 104 °F; above that, it becomes difficult to control the results. Many gelling agents are effective up to 85 °C / 185 °F, but if they are heated to higher than that temperature, the gel can fail.

Another issue to consider is that some of the newer ingredients, like hydrocolloids, come in a range of grades, brand names, and proprietary blends. We list the specific brands we used in developing the recipes as a point of reference and to provide some guidance about the properties that other brands may have. Don't let these slight variations intimidate you; once you get the hang of it, these details become second nature.

Sometimes a recipe will go awry for any number of reasons. Perhaps you're using a finicky hydrocolloid like gellan, which might gel prematurely if your tap water has a particularly high mineral content. Or perhaps your sous vide bags are leaking. We have tried to offer plenty of troubleshooting notes and examples of various scenarios to help you diagnose the most common problems, but we surely haven't caught them all. Unfortunately, there are many more ways to do something wrong than to do it right. When all else fails, try to treat these outcomes as a learning opportunity.

Baker's Percentage

You'll often want to scale a recipe up to get a higher yield or down to make a smaller quantity. You can do this by multiplying the ingredient quantities by a given factor or by doing some division to figure out the ratios of the ingredients.

The best system that we have found for making a recipe easy to scale is called baker's percentage, a method of measurement that is widely used in pastry and baking books. In a recipe that uses baker's percentage, one reference ingredient—usually the ingredient that most affects the yield or the cost of the recipe—is set to 100%. The quantity of each other ingredient is then cited as a percentage of the reference ingredient's weight.

For example, our recipe for Sous Vide Instant Hollandaise (see next page and page 4·228) sets egg yolks as the reference ingredient at 100% and calls for 75 grams of yolks. It calls for vinegar at a scaling of 47%, meaning 47% of the weight of the egg yolks—not 47% of the yield or 47% of the sum of all ingredients, just 47% of the weight of however much the yolks weigh.

Michael Ruhlman's cookbook *Ratio: The Simple Codes Behind the Craft of Everyday Cooking* is dedicated to the idea of using ratios to express quantities in recipes.

Any scaling system is mathematically equivalent to others. We use baker's percentages because they are convenient for the most common scaling situations and are already familiar to pastry chefs.

Example recipes and components of plated-dish recipes have similar formats. In cases where a recipe is inspired by, or adapted from, another chef, attribution is given after the recipe title ① and the date of the original is listed at the bottom of the recipe. ⑩ Temperatures ⑦ are set in heavier type to make them easier to find at a glance. Lines within the recipe ④ group ingredients into blocks; procedure steps apply only to ingredients in the same block as the step. In step 1, for example, "combine" means to combine just the wine, shallots, and vinegar—not to combine all ingredients in the recipe.

The total expected yield of the recipe ② differs from the sum of the ingredient weights when ingredients are lost or discarded during preparation or cooking. In addition to weights, ingredient quantities are specified using baker's percentages ③ to aid in scaling to higher or lower yields—see the previous page for more on using these percentages.

For ingredients that come in standard sizes, approximate numbers ⑤ are given as well. In certain cases, a special scaling percentage ⑥ is given to aid substitutions or to provide greater precision when needed, such as when using gelling agents. The special scaling is calculated as a percent of some combination of ingredients, as explained by a note ⑨ at the end of the recipe. When an ingredient is itself the product of a recipe or a step-by-step technique, a page reference ⑧ is given to the instructions for making it.

Baker's percentages provide an especially handy, reliable method to figure out the right amounts of minor ingredients needed to match the quantity of the major ingredient when scaling a recipe. Without baker's percentages, calculating quantities can be tricky.

EXAMPLE RECIPE

SOUS VIDE INSTANT HOLLANDAISE ① INSPIRED BY DANIEL HUMM **Yields 345 g** ②

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White wine (dry)	100 g	133% ③	① Combine.
Shallots, finely minced	50 g	67%	② Reduce to syrup-like consistency.
White vinegar	35 g	47%	③ Strain.
	④		④ Measure 20 g of wine reduction.
Egg yolks	75 g ⑤ (four large)	100% *(28%)** ⑥	⑤ Blend thoroughly with wine reduction. ⑥ Vacuum seal.
Stock or water	20 g	27%	⑦ Cook sous vide at **65** °C / **149** °F for 30 min. ⑦
Unsalted butter, melted	225 g	300%	⑧ Blend into yolk mixture until fully emulsified.
Salt	4 g	5.3%	⑨ Season.
Malic acid	1 g	1.3%	⑩ Transfer to 1 l / 1 qt siphon.
			⑪ Charge with two nitrous oxide cartridges.
			⑫ Hold siphon in **60** °C / **140** °F.
Two-stage fried egg see page 2·174 ⑧	four eggs		⑬ Garnish eggs with hollandaise as desired.

⑨ *(*% of total weight of wine reduction, stock, and unsalted butter*)

(original 2009, adapted 2010) ⑩

So if you're using 75 grams of egg yolks to make the recipe, you need 35 grams of vinegar, because 75 grams times 47% equals 35. But say you only have 65 grams of egg yolks. How much vinegar should you use? This is where the scaling percentage really simplifies things. Just multiply the same 47% for vinegar times the actual weight of egg yolks available—65 grams—to get the answer: 30.5 grams of vinegar.

Keep in mind that the percentages of the minor ingredients will not add up to 100%, because scaling percentages give the weight as a proportion of the weight of the reference ingredient, not of the total weight of all ingredients in the recipe.

One challenge in using baker's percentages is that they can be difficult to use if you want to omit or add an ingredient, or if you substitute several ingredients of different quantities. This issue comes up most frequently in recipes that involve small quantities of potent thickeners or gelling agents. But it also arises for more common ingredients such as salt. In the hollandaise recipe above, for example, if you decide to use a more flavorful wine and stock, you may choose to reduce it a bit less than the recipe indicates to achieve the balance of flavors you want. But how should you then adjust the quantity of egg yolks to preserve the texture of the sauce?

We provide a special scaling percentage in many cases to help with such situations. A note at the bottom of the recipe explains how the special percentage is calculated. Often it is a proportion of the weight of all ingredients in the recipe or of all *other* ingredients (omitting the weight of the ingredient that has the special percentage listed).

In the example above, we added the weights of the wine-shallot-vinegar reduction, the stock or water, and the butter, which came to about 268 grams when we made the recipe. The weight of the eggs, at 75 grams, is 28% of 268 grams, so we include the 28% as a special scaling percentage.

So, if in your adjustments to the recipe, you find that you end up with 300 grams of reduction, stock, and butter instead of the 268 grams we got, you can easily work out how much egg yolk to use by simply multiplying 300 grams by 28%: 84 grams of yolk should produce a texture very close to the original version.

The special scaling sometimes becomes crucial when using recipes that include hydrocolloids that are quite powerful in small quantities, so they must be added with great precision. Our recipe for a gelled Long Island Iced Tea on page 4·141, for example, suggests using 5.6% as much gelatin as you use of cola, thus 6.75 grams if using 120 grams of cola. But that ratio would not work well if you were to omit the tequila. In that case, you should instead use the special scaling listed for gelatin, which is 1.6% of the total weight of all the other ingredients, or 6.25 grams.

Similarly, if you wanted to add, say, 60 grams of whiskey to the recipe, the special scaling percentage would let you easily work out the right amount of gelatin to use, which is 1.6% of the new total (450 g) of other ingredients: 7.2 grams of gelatin. Without the special percentage, you would be tempted to use just 6.75 grams of gelatin, and the result may not set the way the original recipe does.

Three Kinds of Recipes

The book features three distinct classes of recipes: example recipes, parametric recipes, and plated-dish recipes. Each serves a different purpose in illustrating how particular ingredients or techniques can be applied in the kitchen.

Example recipes are typically the shortest and simplest of the three kinds. Some come from leading Modernist chefs; others we developed ourselves. Each was carefully selected to illustrate the culinary principle at hand. Because they are focused on individual techniques or procedures, example recipes will not always result in complete dishes. In fact, many example recipes serve as components in more involved plated-dish recipes.

Example recipes may look surprisingly short and focused, and that's deliberate. For instance, we have a few recipes for making different types of tofu. We may offer a couple of suggestions for how to serve them, but the fundamental goal is to discuss the tofu itself, a core ingredient that can then be used in myriad dishes. These example recipes are often building blocks rather than complete recipes (although our silken tofu made with GDL is so good you could eat it straight).

The parametric recipes, the second of the three kinds, are quite unlike usual recipes—and, in our view, much more interesting. *Parametric* refers to the fact that these recipes have parameters that are set by one key ingredient or characteristic.

This idea echoes that of the master recipe, which many successful cookbooks have used as a foundation. Examples include books by the editors of *Cook's Illustrated; Sauces* and *Splendid Soups*, by James Peterson; and Raymond Sokolov's *The Saucier's Apprentice*. Master recipes illustrate a basic technique in its purest form first, then use variations to elaborate the theme.

The key difference between a parametric recipe and a master recipe is that the latter must be very general in order to encompass its many variations, which get most of the space. A parametric recipe, in contrast, simply summarizes the variations in a compact form.

So, for example, our parametric recipe for pureed fruits and vegetables cooked sous vide, page 3·288, lists cooking times and temperatures for a wide variety of ingredients. At a glance, you can see that rhubarb puree should be cooked at 88 °C / 190 °F for one hour, whereas mango puree needs to be cooked at 75 °C / 167 °F for 20 minutes.

When recipes get more complicated, the parametric format really shines. Our parametric recipe for hot gels on page 4·160 summarizes the differences between 10 approaches to creating this dish, each of which uses different hydrocolloids that have their own scaling percentages.

We feel the parametric recipe is a strong concept for an instructional cookbook. Such a recipe does more than merely suggest methods for making one dish the same way again and again—it reveals the pattern and reasoning behind the chosen ingredients and methods, and thus makes it clearer how to apply those lessons in other circumstances. The parametric recipe thus takes the master recipe to a more detailed level, and serves as a launching point that allows you to change ingredients and quantities in a number of ways to produce dozens of variations. A single page of parametric recipes in the Gels or Thickeners chapters, for instance, might point the way to hundreds of different preparation options. The parametric approach also makes scaling the yield of a recipe up or down simpler than any other approach we know.

In parametric recipes, we are frequently concerned only with minor ingredients; often the only major ingredient is whatever liquid is being thickened. That liquid is the ingredient that sets the reference quantity, and the amount of other ingredients is given as a percentage of the reference. As an example, our recipe for ham consommé with melon beads (see page 4·66) simply lists xanthan gum at 0.24 %, which would mean using 2.4 grams for every 1,000 grams of base liquid.

This book contains 379 example recipes and 75 parametric recipe tables, each of which typically has 5–10 rows (many more, in a few cases). The total number of recipes in the parametric format is 814. In volume 5 you will find 49 plated dishes, which include a total of 329 component recipes. The grand total is 1,522 recipes in the book.

MAKING A SMOOTH PUREE

①

1 **Prepare the vegetables by cutting them into evenly shaped, small pieces, as indicated in the table below.**

2 **Combine the vegetables with the liquid or seasoning indicated in the table. Set the weight of the produce to 100%. For example, use 12 g of butter for every 100 g of mushrooms.**

3 **Cook as indicated. Suggested methods, temperatures, and times are listed in the table.**

4 **Puree by using the tool indicated.** Optionally, process with a rotor-stator homogenizer, ultrahigh-pressure homogenizer, or ultrasonic homogenizer for a finer texture. For large quantities, a colloid mill is an ideal tool.

Parametric recipes typically contain three parts: an introduction that explains some of the underlying principles at work (not shown in this example), steps ① that outline the general procedure for making the recipe, and one or more tables, typically organized by main ingredient, ② that present the parameters—ingredients, quantities, preparation steps, cooking times and temperatures, etc.—for making a number of variations.

Ingredients for each variation are grouped together between horizontal lines. ⑥ In the example below, the recipe for asparagus puree calls for blending both vegetable stock and unsalted butter together with the sliced asparagus. More than one variation is sometimes given for a main ingredient, ⑨ as indicated by an indented line.

If no ingredient is listed for a variation, ⑤ that indicates that we don't consider any additional ingredient necessary in this case. A value of "n/a" indicates that the value for that column is not applicable for a given variation.

Cooking instructions ③ typically include both temperatures and times, given in minutes (min) or hours (h), as indicated by the unit at the top of the column. When a time is unusually short or long, the abbreviated unit is included with the number. ④

Quantities in parametric recipe tables are often given as percentages of a liquid or a main ingredient, ⑦ as indicated by a note at the bottom of the table. ⑩ References to related example recipes, plated-dish recipes, or step-by-step procedures are often given in a "See page" column. ⑧

Best Bets for Vegetable and Fruit Purees

		Cook							
Ingredient	Prep	Method	(°C)	(°F)	(min)	Liquid	(scaling)*	Tool	See page
apple ②	peeled, quartered	sous vide③	90	194	2½ h ④	⑤		commercial blender	5·17 ⑧
asparagus	thinly sliced	sauté	high heat		10	⑥ vegetable stock	25% ⑦	commercial blender	341
						unsalted butter	15%		
artichoke	hearts, thinly sliced	sous vide	80	176	45	vegetable stock	50%	commercial blender	
						olive oil	5%		
beet	peeled, thinly sliced	sous vide	80	176	1 h	cooked beet juice	50%	commercial blender	
						unsalted butter	15%		
broccoli	stems, peeled and sliced	sauté	medium heat		12	neutral oil	3%	commercial blender	426
⑨	florets, sliced	boil	high heat		4	neutral oil	3%	Pacojet	

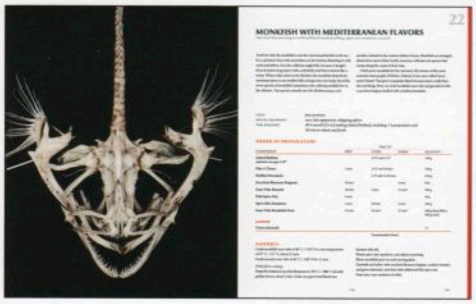
⑩ *(*set weight of prepared vegetable to 100%*)

In many cases we have example recipes tied to entries in the parametric recipe table. These cross-references let you see a full example of how the parameters and formulas work in practice.

The final kind of recipe we use in this book is the plated-dish recipe. This comes closest to the recipes found in traditional cookbooks. Our plated-dish recipes offer instructions for creating an entire restaurant-style dish, including main ingredients, multiple garnishes, and details about how to assemble everything for serving. We describe the entire context of the dish in detail; thus, some of these recipes are quite involved, with many component parts. You can always opt to simplify things a bit by using only certain parts.

Plated dishes come in a wide variety of styles. We have full-on Modernist dishes that would not be out of place at leading Modernist restaurants. But we also have dishes that are far more informal, like barbecue from the American South, a pork belly picnic, and even the perfect omelet. For us, a plated recipe doesn't have to be fancy, as long as it's made with the quality and care of more elaborate preparations. Our hamburger is the best one we know how to make, and we believe that you should put every bit as much effort into making a great hamburger as you would if you were making dishes with loftier ambitions.

Some Modernist dishes are lavishly complex à la Heston Blumenthal, while others are boldly minimalist in the style of Ferran Adrià. Other Modernist chefs, including Grant Achatz, David



Plated-dish recipes are the most involved recipes in the book because they bring together multiple components, including a main dish, side dishes, sauces, and garnishes. A brief introduction ① provides historical or culinary context for the dish. It is followed by a "dashboard" view ② that gives an overview of the recipe components, the time you'll need to budget to make each part, any special equipment that is required (or that is optional but handy), and the assembly steps involved in bringing everything to completion at the same time.

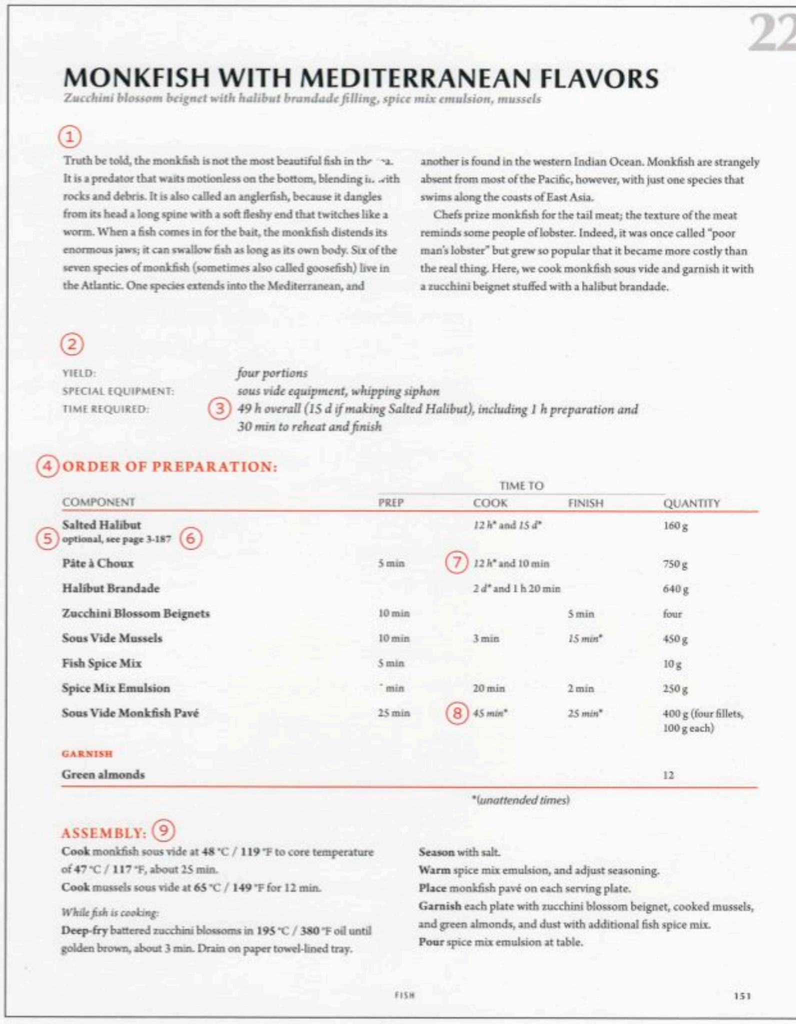
Yield for the recipe as a whole is given as a number of portions. Several times are listed in the TIME REQUIRED: section. ③ The "overall" time indicates clock time from the start of preparation to serving time. Because many recipes require long periods of cooking, curing, fermenting, etc. that do not require a cook's attention, we also indicate the amount of hands-on kitchen time needed for preparation. Finally, we give the reheating and finishing time to let you know how far in advance of serving you should begin final assembly.

The component dishes in the recipe are then listed in a suggested order of preparation, ④ with those parts that are easily (or necessarily) made in advance given first. Although the recipes for most components follow the dashboard page, some may be found instead in other parts of the book, in which case a page reference is given. ⑥ Components that are optional are clearly noted as such. ⑤

For each component, we list the quantity needed and three useful times: the hands-on prep time, the time needed for any finishing steps during assembly, and the cooking time. Cooking steps that do not require active attention are set in italics; ⑧ in cases where a dish involves both attended and unattended cooking steps, times are given separately for each. ⑦

Instructions for finishing and final assembly of the plated dish appear after the table of components. ⑨ The most difficult part of making a complex meal is completing all the last-minute cooking, dressing, and garnishing in the few minutes before it is served. To help you pull off this feat, all of these final steps are presented together in this spot and arranged clearly in a practical order.

The remaining pages of the plated-dish recipe are devoted to recipes for the components, ⑩ each of which is presented using the same approach we take for example recipes (see page 94). Where space permits, we have included photographs showing some of the steps involved. Notes in the margin ⑪ provide tips and ideas for substitutions.



22

MONKFISH WITH MEDITERRANEAN FLAVORS

Zucchini blossom beignet with halibut brandade filling, spice mix emulsion, mussels

①

Truth be told, the monkfish is not the most beautiful fish in the sea. It is a predator that waits motionless on the bottom, blending in with rocks and debris. It is also called an anglerfish, because it dangles from its head a long spine with a soft fleshy end that twitches like a worm. When a fish comes in for the bait, the monkfish distends its enormous jaws; it can swallow fish as long as its own body. Six of the seven species of monkfish (sometimes also called goosefish) live in the Atlantic. One species extends into the Mediterranean, and another is found in the western Indian Ocean. Monkfish are strangely absent from most of the Pacific, however, with just one species that swims along the coasts of East Asia.

Chefs prize monkfish for the tail meat; the texture of the meat reminds some people of lobster. Indeed, it was once called "poor man's lobster" but grew so popular that it became more costly than the real thing. Here, we cook monkfish sous vide and garnish it with a zucchini beignet stuffed with a halibut brandade.

②

YIELD: *four portions*
SPECIAL EQUIPMENT: *sous vide equipment, whipping siphon*
TIME REQUIRED: ③ *49 h overall (15 d if making Salted Halibut), including 1 h preparation and 30 min to reheat and finish*

④ ORDER OF PREPARATION:

COMPONENT	TIME TO PREP	TIME TO COOK	TIME TO FINISH	QUANTITY
Salted Halibut ⑤ optional, see page 3-187 ⑥		*12 h** and *15 d**		160 g
Pâte à Choux	5 min	⑦ *12 h** and 10 min		750 g
Halibut Brandade		2 *d** and 1 h 20 min		640 g
Zucchini Blossom Beignets	10 min		5 min	four
Sous Vide Mussels	10 min	3 min	*15 min**	450 g
Fish Spice Mix	5 min			10 g
Spice Mix Emulsion	[illegible] min	20 min	2 min	250 g
Sous Vide Monkfish Pavé	25 min	⑧ *45 min**	*25 min**	400 g (four fillets, 100 g each)
GARNISH				
Green almonds				12

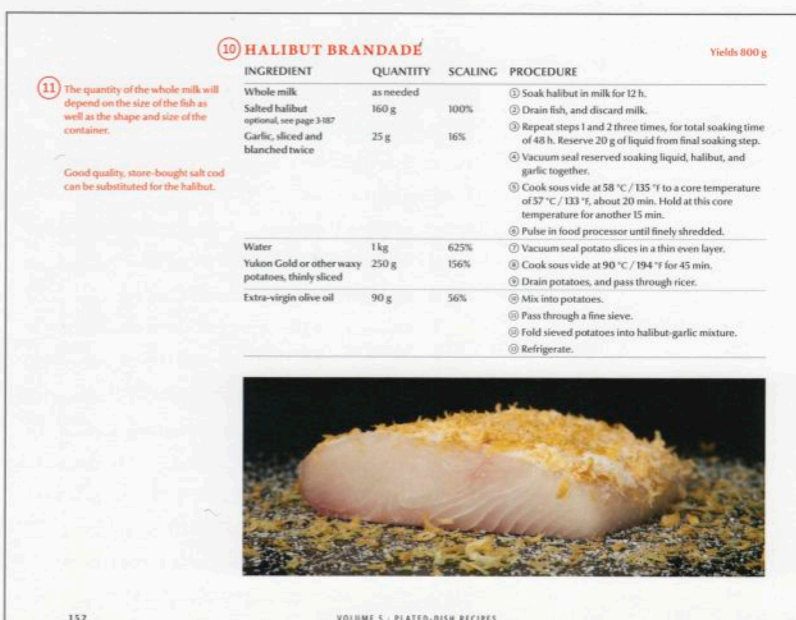
*(unattended times)

ASSEMBLY: ⑨

Cook monkfish sous vide at **48 °C / 119 °F** to core temperature of **47 °C / 117 °F**, about 25 min.
Cook mussels sous vide at **65 °C / 149 °F** for 12 min.

While fish is cooking:
Deep-fry battered zucchini blossoms in **195 °C / 380 °F** oil until golden brown, about 3 min. Drain on paper towel-lined tray.
Season with salt.
Warm spice mix emulsion, and adjust seasoning.
Place monkfish pavé on each serving plate.
Garnish each plate with zucchini blossom beignet, cooked mussels, and green almonds, and dust with additional fish spice mix.
Pour spice mix emulsion at table.

FISH 151



⑩ HALIBUT BRANDADE

Yields 800 g

⑪ The quantity of the whole milk will depend on the size of the fish as well as the shape and size of the container.

Good quality, store-bought salt cod can be substituted for the halibut.

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	as needed		① Soak halibut in milk for 12 h.
Salted halibut optional, see page 3-187	160 g	100%	② Drain fish, and discard milk.
Garlic, sliced and blanched twice	25 g	16%	③ Repeat steps 1 and 2 three times, for total soaking time of 48 h. Reserve 20 g of liquid from final soaking step. ④ Vacuum seal reserved soaking liquid, halibut, and garlic together. ⑤ Cook sous vide at 58 °C / 135 °F to a core temperature of 57 °C / 133 °F, about 20 min. Hold at this core temperature for another 15 min. ⑥ Pulse in food processor until finely shredded.
Water	1 kg	625%	⑦ Vacuum seal potato slices in a thin even layer.
Yukon Gold or other waxy potatoes, thinly sliced	250 g	156%	⑧ Cook sous vide at 90 °C / 194 °F for 45 min. ⑨ Drain potatoes, and pass through ricer.
Extra-virgin olive oil	90 g	56%	⑩ Mix into potatoes. ⑪ Pass through a fine sieve. ⑫ Fold sieved potatoes into halibut-garlic mixture. ⑬ Refrigerate.

152 VOLUME 5 · PLATED-DISH RECIPES

For more on Grant Achatz, see page 68. For more on David Kinch, Joan Roca, and Thierry Rautureau, see page 67, page 58, and page x, respectively.

Kinch, and Joan Roca, have their own styles somewhere in between. Our plated-dish recipes exemplify all of those styles.

The other plated dishes are no less stylistically diverse. It might come as a surprise that we devote so much attention to American barbecue, but we're big fans of this cuisine. Indeed, we find that barbecue exhibits enormous depth and complexity that is rarely understood outside its home region (and too frequently ignored outside the United States). Initially we set out to create one barbecue recipe, but the idea soon grew to include sauces and barbecue styles from every region of the country (see page 5·66). Perhaps we went overboard, but our goal is to serve up a broad range of experiences.

After our test kitchen had made its way through the barbecue recipes, a member of the kitchen team, Anjana Shanker, suggested developing Modernist versions of some Indian curries. She reasoned that Indian curry dishes, like American barbecue, come in a vast variety of regional styles. The recipes she came up with were so good that we had to put them in the book—you'll find them on page 5·89. These recipes illustrate how even culinary traditions stretching back hundreds (or in some cases, thousands) of years can be revisited with a Modernist palate and sensibility—to delicious and thought-provoking effect.

Credit Where Credit Is Due

Because we selected recipes to illustrate important concepts in the development of Modernist cuisine, it is only natural that many originated as contributions from the chefs who first used the given technique in a fine-dining context. For example, Ferran Adrià was the first to introduce spherification to a restaurant setting, and we have included example recipes that cover two of his iconic creations: imitation caviar and faux olives.

The example recipes in the book were inspired by, or adapted from, 72 chefs and cookbook writers.

It is not always the case that the example recipe we have is from the chef who did it first, however; we chose some recipes simply because they seemed to best exemplify the topics explained in the book. Although we have gone to some effort to document history in this chapter, the rest of the book is first and foremost about teaching technique.

Every recipe included here was tested in our kitchen laboratory after a tremendous amount of our own recipe development work. But we've also had a great deal of help from leading chefs around the world, and we believe it is important to give credit where it is due. Some of the people who inspired recipes in this book don't know or necessarily endorse the fact that we've used their recipe as a launching point for one of our own. That is particularly true of historical recipes, from chefs who are no longer with us but who, we hope, would be pleased to play a role in this book. The older, more traditional recipes are also among those we've most modified to recast them in a Modernist style with newer techniques or ingredients.

Thus, if we cite a recipe as being "inspired by" a particular chef, it means we modified the recipe in substantial ways. We may have applied Modernist ingredients or techniques to a basic recipe idea that was first developed in a traditional context.

For example, we include a recipe for spot prawns in a foie gras nage, inspired by a dish from Thierry Rautureau, a French chef in Seattle with whom I apprenticed for some time. His version is a fantastic dish, but it is entirely traditional in its technique and ingredients. Our version uses a Modernist emulsifier—propylene glycol alginate—to keep the nage from separating, and we cook the prawns sous vide or with low-temperature steam. On one hand, ours is very different from Rautureau's recipe, but on the other, it is completely inspired by a truly memorable meal at which he served this dish more than 10 years ago.

Another reason we might note that a recipe is "inspired by" a particular chef is that we are using only a single component from a dish that chef created. The goal in this case isn't to showcase the chef's cuisine and the original dish in its full form but simply to use part of the recipe as a teaching tool, somewhat out of context. We're deeply grateful to all these chefs who—whether they know it or not—have inspired the development of recipes in this book.

In other cases, we started by creating a dish or an element of a dish, then sought out a traditional recipe in which to embed our new creation. This process led to some of the "inspired by" recipes in the book—they have at least one element that was inspired by the chef we name, but the rest of the components may be quite different.

We say that a recipe is "adapted from" a particular chef when it is one step closer to how that chef might actually make it. In most such cases, we have still made some adjustments to techniques or ingredients, and we may have rearranged procedures a bit to explain things more clearly.

Ultimately, we take full responsibility for all recipes in this book and how they turn out in your kitchen. We've tested them all extensively, and although we'd like to feel they are foolproof, it's likely that some steps allow a bit more latitude than we anticipated, leaving a little room for error.

After a lot of discussion, we decided to credit the recipes (both "inspired by" and "adapted from") to individual chefs rather than to restaurants. There are several reasons for this. First, many chefs have more than one restaurant. Heston Blumenthal runs both The Fat Duck and a pub called The Hinds Head. Some of his recipes that we use have been served at either or both of these restaurants.

But that's not all, because Blumenthal also participates in TV shows, and several of the recipes that we used were actually developed for his shows rather than for his restaurants. It would seem odd to credit those recipes directly ("as seen on BBC TV"), so instead we chose to attribute them to Blumenthal personally, since he is the driving force behind his various ventures.

Similar issues come up with cookbook writers; in those cases, it seems clear that credit should go to the author, not to the book. The same holds for web sites and other venues for disseminating recipes. So we decided that, as a rule, we would assign credit to individuals.

Of course, we recognize that the development of recipes is often a team effort. So when we credit chefs like Blumenthal or Adrià, that credit should be interpreted as going to the culinary teams they lead. Many of the innovations likely have been developed, honed, or improved by many people on the team, not just the chef who leads the group.

The word *chef*, of course, is French for "chief, manager, or leader." The very best chefs are exactly that: leaders who inspire and manage a team. It is customary to attribute any team's efforts to the leader, particularly in the kitchen, but we all know that the leaders would be a lot less productive without their teams' support. This book, by the way, is no different; without an incredible team of talented people, it would have been impossible to create it.

As for the photographs that accompany our recipes, most are images that we took ourselves, though in a few cases we do include an image that was supplied by the chef who created the dish. We recognize that the way we've assembled and presented each dish may or may not be done exactly as it would have at the chef's restaurant; but the intent is to exemplify the chef's inspiration. We have no expectation that this book duplicates chefs' recipes and culinary styles as they would express them in their own cookbooks. After all, that is why they write them. Our book is instead a repository of culinary technique, with many ideas that most cookbooks don't have the space or resources to provide.

The remaining recipes are those that we developed from scratch on our own. For example, we wanted to figure out how to make an instant soufflé, but we really had no starting point to work from. We just began working through a range of ideas and options without a clear path, eventually creating a recipe that calls for expelling a premade soufflé mixture from a whipping siphon into a ramekin, then putting it in the oven. It's a method we're quite pleased with. For all we know, someone else out there had already done the same thing—we just weren't able to find it. If we've inadvertently missed someone who feels she or he developed a dish that we have not given that person credit for, we apologize.

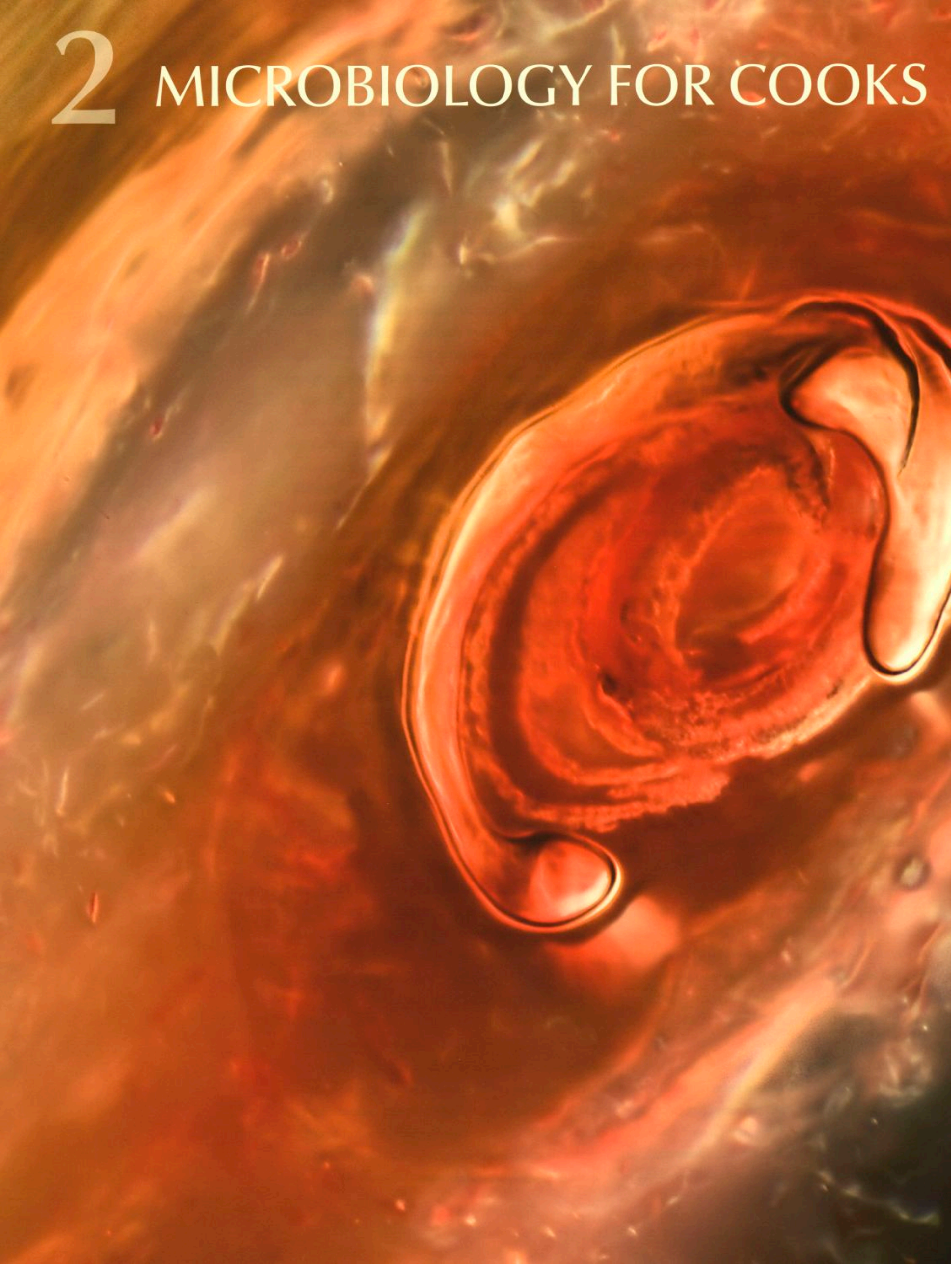
Safety

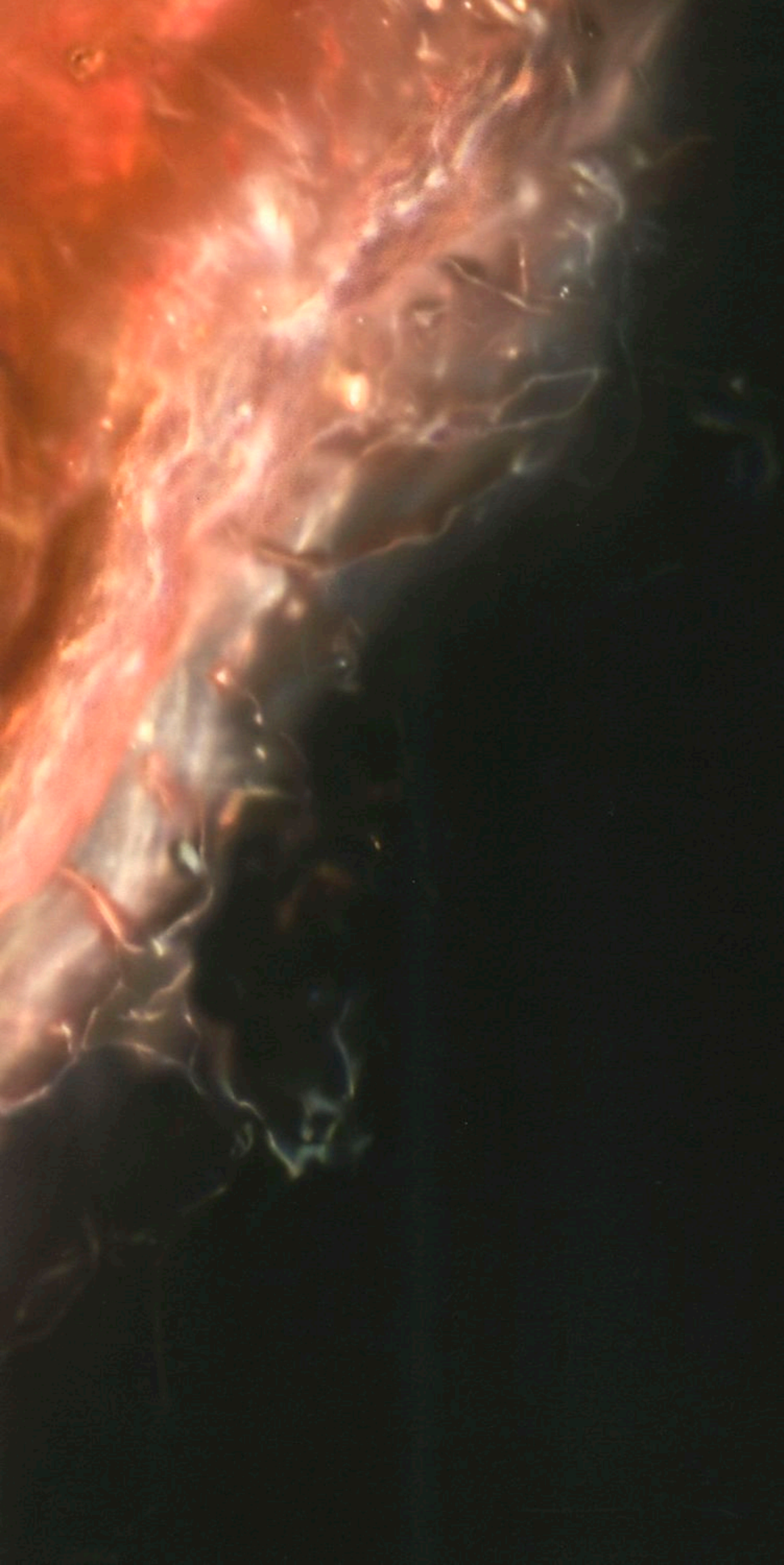
Physical safety is always an important consideration in the kitchen, and it can be especially so with certain aspects of Modernist cooking. Some items in the Modernist toolbox, such as liquid nitrogen, are unusual, and you need to learn unique safety precautions in order to handle them. But we'd also point out that many elements of traditional cooking can require special precautions as well. Oil heated to 205 °C / 400 °F for deep-frying is a pretty dangerous liquid, too.

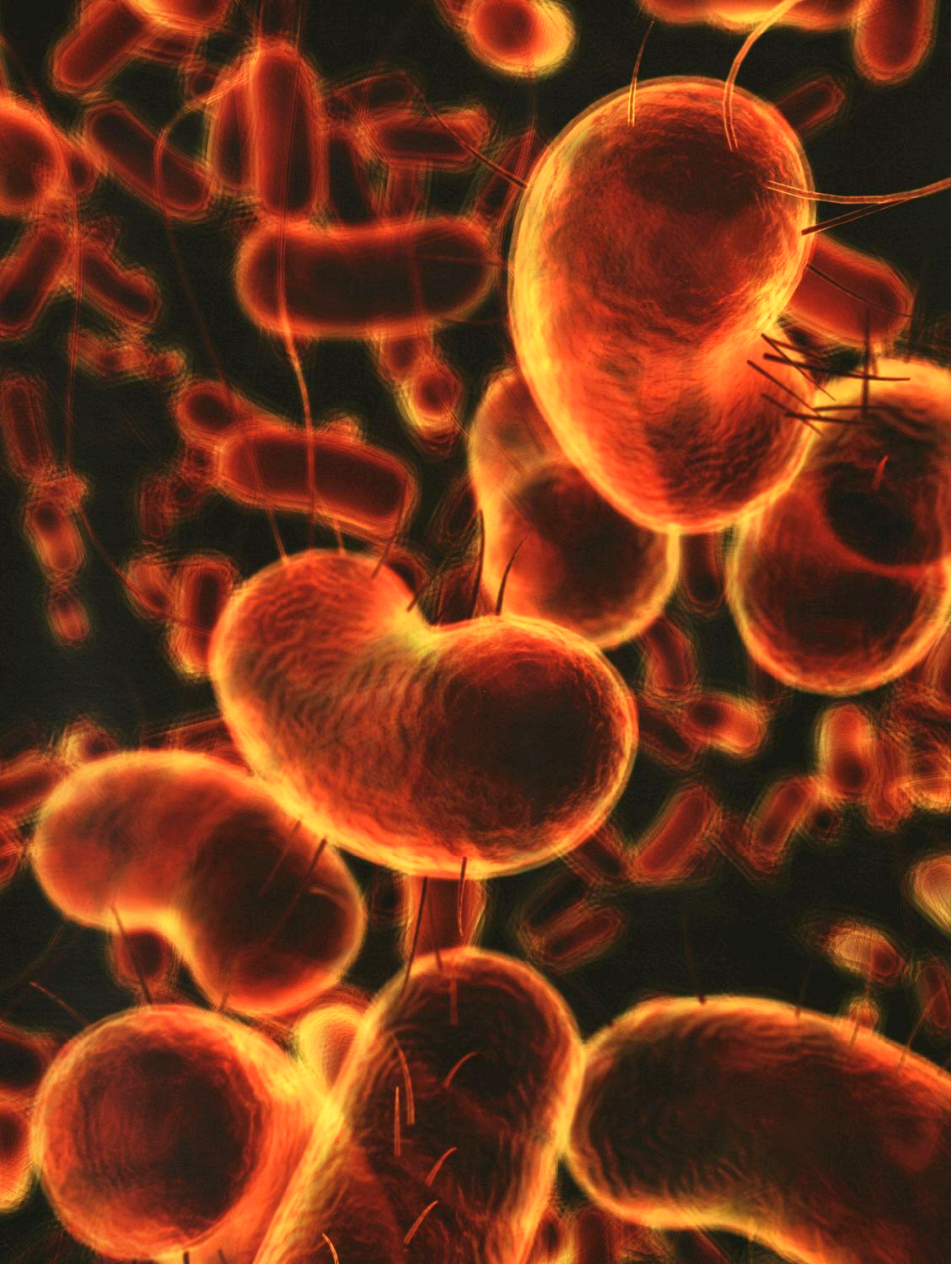
Food safety is important as well—so much so that we devote chapters 2 and 3 to the subject. In addition to these specialized sections, we have provided safety-related notes in many of the recipes. These notes are not meant to be exhaustive—cooks should exercise the appropriate care and caution in every dish they make—but they may call attention to cases where safety issues are not necessarily obvious.

We have 100 how to step-by-step guides that walk the reader through the procedure.

2 MICROBIOLOGY FOR COOKS







MICROBIOLOGY FOR COOKS

Aside from diners at a safari camp on the African savanna, people need not worry about being savaged by wild beasts while they consume their dinner. Yet wild beasts of a different sort can attack us during a meal, albeit at a scale we are not able to see. The dangers of eating come in the form of hidden microorganisms in our food that can render a person deathly ill—or dead. Those tiny microbes can be just as savage and deadly as a lion or a leopard. Because we cannot see germs with the naked eye and because our intuition about what harbors them often fails to work properly, microbes can in some ways be even more intimidating than predators.

Fortunately, centuries of accumulated experience have taught us how to protect ourselves from killers big and small. Health professionals have distilled this body of compiled wisdom into a set of standard rules that most food safety manuals for chefs reiterate in simple form. Just follow the rules, leave the details to the pros, and all will be well—at least that's the unstated assumption. Guidebooks usually gloss over why the rules apply and what lethal properties microorganisms possess. Too often, they explain food safety rules in incomplete ways that are misleading or simply false. Even worse, the guidelines they give are themselves often incorrect, buttressed by false "facts" and scientifically inaccurate descriptions.

Many guides take this somewhat paternalistic approach because they find microbiology intimidating. The science is undeniably complicated. Understanding how and why some foodborne microorganisms sicken or kill us involves learning a bit of biochemistry, some immunology, and dabs of other medical subject matter—all from fields in which the latest thinking may change radically as ongoing research produces unexpected results.

Many professional books on food safety or microbiology dive headlong into so much detail that the discussion loses all practical relevance to kitchen work. Scientific names and jargon clutter the pages, but authors don't clearly explain what every cook truly needs to know—what to do to make the food you prepare safe.

That aspect of food preparation is important in any kind of cooking, but it is particularly crucial for Modernist cuisine, which uses novel techniques so different from ordinary cooking that they seem to fly in the face of many widely accepted rules of thumb, including some related to food safety. Food cooked sous vide, for example, is often held for long times at temperatures that seem quite low by traditional standards. Biology tells us that this type of cooking is safe when done properly. But many guide books—and even some underinformed health departments—suggest otherwise because their opinions have not caught up with advances in science.

We aim in this chapter to describe the most salient facts about how microorganisms can contaminate, poison, spoil, or otherwise damage food. We offer a broad survey of the field, complete with the names and descriptions of key microorganisms, the common terms used by health inspectors and other public health professionals, and the specific steps required to help keep your food safe. Chapter 3 on Food Safety, page 162, covers regulations and more practical aspects of food safety that can help chefs avoid microbiological hazards.

Our hope is that we have captured enough useful detail, without oversimplifying, to impart a solid working knowledge of the fundamental underpinnings of food safety. Together, these two chapters provide enough guidance firmly anchored in science to help you make better-informed judgments in the kitchen. A little well-chosen wisdom will go a long way toward helping you to maintain your focus on which *bonne bouche* to prepare for your guests and to stop worrying about which microbe may be growing in their food.

Disclaimer:

This book cannot and does not substitute for legal advice about food regulations in the United States as a whole or in any U.S. legal jurisdiction. Nor can we guarantee that following the information presented here will prevent foodborne illness. Unfortunately, the many variables associated with food contamination make eliminating all risk and preventing all infections virtually impossible. We cannot accept responsibility for either health or legal problems that may result from following the advice presented here. If you operate a commercial establishment and serve food to the public, consult the rules and health regulations in your area.

Many people have been raised to overcook pork out of a fear of the trichinella parasite (opening photograph), even though it has been almost entirely eliminated from the food supply in industrialized nations. Salmonella (shown in a computer rendering, previous page) is a far more common cause of foodborne illness.

MICROBES AS GERMS

Most threats to food safety can be linked to **microorganisms**: living creatures, typically consisting of a single cell, that can be seen only with the aid of a microscope. These microbes have colonized our planet in astonishing abundance. No one knows how many kinds there are, but many biologists believe the tally of species may be well into the millions—and that's just bacteria!

The vast majority of bacteria and other microscopic life forms are perfectly harmless or even beneficial. That's lucky for us because the human body accommodates a teeming menagerie of microbes inside and out, including tiny mites, fungi, viruses, and bacteria. Some researchers estimate that as many as 500 bacterial species may live on your skin alone, and research suggests that the belly button, inner forearms, and buttocks are also hot spots of microbial biodiversity. The adult human gut is host to roughly 100 trillion microbes spanning some 400 bacterial species. That's pretty impressive if you consider that your entire body contains just 10 trillion or so human cells. And we should welcome these microbial guests because our lives would be difficult or impossible without them. Many of these tiny organisms play crucial roles in digestion, for example.

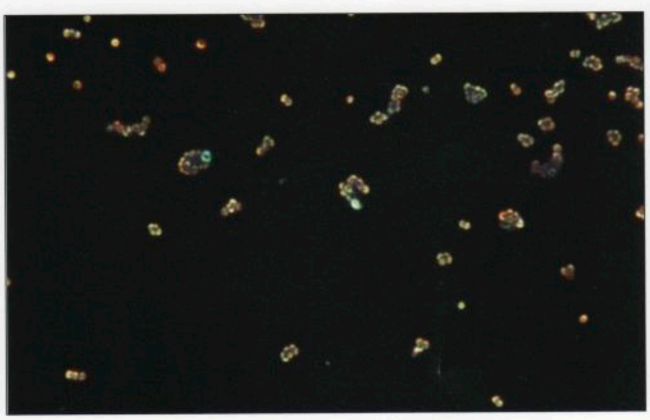
But what about the bad bugs? Scientists refer generically to microorganisms that cause disease as **pathogens** or **pathogenic**; the public calls them germs. Within the broad range of these microorganisms, several major categories of **foodborne pathogens** are the main concern of cooks (see A Bestiary of Foodborne Pathogens, page 108). Each class of microbes presents unique risks and hazards. Cooking and storage methods that thwart one kind of pathogen, for instance, may be useless against another. To maintain good culinary hygiene in the kitchen, a working understanding of the differences and similarities among microbial contaminants is crucial.

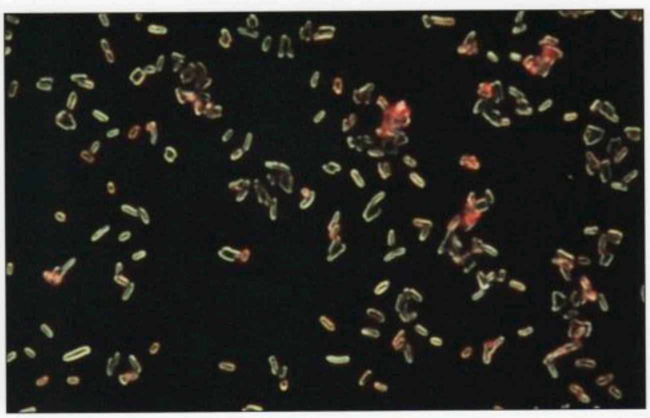
THE TECHNOLOGY OF

Bacterial Staining as a Form of ID

Among the many methods scientists have used to classify bacteria, chemical staining has been a standby for more than a century. The most common method is the Gram stain, a technique that uses a dye developed by the Danish physician Hans Christian Gram in 1884. Researchers label bacteria that stain purple when doused with the dye "Gram-positive" (below left), whereas those that instead take up a pink or red counterstain are "Gram-negative" (below right).

The difference in stain absorption depends on the makeup of the bacteria's protective outer wall. Only some species have a relatively thick, chain-mail-like layer of sugars and peptides that absorbs Gram's dye, which is called crystal violet. Although he did not know exactly how the stain worked, Gram found he could diagnose diseases by using crystal violet to differentiate among bacteria causing similar symptoms—a useful practice that continues to this day.





A Window into the World of Single-Celled Life

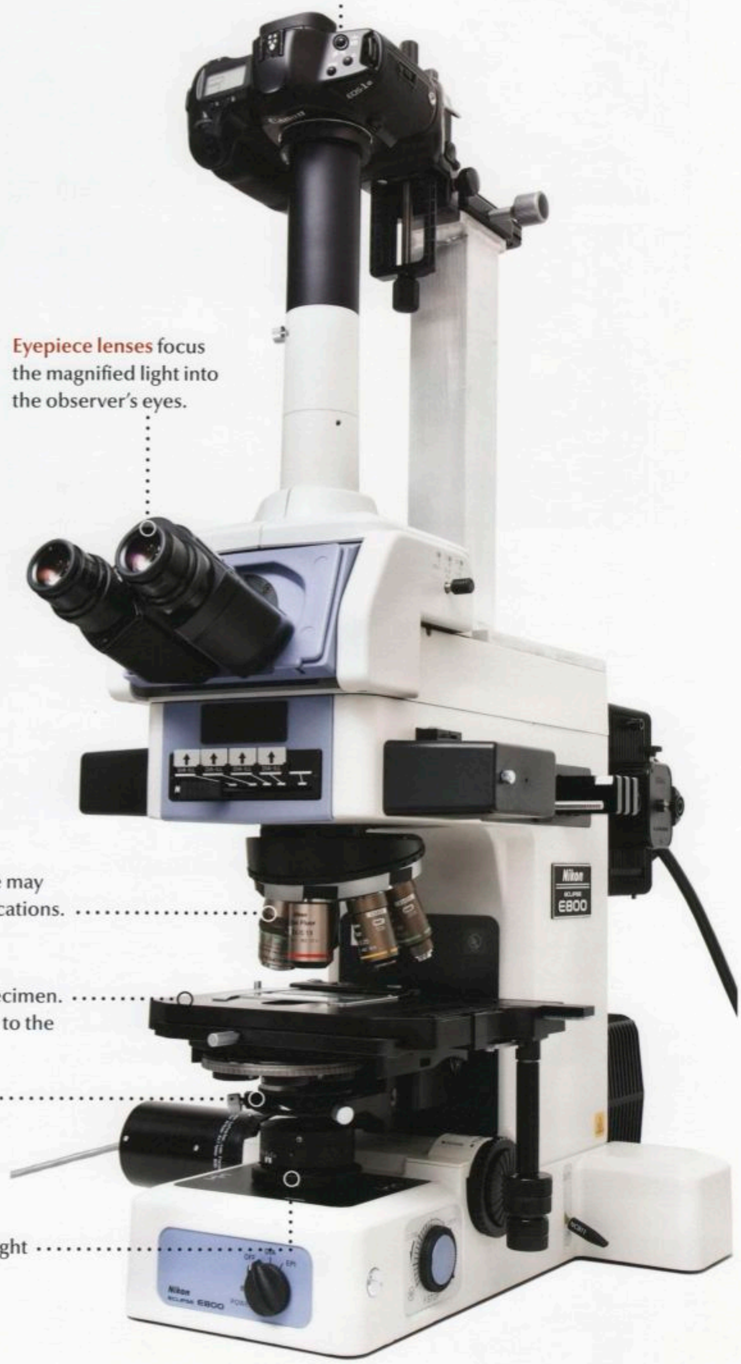
The microscope, the device that opened the microbial universe to human observation, boasts a truly international history. One thousand years ago, pioneers in Europe and the Middle East laid the foundations for the technology by producing simple magnifying lenses that are convex: thick in the middle and thinner toward the edge.

The first true microscope dates to late 16th-century Holland, when a lens grinder there placed two lenses inside a tube and saw that the apparatus could greatly magnify objects in its view. The Tuscan astronomer Galileo, who is more commonly associated with telescopes, studied the initial crude device, then crafted a better version that used a compound lens.

In 1665, British physicist Robert Hooke published the first microscope-aided scientific study, *Micrographia*, an illustrated book that detailed previously unseen marvels such as the porous microstructure of cork that confers its buoyancy. Shortly thereafter, Dutch fabric merchant Antony van Leeuwenhoek began constructing simple but refined single-lens microscopes. He used his instruments to describe insect parts, blood cells, sperm, parasitic worms, protists, and what he called "animalcules"—tiny organisms in dental plaque that were the first recorded observations of living bacteria.

Frequent innovations in the centuries since have produced microscopes that today enable researchers to magnify matter at the subatomic level.

We used this microscope, and several others like it, in creating the pictures for this book.



Digital camera allows users to quickly document objects they see through the eyepiece.

Eyepiece lenses focus the magnified light into the observer's eyes.

Objective lenses magnify the image. A good microscope may come equipped with five or six lenses of various magnifications.

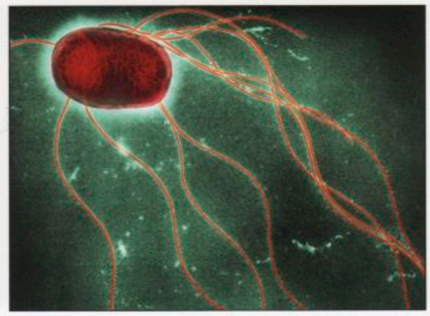
A mechanical stage holds the glass slide with the specimen. Turning the associated knob allows fine adjustments to the portion of the slide that's in view.

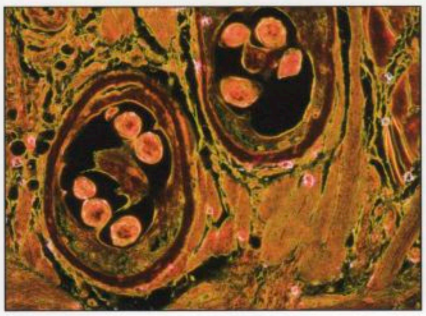
A condenser concentrates light and shines it through specimens to reveal their details. Specialized versions show specimens on a dark background.

An illuminator beams light through the specimen from below.

A Bestiary of Foodborne Pathogens

The foodborne pathogens that are known to science come in a wide array of shapes and sizes, and they vary wildly in their behavior and virulence. The six groups that pose the greatest concern to cooks are listed below from largest to smallest. Each has different risks, but the means of addressing the risks vary in each case. Although plasmids—infectious strands of DNA—can exist within a range of organisms, we discuss them in the context of their bacterial hosts, in which they play critical roles in causing disease.





Parasitic worms (see page 120)

Parasitic worms are the largest of the foodborne pathogens. They can live for decades and grow to dimensions that are clearly visible to the naked eye.

Size: they range from microscopic worms a tiny fraction of a millimeter long to tapeworms that can reach 9 m / 30 ft in extreme cases

Associated illnesses: trichinellosis, anisakiasis, ascariasis, fascioliasis, "fish flu," and taeniasis

Examples: roundworms such as *Trichinella spiralis* (above top and bottom), *Anisakis simplex*, and *Ascaris lumbricoides*;
flukes such as *Fasciola hepatica* and *Nanophyetus salmincola*;
tapeworms such as *Taenia saginata* and *Taenia solium*

Protists (see page 126)

This incredibly diverse group of mostly single-celled microorganisms includes fungus-like, plant-like, and animal-like varieties. Most animal-like protists (or protozoa) are harmless, but a few parasitic species can be deadly, including *Toxoplasma* species.

Size: typically 0.005–3 mm, although brown algae can range from 0.001 mm to 100 m / 328 ft

Associated illnesses: toxoplasmosis, giardiasis ("beaver fever"), cyclosporiasis ("traveler's diarrhea"), and amebiasis

Examples: *Toxoplasma gondii* (above top)
Giardia lamblia (above bottom)
Cyclospora cayetanensis
Cryptosporidium parvum
Entamoeba histolytica

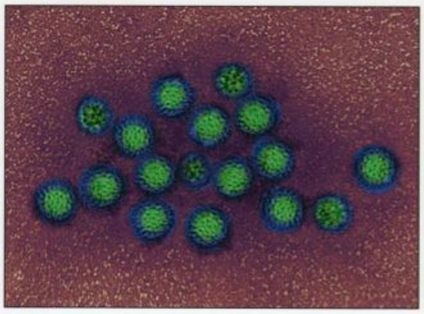
Bacteria (see page 130)

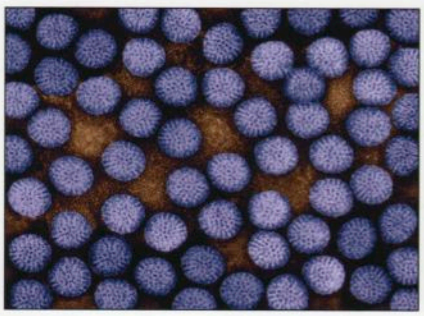
Bacteria are perhaps the most famous form of single-celled life; they are diverse, hardy, and highly adaptive. Bacteria can cause foodborne illnesses in more ways than any other pathogen because they can multiply on food before consumption.

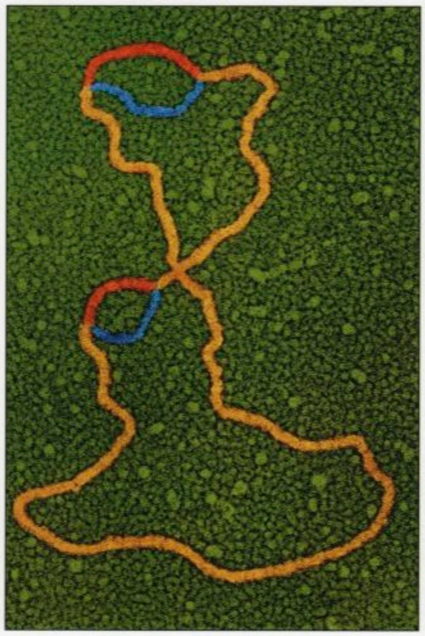
Size: although the typical range is 0.001–0.005 mm, these microorganisms have diameters that run from 200 nanometers (200 billionths of a meter) to 700 microns (700 millionths of a meter, or 0.7 mm)

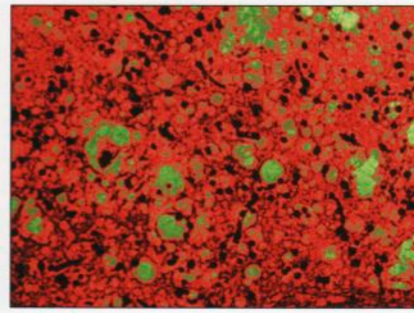
Associated illnesses: salmonellosis, shigellosis, listeriosis, and other bacterial infections such as those caused by *Escherichia coli* strain O157:H7 and *Campylobacter* species; also multiple forms of food poisoning such as botulism

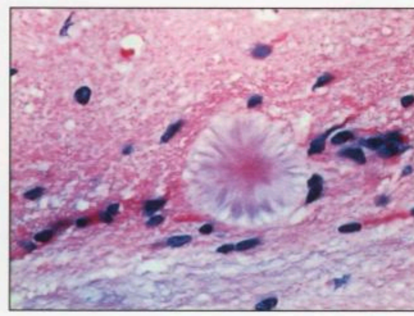
Examples: *E. coli* (above top)
Campylobacter jejuni
Listeria monocytogenes
Yersinia enterocolitica
multiple Salmonella species
multiple Shigella species
Clostridium perfringens (above bottom)
Staphylococcus aureus
Bacillus cereus











Viruses (see page 152)

Because viruses have genes that are composed of DNA or RNA, these microorganisms can evolve like other life forms. Yet most scientists do not consider them fully alive because they cannot grow or reproduce beyond the confines of the cells they infect. A single group, the noroviruses, causes two-thirds of all known foodborne illnesses in the United States.

Size: 20–400 nanometers (billionths of a meter)

Associated illnesses: norovirus-, rotavirus-, or astrovirus-linked gastroenteritis, and foodborne hepatitis

Examples: norovirus (above top)
rotavirus (above bottom)
hepatitis A virus
astroviruses

Plasmids (see page 133)

Plasmids are naked strands of DNA that supplement a microbe's normal set of genes. Multiple and identical copies of a plasmid can exist within the same cell, and in bacteria those DNA strands often move from one cell to another, sometimes converting the recipient into a potent killer.

Size: The plasmids that reside in bacteria can contain from 1,000 to more than 1.6 million base pairs, or "letters," of DNA. If a plasmid's genetic strand were stretched out from end to end, its length could exceed that of the host organism. Plasmid DNA is normally tightly coiled, however, so that many copies can fit easily inside a cell.

Associated illnesses: shigellosis, *E. coli* O157:H7 infection, and many other diseases related to foodborne bacteria

Examples: the pINV plasmid that is required for invasive *E. coli* and *Shigella* bacterial strains to function;
the p0157 plasmid within *E. coli* O157:H7;
the pSS plasmid of *Shigella sonnei*;
plasmids associated with *Yersinia enterocolitica*, *Clostridium perfringens*, and other disease-causing bacteria

Prions (see page 156)

Prions are the simplest pathogens yet discovered; they are infectious proteins that can change normal bodily proteins into misshapen versions that create disease. These "good proteins gone bad" can cause rare foodborne illnesses that eventually prove fatal.

Size: Scientists estimate that a human prion is 4–5 nanometers (billionths of a meter) in diameter

Associated illnesses: kuru (above top) and variant Creutzfeldt-Jakob disease (above bottom); researchers have linked kuru to bovine spongiform encephalopathy (BSE), known informally as "mad cow disease"

Examples: a prion is often referred to by biochemists as either a prion protein cellular, or PrP^{C}, when it is normal, or as a prion protein scrapie, or PrP^{Sc}, when it is abnormally folded and therefore capable of causing disease (scrapie is a disease of sheep that is similar to BSE)

FOODBORNE ILLNESS

Foodborne illness almost always takes one of three forms:

Invasive infection: pathogenic organisms penetrate and grow in human tissue and may secrete toxins. Examples include all foodborne protists and viruses, the parasitic worm *Trichinella spiralis*, bacteria such as *Escherichia coli* O157:H7 and *Listeria monocytogenes*, and the bovine spongiform encephalopathy prion (the agent of mad cow disease).

Noninvasive infection: pathogens live in the gut but do not penetrate it and may secrete toxins there. Examples include the beef tapeworm *Taenia saginata* and bacteria such as *Vibrio cholerae* and *Yersinia enterocolitica*.

Food poisoning: bacteria release toxins into food before it is eaten. Examples include bacterial species such as *Bacillus cereus*, which secretes four different toxins, and *Clostridium botulinum*, the organism that produces the compound in Botox injections that smoothes wrinkled skin.

Scientists have found that food can be a conduit for more than 250 diseases. The more you know about them, especially the common and severe ones, the better you can avoid food-related illnesses. The vast majority of foodborne pathogens sicken people in one of three ways.

An **invasive infection** can occur when microorganisms penetrate a human body and grow within it. This bacterial presence can directly lead to inflammation and disease symptoms. Some microorganisms (primarily bacteria) also secrete toxins. All forms of microorganisms have at least one representative capable of invasive infection.

Certain pathogens that multiply in food remnants in the human gut but do not penetrate gut tissue can cause a **noninvasive infection**, the second primary mode of infection. A noninvasive infection causes illness mainly through secreted bacterial toxins. In general, people with invasive infections suffer more and for longer periods than those with noninvasive infections, but the scope of each condition depends upon the specific interaction between the pathogens and their host.

Food poisoning, the third major mode, results from bacterial contamination only. Certain pathogenic species and their subtypes, or strains, can release very powerful toxins into food long before it is eaten. Food poisoning usually initiates symptoms much more rapidly than infections because the toxins are already in the food when it is eaten, so no time is needed for the bacteria to grow inside the body, as happens in an infection.

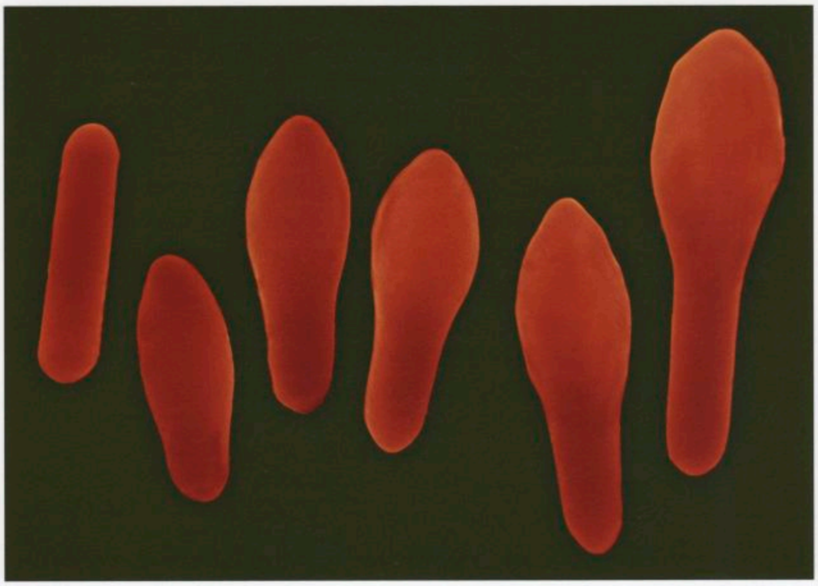
Although it occurs only rarely, some bacteria can cause foodborne illnesses by using various combinations of these three strategies, a further complication for those who administer treatment to patients with food-related maladies.

Tracking Foodborne Illness

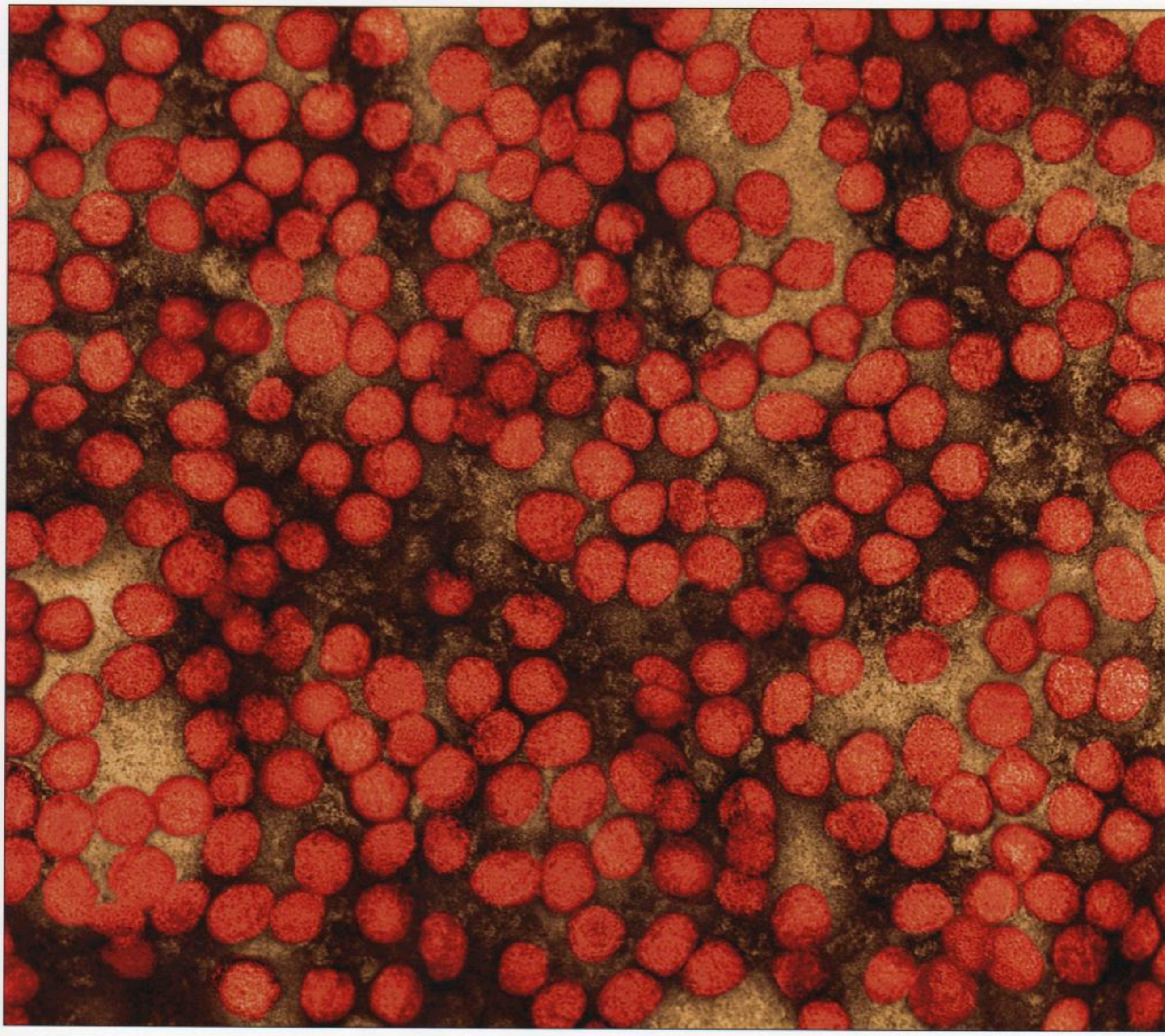
Health authorities find it difficult to track foodborne illnesses, in part because many cases resolve themselves as the symptoms disappear after only a day or two, so many victims do not seek medical attention. And even when they do, doctors seldom report new cases. In 1999, researchers at the U.S. Centers for Disease Control and Prevention (CDC) published one of the best large-scale studies of foodborne illness to date. They relied on data collected by several medical surveillance systems and made careful estimates to track illnesses from 28 foodborne pathogens.

The study's conclusions may not hold true for all parts of the world or even for the U.S. in future years, but the broad patterns it indicates are mirrored in many other developed countries. Unsafe drinking water sources are common in less-developed parts of the world, which makes both foodborne and waterborne disease much more prevalent and serious an issue in those areas.

The incidence of common and even **endemic** (or always present) pathogens can, in addition, vary widely because of economic, geographical, climate-related, and other factors. Cholera and amebiasis, for example, are endemic in many poorer sub-Saharan African countries but are relatively rare in affluent northern European regions. Even so, pathogens do not respect national borders, and the many examples of foodborne illnesses worldwide represent variations on a common theme.



Clostridium perfringens is an anaerobic bacterium that causes some types of food poisoning, a condition caused pig bel, and even gas gangrene. The bacterium (at far left) is rod shaped. Its spores (shaped like bowling pins) are far more difficult to kill with heat. For that reason, the spores can cause food safety problems.



Rotaviruses cause fever and vomiting. They are the main cause of severe diarrhea among children. Although deaths from rotavirus infection are uncommon in developed countries, these pathogens kill nearly one million people worldwide each year.

The two charts on page 113 summarize some of the CDC study's more intriguing findings in this field. The first chart depicts, by type of causal microorganism, the distribution of foodborne illnesses that together caused the roughly 13.8 million annual cases that can be associated with known sources; another 62 million cases are attributed to unknown microbes. Viruses accounted for 9.28 million cases, whereas bacteria caused another 4.18 million, and protists are held responsible for most of the rest, or about 357,000 cases (2.6%) per year. The CDC study links parasitic worms to only 52 cases, and it reports no prion diseases occurring in the United States.

The relative importance of these pathogens changes considerably if you look at the most serious cases of foodborne illness: those that end in death (second chart). Of the estimated 13.8 million annual cases from known sources, only 1,809 resulted in fatalities. Rather than viruses, however, bacteria claimed by far the most victims—1,297 in all (71.7% of the total). Protists rank second with 383 deaths (21.2%)—all but eight of those are blamed on *Toxoplasma gondii*. The death rate for protist infection is much higher than that for other infections, but it is still only about one in every 1,000 cases, so mortality for even the deadliest foodborne pathogens is quite low.

THE ORIGIN OF

Scientific Names

In 1735, the great Swedish botanist Carl von Linné (better known as Carolus Linnaeus) invented a naming system that is still the preferred method for the scientific classification of living things. Under Linnaeus's system, every organism receives a two-part **scientific name**. The first part, the **genus**, is akin to a family's surname, whereas the second, the **species**, refers to a specific representative of that clan.

A typical scientific name of a bacterium, for example, is *Escherichia coli*. In this case, *Escherichia* denotes the genus, and *coli* refers to the species. By convention, researchers italicize the full name, capitalize the first letter of the genus, and leave the species in lowercase letters. An abbreviated scientific name consists of only the first letter of the genus, followed by the full species name: *E. coli*.

The same naming convention applies to nearly all organisms, extant or extinct, which makes the king of the dinosaurs *Tyrannosaurus rex*, or *T. rex*, and we humans *Homo sapiens*, or *H. sapiens*. To refer to an entire genus, the abbreviation "spp." is sometimes used: *Salmonella* spp. means the species within the genus *Salmonella*.

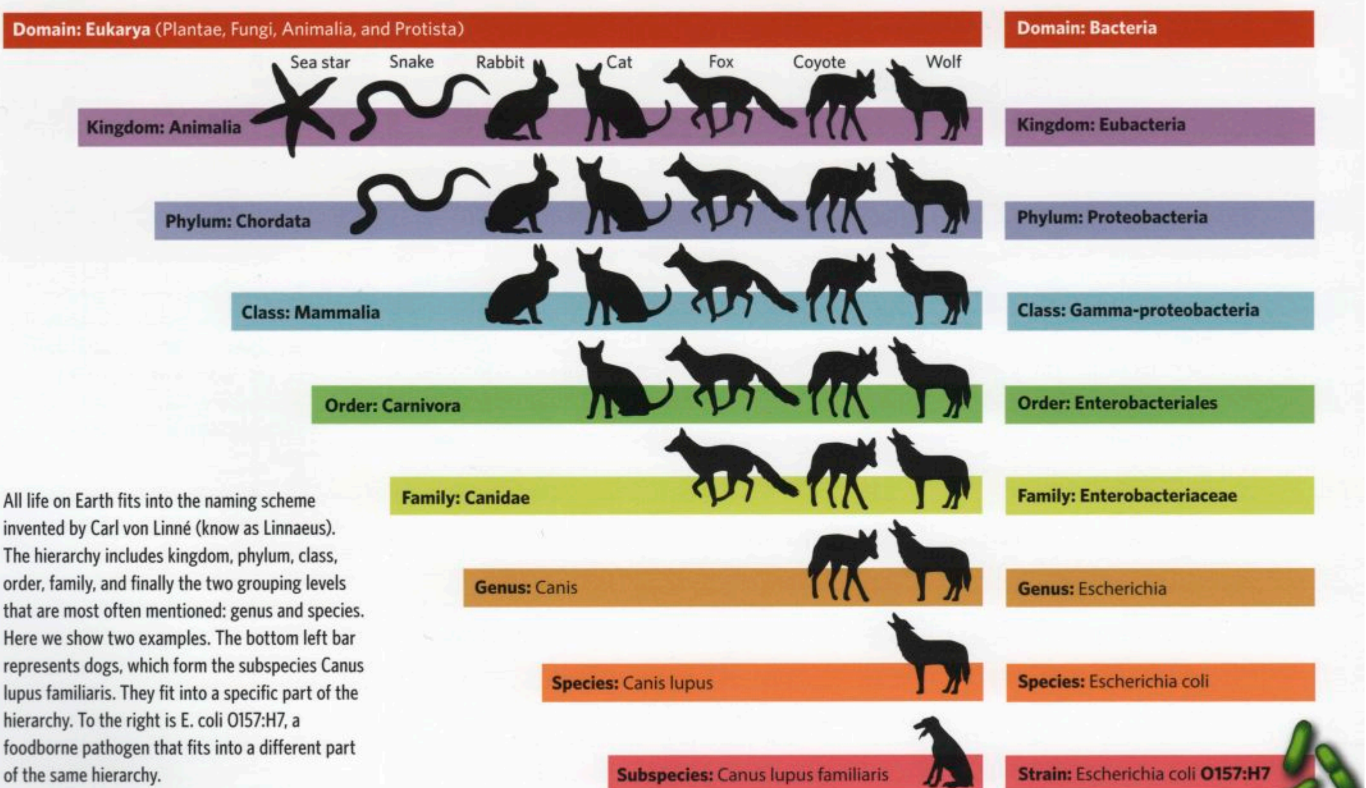
Species in the same genus are close relatives: *E. coli* and *E. albertii*, for example. But they can remain quite different, even though they may still interbreed. *H. sapiens*, for example, differs rather markedly from the now-extinct Neanderthal, or *H. neanderthalensis*.

The person who first describes an organism generally names it as well. Sometimes the scientist's name becomes part of the organism's: *E. coli*, for instance, was named in honor of the German pediatrician Theodor Escherich, who observed the bacterium in 1885.

Scientists have argued for years over how to name viruses. Most researchers now accept a genus-species classification system for viruses while often pairing scientific and informal monikers: Desert Shield virus and Norwalk virus, for example, are two species within the genus Norovirus.

Note that viral species names are often not italicized. Informally, their names still can be a single word—norovirus, for example—or multiple words such as human immunodeficiency virus, otherwise known as HIV.

Naming prions has proved even more problematic, but the largest international database of viral names gives prions their own genus. Labels for other nonliving biological entities such as plasmids do not follow species-naming conventions at all and can be rather complicated.



All life on Earth fits into the naming scheme invented by Carl von Linné (know as Linnaeus). The hierarchy includes kingdom, phylum, class, order, family, and finally the two grouping levels that are most often mentioned: genus and species. Here we show two examples. The bottom left bar represents dogs, which form the subspecies Canus lupus familiaris. They fit into a specific part of the hierarchy. To the right is E. coli O157:H7, a foodborne pathogen that fits into a different part of the same hierarchy.

Foodborne diseases from viruses proved far less severe in general, resulting in only 129 deaths (7.1%), despite the huge number of viral cases. And the few cases that the study ascribes to parasitic worms did not cause any fatalities at all. The CDC study indicates, for instance, an estimated mortality rate of three deaths per 1,000 cases of **trichinellosis**, compared with 200 deaths per 1,000 cases of listeriosis.

Foodborne diseases can be exceedingly common. The CDC study, for example, estimates that every year, some 76 million cases occur in the United States alone—representing a case in roughly one in four U.S. residents. Nevertheless, the vast majority of cases produce few symptoms, and most cases that result in serious illness, hospital admission, or death tend to occur among people who are vulnerable for various reasons: infants, the elderly, or people with compromised immune systems, such as chemotherapy patients or those with acquired immune deficiency syndrome (AIDS) or AIDS-related complex.

But while many people experience a mild bout of foodborne illness, very few die from it in the richer countries of the world. Based on the estimated U.S. population of 273 million in 1999, the odds of someone dying from a foodborne illness that year in the United States would have been about one in 52,500. Given that Americans consumed about 300 billion meals that year, the odds of any particular meal proving lethal were about one in 58 million.

Compare that with the risks of driving to dinner or the supermarket. In the same year that the CDC did its study, about 42,000 Americans were killed in motor vehicle accidents, yielding odds of one in 6,500 of dying from a car crash that year, a factor of eight higher than the odds of dying from foodborne illness. This comparison in no way minimizes the importance of taking adequate precautions to avoid foodborne illness, of course, but provides perspective. It is worth remembering that life carries risks and that the risk of fatalities resulting from foodborne diseases is considerably lower than those related to other routine activities.

Contamination Sources

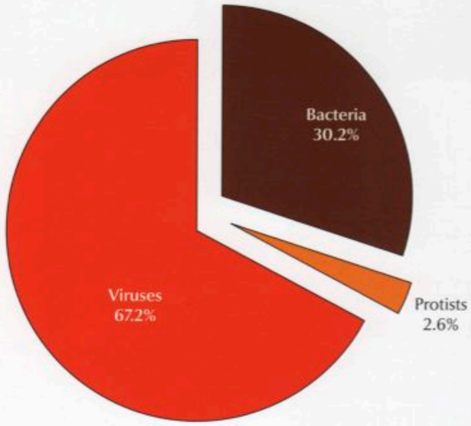
Food is not a natural habitat for pathogenic microorganisms. Instead, it must be contaminated from external sources with live organisms, their spores,

Viruses Sicken, but Bacteria Kill

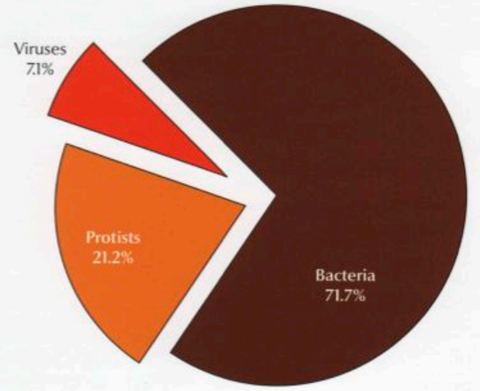
The vast majority of illnesses and deaths from foodborne microorganisms in the United States are caused by three kinds of microbes: viruses, bacteria, and protists, according to estimates made in 1999 by researchers at the U.S. Centers for Disease Control and Prevention (CDC). Viruses, led by norovirus infections, are the biggest culprits in foodborne morbidity. They are implicated in about two-thirds of illnesses from contaminated food (left).

But most viral illnesses are mild, so the picture for mortality (right) is quite different. Protists, which cause fewer than 3% of cases, result in more than 20% of deaths, due in large part to the lethality of Toxoplasma gondii. And although bacteria may cause fewer than half of foodborne illnesses, they are blamed for almost 75% of fatalities; salmonellas and listerias are the worst offenders. The only parasitic worm included in the CDC study is Trichinella spiralis, which is so rare a pathogen as to barely show up in the statistics.

Illnesses by organism



Deaths by organism



THE DIAGNOSIS OF

Which Bug Is to Blame?

Definitive diagnoses of most foodborne illnesses require the expertise of physicians and advanced tests. In fact, doctors working without test data commonly misdiagnose foodborne illnesses. Determining the true causes can require specialized techniques, such as tests that identify pathogenic DNA and the timing of a patient's exposure to the contaminant. Most physicians do not, in practice, diagnose a foodborne illness unless it is severe or part of an outbreak that affects many people.

The type, timing, and severity of symptoms can, however, point physicians and health professionals toward the offending pathogen. The sudden onset of vomiting, for example, can often be linked to food poisoning from bacteria such as *Bacillus cereus.*

The list below gives a simplified version of the guidelines that health professionals use to determine whether an illness is related to the consumption of food. Confirmation of that link requires biomedical test results.

CLASS OF SYMPTOMS

Gastroenteritis
(primarily vomiting but also possibly fever and diarrhea)
Common culprits: rotavirus in an infant; norovirus or related viruses in adults; food poisoning from ingested toxins of *Staphylococcus aureus* or *Bacillus cereus.* Symptoms can also indicate heavy-metal poisoning.

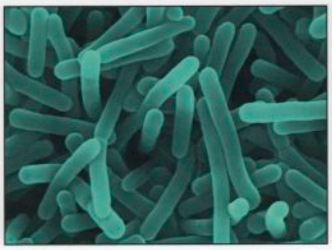
Noninflammatory diarrhea
(usually no fever)
Common culprits: nearly all foodborne pathogens, including bacteria, protists, and viruses. Noninflammatory diarrhea is a classic symptom of *Escherichia coli* toxin in the small intestine.

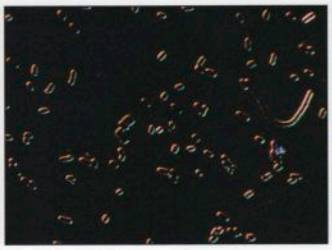
Inflammatory diarrhea
(often bloody stools and fever)
Common culprits: invasive bacteria such as *Shigella* spp., *Campylobacter* spp., *Salmonella* spp., and *E. coli*; the protist *Entamoeba histolytica.* Inflammatory diarrhea can be a sign of invasive gastroenteritis in the large intestine.

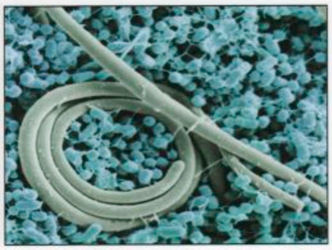
Persistent diarrhea
(lasting days to two or more weeks)
Common culprits: parasitic protists, including *Cryptosporidium* spp., *Cyclospora cayetanensis*, *E. histolytica*, and *Giardia lamblia*.

Neurologic symptoms
(tingling or numbness, impaired vision, breathing difficulties)
Common culprits: botulism caused by the bacteria *Clostridium botulinum*; poisoning by pesticides, thallium, or mushrooms; toxins from fish or shellfish.

General malaise
(weakness, headaches, muscle and joint pain, fever, jaundice)
Common culprits: bacteria such as *Listeria monocytogenes*, *Salmonella typhi*, and *Brucella* spp.; worms, including *Trichinella spiralis*; viruses such as hepatitis A; protists, including *Toxoplasma gondii.*







TIME TO ONSET OF SYMPTOMS AFTER EXPOSURE

½–8 h: ***Staphylococcus aureus***
1 h–1 d: ***Bacillus cereus***
2 h–8 d: ***Clostridium botulinum*** **and its toxins**
6 h–1 d: ***Clostridium perfringens***
6 h–10d: ***Salmonella*** **spp. (nontyphoidal)**
9–48 h: ***Listeria monocytogenes*** **(initial gastrointestinal symptoms)**
12–48 h: **norovirus**
12 h–6 d: ***Shigella*** **spp.**
1–3 d: **rotavirus**
1–10 d: ***E. coli*** **O157:H7,** ***Yersinia enterocolitica***
2–10 d: ***Campylobacter jejuni***
3 d–3 wk: ***Giardia lamblia***
10–13 d: ***Toxoplasma gondii***
15 d–7 wk: **hepatitis A**

or their eggs, which are otherwise known as **oocysts**. Each pathogenic species has a characteristic source of contamination, as well as a distinct **infectious dose**, which refers to the number of organisms an average person would need to consume before contracting a foodborne illness.

Many of the pathogens that most commonly cause foodborne illness spread predominantly through the secretions (such as saliva) and excretions (such as feces and vomit) of animals, including humans. It is therefore not much of an exaggeration, if any, to say that just two basic rules would prevent 99% of foodborne illnesses, if only people could follow them scrupulously:

1. Do not consume the feces, vomit, or spittle of other humans.
2. Do not consume the feces, vomit, or spittle of animals.

Sounds simple, right? The unfortunate fact is that this is much harder to do than it would naively seem. The surprising situation is that food safety problems are not, to first order, intrinsic to the food supply, as many people seem to believe (see Common Misconceptions About Microbes, page 117). In truth, the problem is us: the cooks and consumers of food, who typically buy that food clean and then too often contaminate it ourselves as we handle it.

To discern why this is true, it helps to understand a few technical concepts. In most cases, just one microbe is not enough to cause illness. The exact number that does lead to symptoms, the so-called **infectious dose**, varies according to the individual—some people can tolerate more pathogens because of differences in their digestive tract or immune system. Scientists thus often speak of the number of microorganisms that gives the disease to 50% of the individuals exposed to it. They call that average infectious dose the **ID_{50}**. Similarly, the **lethal dose** corresponds to the number of organisms required to kill an individual, and the **LD_{50}** refers to the dose that kills half of those exposed to it.

During, and immediately after, an illness, infected hosts can shed pathogens through their feces. The **fecal load** refers to the number of disease-causing organisms in one gram (four hundredths of an ounce) of contaminated feces that an infected person or animal releases. Although the numbers can vary considerably based on the characteristics of both the invading microbe and host, the fecal load for many foodborne pathogens is around 100 million organisms a gram.

As a theoretical exercise, consider what that statistic means for a pathogen that has an ID_{50} of one, meaning that half the people consuming a single microbe would become infected. Then a single gram of feces harboring 100 million of the microbes could, in principle, infect 50 million people. The total feces shed (usually as diarrhea) during the course of an illness contain enough

A Dose of Pathogen-Related Terms

Infectious dose: the number of organisms (viral particles or bacterial cells, for example) required to cause an infection in a particular individual

ID_{50}: the number of pathogens per individual required to cause infection in 50% of test subjects

Lethal dose: the number of pathogens required to cause fatal disease in a particular individual

LD_{50}: the number of pathogens per individual that causes fatal disease in 50% of test subjects

Fecal load: the number of pathogens per gram in a sample of human or animal feces

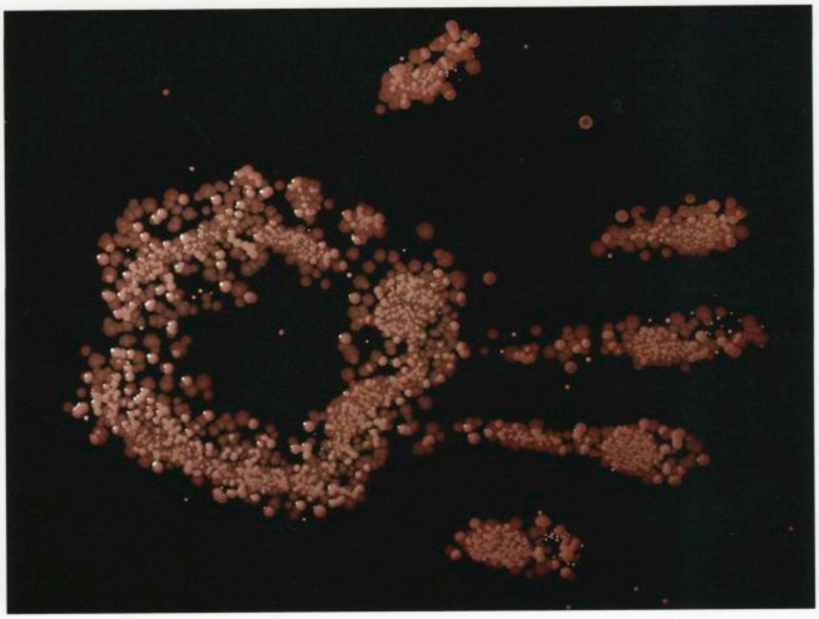
THE SCIENCE OF

Determining the Infectious Dose

Public health professionals determine infectious dose numbers in a two-stage process. In the first phase, specialists who investigate food-related outbreaks measure the amount of contamination in the pathogen source. They also estimate the size of the portion of contaminated food its victims consumed, then calculate the average infectious dose (ID_{50}).

After that, other researchers attempt to confirm the projected infectious dose level through volunteer studies in which healthy people consume measured amounts of a specific pathogen. For ethical reasons, these studies are not done for serious or potentially fatal diseases, but they yield solid numbers for less severe diseases.

Different strains of the same pathogenic species can have vastly different infectious doses. Some strains of *E. coli*, for example, require as many as 100 million microorganisms for an infection, whereas other strains can be infectious with as few as 50. Noroviruses have ID_{50} values estimated at fewer than 20 viral particles. For a few foodborne pathogens, the ID_{50} is as low as one—meaning that for half a population, ingesting a single microbe is enough to cause an infection.



Place an unwashed hand on a petri dish full of growth medium, and this is what sprouts forth: a menagerie of microbial life, not all of it friendly. For more on how to wash your hands and kitchen equipment properly, see Hygiene, page 196.

pathogens to theoretically infect a continent or perhaps even the entire world—should some supervillain figure out a way to distribute them.

The point is simply to illustrate what an incredibly tiny quantity of pathogen it takes to cause a tremendous amount of disease. That extreme ratio is one of the primary reasons for the ubiquity of foodborne illness. Looked at another way, if a tour boat flushes one liter of feces into a very large lake and it becomes diluted in 100 cubic kilometers of water, a liter of water from the lake could still contain enough pathogens to infect an average person. Indeed, after an outbreak of *Escherichia coli* sickened 21 children in 1991, investigators determined they had become infected after swimming in a lake near Portland, Oregon, that was contaminated with feces from other bathers.

Pathogenic bacteria generally have infectious doses that are higher, so the ratio is not as extreme. If a strain of *E. coli* has an infectious dose of 100 million organisms, for example, you might think you would have to eat a gram of feces to get to sick—a very unlikely scenario.

But bacteria often multiply on the food after contamination. Under favorable conditions, a single *E. coli* bacterium can produce millions of progeny in just a day. So even a tiny amount of fecal contamination that puts a small number of the wrong bacteria on food can cause a problem.

This might lead you to conclude that ingesting fecal matter is a serious—and often deadly—public health problem. And indeed, the CDC study estimates that 9.6 million annual cases of foodborne disease are linked to fecal contamination. But fecal matter leads to such illnesses only when it harbors pathogens. Fortunately, most people and domestic animals do not routinely excrete pathogen-laden feces. Among humans in particular, most pathogenic organisms in feces emerge during the course of a foodborne illness or during a limited window of a few days to a week afterward.

Unfortunately, this discussion implies a rather uncomfortable fact: *we all regularly consume feces-contaminated food.* For a variety of practical reasons, we can't always follow those two simple rules about not consuming feces or body fluids.

Most of the time, we get away with it. But given the minuscule quantities of organisms needed to contaminate food, how do we reduce the risk? The next chapter, Food Safety, describes various approaches to achieving that goal, all of which mainly boil down to minimizing the opportunity for pathogens to get into your kitchen—and preventing those that do get in from establishing a foothold.

Don't Eat That....

The technical term for the transmission of contaminated feces from one person to another is the **fecal-oral route**. Contamination by the human fecal-oral route normally occurs in a very straightforward way: via poor hygiene. Namely, after using the toilet, people who handle food either do not wash their hands or do so improperly.

Cross-contamination of one food source by another or by contaminated water also spreads fecal matter. Human fecal contamination can even occur in the ocean via filter-feeding clams and oysters—more on that shortly.

Aside from exposure to human feces, foodborne illness spreads chiefly through four other types of contamination: animal feces, soil-based and free-floating microbes, human spittle, and animal flesh. Animal fecal contamination of food occurs primarily on the farm or in the slaughterhouse. Washing baths are particularly prone to contamination by animal feces because even a small fleck of feces in a washing tank that cleans multiple carcasses can contaminate all of them. Animal feces also can contaminate fruit and vegetable crops, either in the field or through cross-contamination at various points along their path from initial production to the dinner plate.

Environmental contamination involves generally ubiquitous microbes. *Clostridium botulinum*, for example, is widespread in soil, whereas many *Vibrio* species thrive in seawater. *Staphylococcus aureus* and related species normally live quietly on human skin, in the nose, and elsewhere in the environment, but they can do considerable damage if they are allowed to grow on food and produce toxins that cause food poisoning. Staphylococcus species alone can secrete up to seven different kinds of poisons.

Human oral contamination mainly occurs from spittle. Group A streptococcus, the bacterial strains that are to blame for strep throat, are common malefactors spread this way. Most restaurants use "sneeze guards" at salad bars to cut down on oral transmission of strep infections by blocking the fine mists of spittle that people eject during sneezes or coughs.

Finally, flesh contamination, although not as common, is the primary source of infection by some parasitic worms and by a form of salmonella that infects hen ovaries and subsequently contaminates their eggs.

Even if you know the foodborne pathogen that is causing an infection, however, tracing that infection back to its original source of contamination can be tedious and ultimately futile. Consider the bacterial pathogen *Yersinia enterocolitica*. According to the U.S. Food and Drug Administration, the microbe can be transmitted through meat, oysters, fish, and raw milk, among other foods. But the species is common in soil and water samples, as well as in animals such as beavers, pigs, and squirrels.

Poor sanitation and sterilization by food handlers could contribute to contamination. So could infected workers who spread the disease through poor hygiene. So for that one foodborne pathogen, an illness could arise from environmental, human fecal, or animal fecal contamination.

Likewise, campylobacter infections are normally associated with fecal contamination. But raw milk can become contaminated by a cow with an infected udder as well. Many other foodborne pathogens can also exploit multiple avenues to reach the kitchen—one reason why they can be so difficult to avoid ingesting.

Even so, a review of the records of foodborne outbreaks in which the source has been identified suggests that an overwhelming majority are linked to fecal contamination. And that means that most food contamination occurs through an *external* source—it is basically dirt (or worse) on the outside that never reaches the interior of the food.

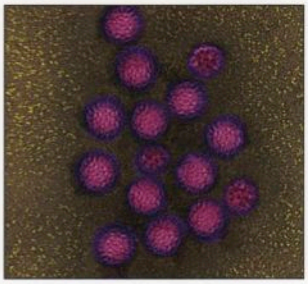
There are some important exceptions to this rule of thumb: oysters and clams, for example, are filter feeders and can internalize feces from contaminated water. Salmonella can contaminate intact eggs. Nevertheless, the fact that most microbial contamination arrives from a source beyond the food itself has multiple implications for food safety and kitchen practices, which are the subject of the next chapter.

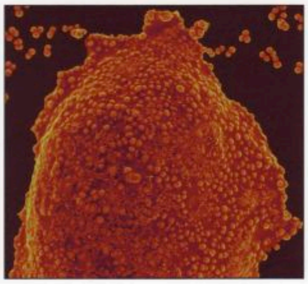
Common Misconceptions About Microbes

As we began looking closer at research on the main kinds of foodborne pathogens, we were frankly somewhat surprised to learn just how large a fraction of foodborne illness is caused by contamination by human or animal fecal matter. Like many people with culinary training, we had assumed that the problem was intrinsic to the food supply. Before a pig becomes pork, for example, the worm *Trichinella spiralis* that causes the disease trichinellosis (also called trichinosis) can infect the animal. Salmonella lurks in eggs and chickens as a matter of course. We had naively assumed that all food pathogens are somehow just present in the food or its environment.

But for the vast majority of foodborne illnesses, that just isn't the case. Consider trichinella, which burrows into the muscle of contaminated pigs. Our mothers taught us to always cook pork well-done—or else. That dire warning is repeated in many cookbooks, web sites, and even culinary schools. Fear of trichinellosis has inspired countless overcooked pork roasts.

In reality, however, the U.S. pork industry has succeeded in essentially purging trichinella from pig farms—and just in case any slips through, the industry routinely freezes the meat, which





Fighting viral threats (top) may have the biggest impact on foodborne illnesses in developed countries, whereas reducing contamination by bacteria (middle) and protists (bottom) could lead to the largest decrease in deaths.

kills the worm and its oocysts. For these and other reasons that cooks in well-developed countries need no longer worry about trichinellosis from pork, see Misconceptions About Pork, page 179.

The common fretting about trichinella is a symptom of an enduring problem with the transmission of all kinds of food safety information from health professionals to the public: it's not getting where it needs to. While millions of cooks in restaurants and homes overcook their pork with almost religious zeal, few have ever heard of the noroviruses that, through food, sicken nine million Americans every year.

Overemphasis on the wrong pathogen also occurs with botulism—a foodborne disease that strikes fear into the hearts of cooks everywhere. The CDC study mentioned earlier estimates that a mere 58 cases a year of botulism occur in the U.S., causing four deaths. Any death is tragic, of course, but one needs to place the numbers in perspective; more than 20 times as many people die every year in the U.S. from hornet, wasp, or bee stings (82 in 2005).

Meanwhile, *Toxoplasma gondii,* a protist primarily found in the feces of pet cats, sickens 112,500 people a year, killing 375 of them and thus claiming nearly 100 times as many victims as botulism does. Indeed, toxoplasma is the primary reason that protists command such a fat slice of the pie chart on page 113—*T. gondii* alone accounts for 98% of all protist-related fatalities. Toxoplasma may cause schizophrenia and other psychological damage as well (see page 126).

Not all microbial infamy is undeserved, of course. *Salmonella* really is as dangerous as most people imagine. But here, too, confusion reigns over the true source of contamination.

Salmonella bacteria do not live in chicken meat (muscle tissue), the source most commonly fingered as the culprit. Instead, the bacteria normally live in the intestinal tracts and feces of chickens and can contaminate the meat during slaughter and processing (except *S. enteritidis,* which can infect hen ovaries and contaminate intact eggs regardless of fecal contact).

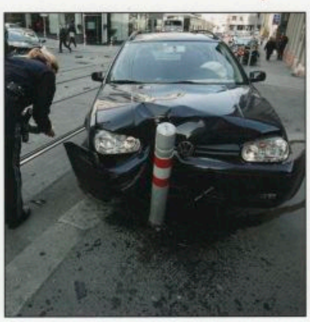
The poultry industry has made enormous strides in containing contamination, and chickens are far from alone in spreading the disease. In 2008, for instance, U.S. investigators traced a major outbreak of salmonellosis to tainted peanut butter and other peanut-containing foods. Investigations of the sources of other recent contagions have implicated hot peppers and tomatoes.

Similar misinformation underlies an even broader food-related safety belief. The public tends to view meat, fish, and poultry as being more suspect than fruits and vegetables, particularly with regard to the frequency of contamination by bacterial pathogens like *Salmonella* species and *E. coli* O157:H7. Yet this is emphatically not so.

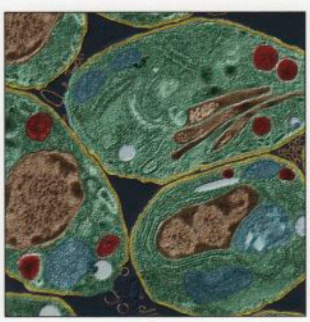
What matters most are the specific ways foods are handled. Because bacterial foodborne illness generally results from exposure to feces, it follows that agents such as *E. coli* O157:H7 *can contaminate any food.*

E. coli does infect cattle and is found in their feces, but meat-packing plants have worked hard to avoid contamination in the slaughterhouse, and

Annual mortality rates in the U.S. from:



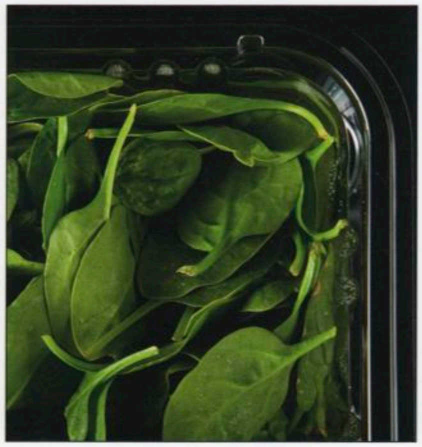
Traffic Accidents:
one in 6,500



Foodborne Toxoplasmosis:
one in 728,000

Hornet, Wasp, and Bee Stings:
one in 3.6 million

Foodborne Botulism:
one in 68 million



Strawberries, spinach, and peanut butter are just as likely to harbor foodborne pathogens as meat, fish, and poultry are. Most recent outbreaks of foodborne illness have, in fact, been linked to fruits, vegetables, and nuts.

widespread outbreaks have been relatively rare in recent years. Investigators, in fact, traced the largest recent outbreak of *E. coli* infections in the United States to contaminated baby spinach.

The 2006 episode led to 205 confirmed illnesses, three deaths, and a tentative link to wild boars living in the coastal mountains of California. Epidemiologists discovered that the boars had become infected with *E. coli* O157:H7, probably by consuming the feces of infected cattle. The boars presumably passed on the bacterial contamination when they defecated in spinach fields. The harvested spinach was washed, but this seems to have simply diluted and spread the contamination from a few isolated samples to the entire output of the processing plant.

Previous outbreaks of *E. coli* infections in the U.S. have involved strawberries, lettuce, and other produce. Meat, particularly ground beef, also has been implicated, but the common assumption that *E. coli* contamination is primarily a problem with meat doesn't square with the facts.

Why do trichinella and botulism evoke such paranoia while toxoplasma and noroviruses are virtually ignored? Why do so many people disregard the most common and easily thwarted sources of contamination from foodborne bacteria? It seems clear that people don't know all that they should about the true distribution and traits of parasitic worms, protists, bacteria, viruses, and other food pathogens. We hope the rest of this chapter sheds some light on the subject.

THE ETYMOLOGY OF

Disease Names

Just as biologists follow naming conventions for pathogens, medical professionals have developed a method of naming diseases. Several different approaches are used, which can make things confusing to the uninitiated.

One common convention is to append "-osis" or "-asis" to the root of the pathogen's genus. An infection with *Trichinella* spp. therefore becomes **trichinellosis.** Medical authorities sometimes modify this straightforward method to yield less obvious derivatives. Thus, infection with the protist *Entamoeba histolytica* is called **amebiasis.**

When the pathogen is unknown or ill-defined, medical researchers may name a disease or condition after its symptoms. The term **gastroenteritis**, for example, describes an acute infection of the gastrointestinal system without specifying the responsible pathogen.

Finally, doctors refer to some diseases or disease conditions by ad hoc names, bowing to popular usage or medical tradition. Botulism and strep throat are all well-known examples.

PARASITIC WORMS

Fear of *Trichinella spiralis*, perhaps the most infamous foodborne worm, has inspired countless overcooked pork roasts. The trichina is widely dreaded for its ability to burrow into the muscles of pigs and other livestock, inflicting people who eat the contaminated meat with the disease trichinellosis (also called trichinosis). Most of us learned of the danger from our mothers as well as from some public health authorities and nearly all cookbook authors, who have insisted for years that pork should always be cooked well-done.

Yet in reality the *Trichinella* roundworm has little impact on either the number or severity of foodborne disease cases in the United States. A CDC surveillance report that covers the years 1997–2001 confirms that physicians have seen case loads associated with eating pork plummet: of 55 cases in which people developed symptoms of trichinellosis, investigators could link only eight to commercial pork products purchased in the U.S. Most of the few dozen other cases resulted from eating the meat of wild game—bears in particular, but also boars and mountain lions—or pork obtained directly from farms or home-raised pigs, to which industry standards and regulations do not apply (see Misconceptions About Pork, page 179).

Although concern about foodborne worms can be overblown, no one wants to harbor parasites that can stick around for years or even decades. So all cooks should know some basic facts about the parasitic roundworms, flukes, and tapeworms that sometimes make their way into the food supply.

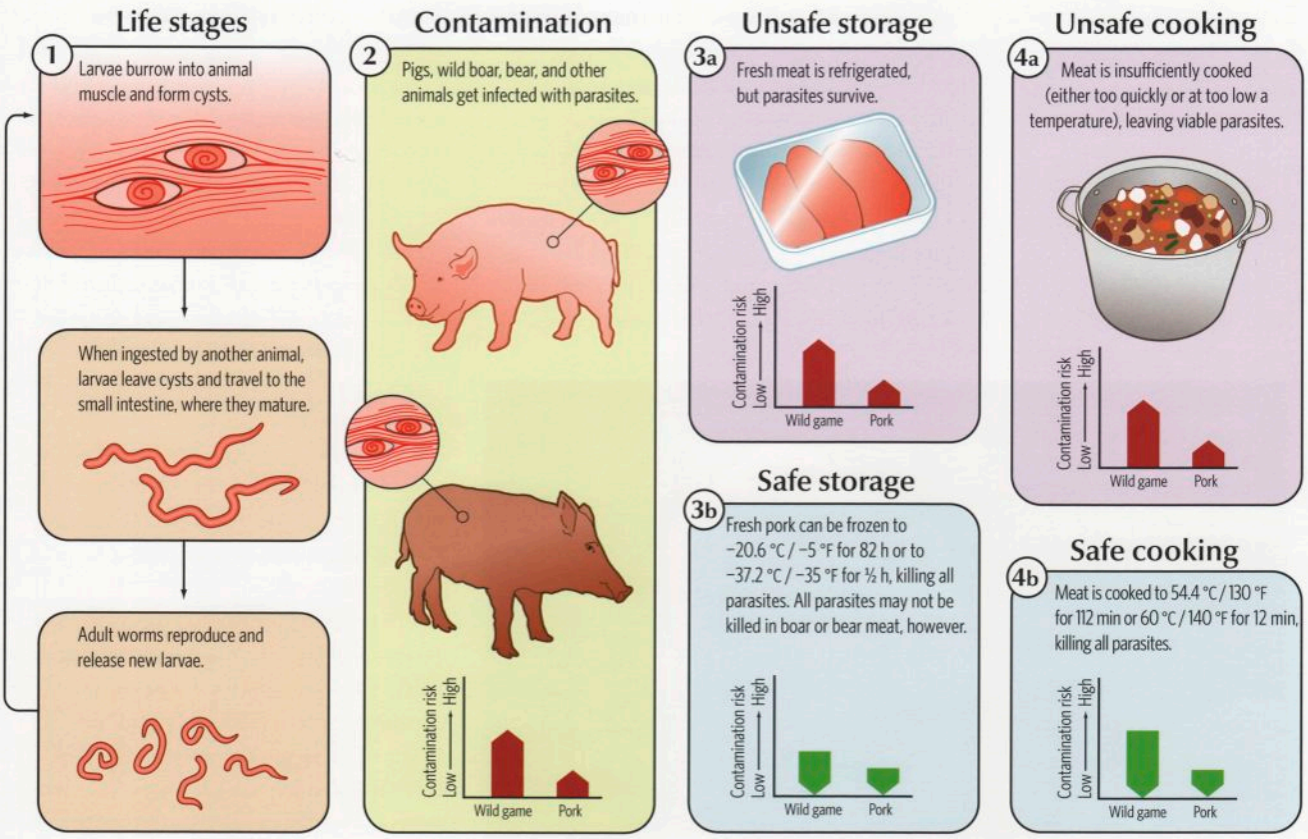
The diversity of these organisms is underappreciated. Beyond *Trichinella* and other roundworms or **nematodes**, foodborne worms of note include flukes (trematodes) and tapeworms (cestodes). In general, these parasites produce disease through two main mechanisms: the worms either penetrate body tissue during invasive infections, or they live in the gut as noninvasive infections.

Roundworms, such as this female Trichinella, are among the few foodborne pathogens that naturally exist inside intact meat or fish.

How *Trichinella* Can Get into Meat

An invasive infection by worms, typified by the *Trichinella* life cycle, begins when an animal consumes muscle tissue that contains encysted worm larvae. Freed from the tissue by the new host's digestive process, the larvae rapidly mature into male and female adults, which mate and release new larvae. Each larva burrows into a muscle cell, converting it into a so-called nurse cell by secreting proteins that promote the formation of blood vessels. Blood vessels then grow around the larva and feed it. Larvae can live in protective calcified cysts for years until the host dies and is eaten, which starts the cycle anew in another host.

Trichinella worms can survive refrigeration, but sufficient freezing will kill the worms in pork. For other meats, and as an alternative for pork, safe cooking practices will render any worms in the food harmless.



Roundworms

Flesh-burrowing roundworms are among the few pathogens that normally live inside human food, typically buried deep inside the muscle tissue of domestic pigs as well as wild boars, bears, and other carnivorous animals. One *Trichinella* subspecies that lives in polar bears and walruses has been linked to outbreaks among Inuit communities near the Arctic Circle.

With few exceptions, *Trichinella* infections do not cause death, although they can cause serious cardiac or neurological complications if they enter the heart or brain. Once the larvae invade tissue, they wait patiently for the host to die. In the wild, dead animals are invariably eaten by scavengers, which gives trichinae a chance to propagate.

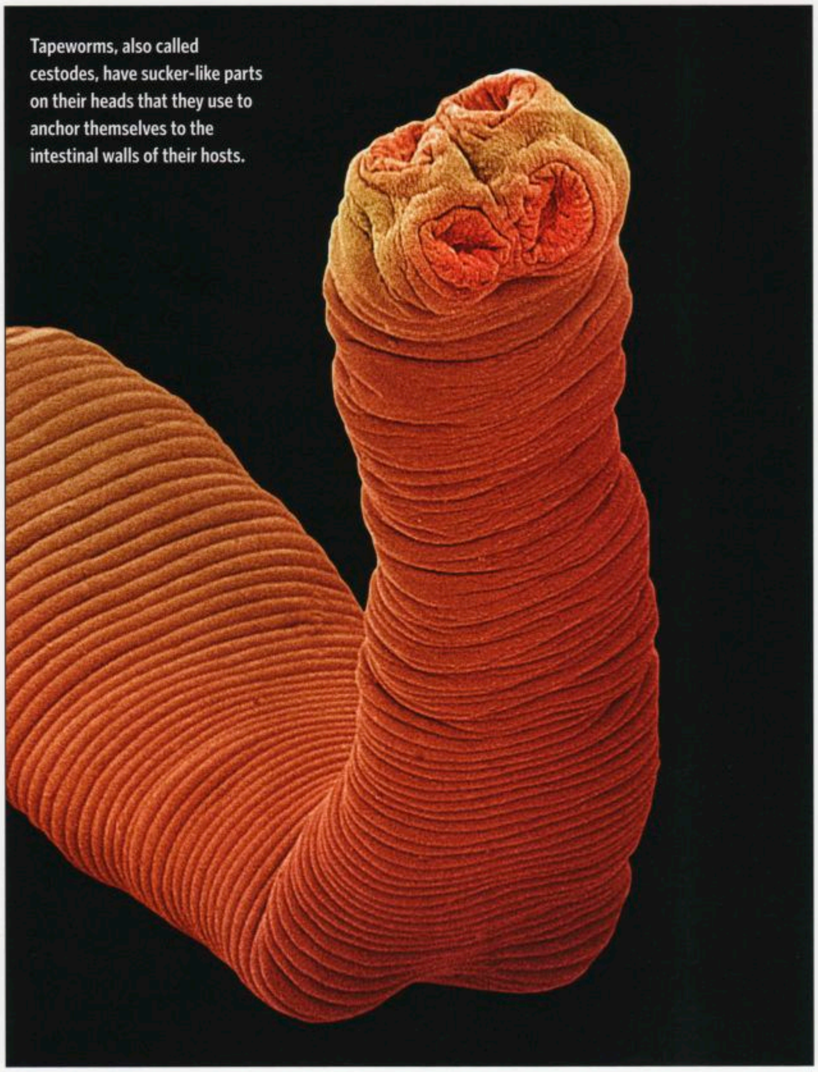
One way to prevent trichina worms from infecting livestock is to cook farm slops or feed that contains meat scraps before giving it to pigs. In the kitchen, however, killing trichinae does not require the excessive heat that most people imagine. The FDA Food Code recommends using the same time-and-temperature combinations for cooking pork as it does for cooking beef or lamb (for example, 54.4 °C / 130 °F for 112 minutes or 60 °C / 140 °F for 12 minutes). U.S. Government regulations for killing trichinae specify even lower values: 54.4 °C / 130 °F for 30 minutes or 60 °C / 140 °F for one minute.

So why did Mom think she had to cremate the pork roast? Well-meaning public health authorities have long exaggerated both the threat of

For more on proper freezing techniques for fish, see Freezing, page 186.

trichinellosis and the cooking temperature needed to prevent it. Such overstatement may have arisen from good intentions, but at some point misleading recommendations become irresponsible.

Freezing also kills trichinae in pork. For this reason, virtually all pork and pork products sold in the U. S. have been frozen, even if they are labeled "fresh" at the store. Unfortunately, freezing is no surefire way to eliminate trichinae in wild game. Bears, for example, hibernate in the winter, so their muscle cells contain special proteins that prevent the formation of ice crystals, and some health authorities fear that those proteins may also protect encysted *Trichinella* larvae from low temperatures. As a result, freezing may not be a reliable means of killing the worms in bear meat.



Tapeworms, also called cestodes, have sucker-like parts on their heads that they use to anchor themselves to the intestinal walls of their hosts.

A separate family of parasitic worms, known as nematodes or **anisakids**, includes species such as *Anisakis simplex* and *Pseudoterranova decipiens* (which is also listed under the genus *Terranova* or *Phocanema*). These worms follow a life cycle that resembles that of trichinae but in a marine environment.

Adult anisakids infect marine mammals such as whales, dolphins, and seals. Eggs in the animals' feces pass into the ocean, where the newly hatched larvae infect copepods, or tiny shrimp-like crustaceans. Fish or squid then eat the infected copepods, other marine mammals next eat the fish or squid, and the cycle continues.

Humans who eat fish provide the anisakids with a ready stand-in for marine mammals. The human gut is, however, sufficiently different that the worms cannot mature, so they generally die after a week or so in the human body. Such an infection can, in the meantime, generate quite a stomach-ache, with symptoms so severe that physicians sometimes misdiagnose the condition as appendicitis. A strong allergic reaction to the worms, although less common, could culminate in anaphylactic shock.

Raw fish poses the biggest risk of infection because cooking fish to an internal temperature of 60 °C / 140 °F or more for at least one minute kills the worms. Several food safety guides assert that 15 seconds at an interior temperature of 63 °C / 145 °F will also do the trick. Those temperatures, however, are high enough to overcook the fish, at least to many people's taste.

Not surprisingly, sushi-loving Japan is the epicenter of foodborne anisakid infections, also known as anisakiasis. Tokyo alone tallies about 1,000 cases annually, most of which are from home-prepared sushi and sashimi. Only rarely are sushi bars with professional sushi chefs implicated. The U.S. reports fewer than 10 cases a year.

Anisakid infection occurs more frequently in certain fish species that fishermen catch near the shore, such as salmon, mackerel, squid, herring, anchovies, and rockfish, than it does in other species. Coastal fish are more likely to eat infected copepods that regenerate in seals and other marine mammals. Farmed salmon do not eat copepods and are therefore generally anisakid-free, as are wild tuna and other deep-ocean species.

Wild salmon, however, are especially prone to infection. In 1994, for instance, an FDA study found anisakids in 10% of raw salmon samples that were obtained from 32 sushi bars in the Seattle area. Despite this alarming statistic, human anisakiasis cases are still relatively rare because most ingested larvae die or pass harmlessly through the intestinal tract.

The technique traditionally used by chefs to detect worms requires them to hold fish fillets up to a light and inspect them visually, a procedure called candling. Master sushi chefs say they can feel the worms with their fingers. And although some chefs can indeed find a few worms through candling or handling, studies suggest that others may be easily missed, especially in salmon or mackerel. No matter how experienced the sushi master, then, neither method is fully reliable.

Freezing kills anisakids, and in this way the food industry ensures that worms pose no health risk in fish that is served raw. For commercial retailers, the FDA recommends freezing and storing the fish in a blast freezer for seven days at −20 °C / −4 °F, or for 15 hours at −35 °C / −31 °F. Most sushi is, in fact, frozen before it is served; the 1994 FDA study found that all but one of the anisakid worms spotted in the Seattle sushi were dead or dying—casualties of the freezing process. If done improperly, however, freezing can negatively affect the taste and texture of the fish.

Other notable nematodes include the giant intestinal roundworm, *Ascaris lumbricoides*, which can grow to 41 cm / 16 in. It causes ascariasis, the most common parasitic worm infection in the world. Investigators have linked ascariasis to cabbage and other raw produce that was grown in contaminated soil and to improper food handling in tropical regions and rural parts of the southeastern United States. The roundworm migrates through the lungs to the small intestine, where it can live for up to two years.

Flukes and Tapeworms

Among foodborne parasites, flukes don't get a lot of public attention. But concern about species such as *Fasciola hepatica* has grown among public health authorities throughout western Europe—especially France, Spain, and Portugal—as well as in the Americas. Commonly known as the sheep liver fluke, the leaf-like worm counts sheep, goats, and cattle among its principal hosts, although it can also make its way into humans through the fecal-oral route.

One of the larger parasitic worms, *F. hepatica* can grow to 2.5 cm / 1 in; its aptly named cousin *F. gigantica* can reach lengths three times as long. As part of the fluke's complicated life cycle, embryos that are released in egg-laden animal feces infect freshwater snails, in which they develop into mature larvae before dispersing again as cysts that glom onto aquatic vegetation.

Humans who eat raw or undercooked watercress or food that has been washed with contaminated water can accidentally ingest these cysts and contract a potentially serious invasive infection known as fascioliasis. Immature worms first migrate through the liver, causing fever, inflammation, and abdominal pain as they go. Eventually they make their way to the bile ducts, where a progressive buildup of the parasites can in time block the ducts. Other species of liver fluke are endemic to Asia and Eastern Europe,

Tapeworms can persist in raw, smoked, and dried foods but are killed by freezing (for 48 hours at −18 °C / −0.4 °F), by hot-smoking (for 5 min or more at 60 °C / 140 °F), or by using standard cooking recommendations.

A live anisakid emerges from a piece of halibut we bought at a reputable, high-end organic grocery store near Seattle.

where researchers have linked them to eating raw or undercooked freshwater fish.

Researchers have tied many infections, mostly in Asia, to eating raw, pickled, or poorly cooked freshwater crabs and crawfish (especially Chinese "drunken crabs") that are contaminated with lung flukes, another major fluke group comprising eight known species. These animals produce a serious human disease called paragonimiasis, in which immature worms infect the lungs and encapsulate themselves in protective cysts, where they can remain for decades.

Investigators have also linked more than 65 fluke species, primarily from Asia, to human intestinal tract infections. One noteworthy geographical exception is *Nanophyetus salmincola*, an intestinal worm that is sometimes called the "salmon-poisoning fluke," which has been transmitted to people in parts of the U.S. Pacific Northwest, southwestern Canada, and eastern Siberia. "Fish flu," as infection with this fluke has been dubbed, naturally infects skunks, raccoons, and minks.

Health officials have implicated the practice of eating raw, underprocessed, or smoked salmon and steelhead trout in many cases of human infection. Although exposure is often fatal to dogs because of a secondary infection carried by the fluke, the human disease generally leads to little more than abdominal discomfort, diarrhea, and nausea. Physicians can easily treat the malady once they properly diagnose it.

Like flukes, tapeworms are relatively uncommon in the United States and other developed countries, but they can persist for months or years inside travelers, immigrants, and others who have dined on raw or undercooked pork, beef, or freshwater fish that harbor the organisms. The beef tapeworm, *Taenia saginata*, and the pork tapeworm, *T. solium*, are the most prevalent of these noninvasive infection-causing parasites. Unlike most other pathogens, both live out most of their lives inside human hosts, where they reproduce and produce their eggs. Unfortunately, tapeworms can survive for as many as 30 years within human intestines, where they can grow to astounding lengths—up to 9.1 m / 30 ft!

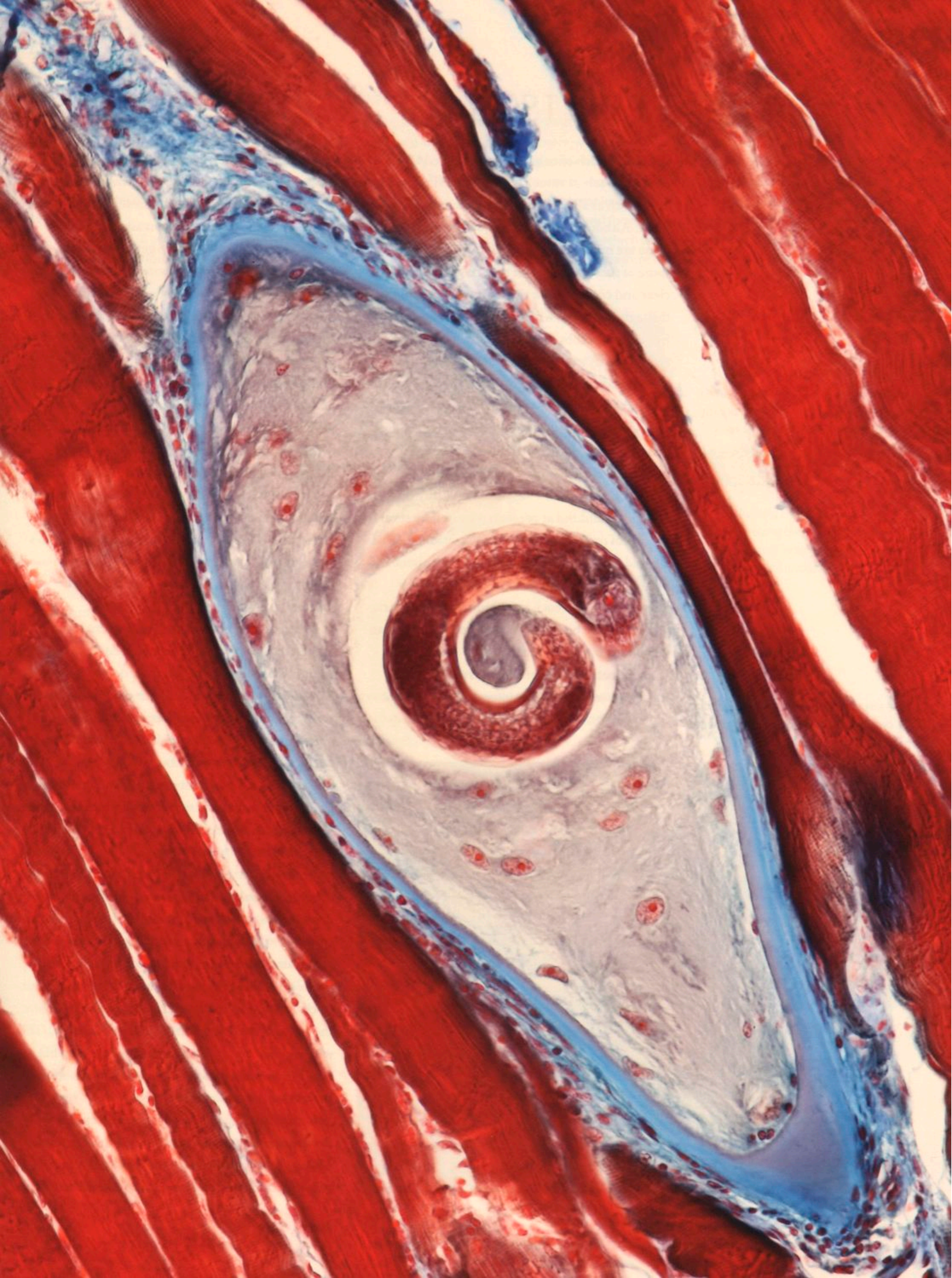
Once tapeworm eggs are shed through human feces, the hardy capsules remain viable for months while exposed, waiting until they are eaten by an intermediate host. For *T. saginata*, cattle serve as the primary intermediate host, whereas *T. solium* relies on pigs for transmission.

A third tapeworm species, *Diphyllobothrium latum*, exploits small freshwater crustaceans as intermediates, which are in turn gobbled up by larger fish. Inside their animal hosts, tapeworm eggs hatch into tiny larvae that burrow into the intestinal wall and hitch a ride through the bloodstream to muscles and other tissues. Once in place, the larvae form protective cysts that can be transferred to humans who eat contaminated beef, pork, or fish. The cysts then hatch in the digestive system, where they develop into flat, ribbon-like worms that use tiny suckers to latch onto the slippery intestinal wall in much the same way that mountain climbers stick to ice walls with crampons and ice axes.

Most cases of tapeworm infection are asymptomatic, although the parasites can cause abdominal pain, weight loss, or even intestinal blockage in their hosts. In some people, *D. latum* can produce anemia by absorbing vitamin B_{12}. Contamination of food or water with the eggs of *T. solium* can result in a far more serious disease called cysticercosis, in which the hatched larvae migrate to various body tissues and form cysts. The cysts can prove fatal if they lodge in sensitive organs such as the heart, brain, or spinal cord.

Smoking and drying foods does not kill tapeworms, and freshwater fish—including walleye and northern pike—that is served as sushi can contain pathogenic cysts. Fortunately, the cysts are usually visible in infected flesh, and the larvae of all three tapeworm species can be dispatched by freezing for 48 h at −18 °C / −0.4 °F, by hot-smoking for 5 min or more at 60 °C / 140 °F, or by following the time-and-temperature cooking recommendations given in chapter 3 on Food Safety, page 162.

A Trichinella worm lives within a cyst in pork muscle.



PROTISTS

Protists, which encompass single-celled algae, protozoa such as amoebas, and some single-celled fungi such as slime molds, live abundantly in pond water. Although protists are mostly harmless, some are quite pathogenic. Under a microscope, some of these strange and tiny creatures appear clear and covered with tiny hairs that propel them through the water, whereas amoebas resemble free-flowing blobs filled with jelly-like protoplasm; they move by extending their "false feet," or pseudopodia. In many protozoan species, individuals have a specific gender and engage in sexual reproduction. They also produce egg-like bodies called oocysts. Other varieties of protozoa reproduce asexually by simple cell division.

Banning cats and kitty litter from all food-preparation areas can greatly reduce the risk of toxoplasmosis.

In fact, malaria, the single most deadly disease affecting mankind at present, is caused by several species of protists in the genus *Plasmodium*. This age-old malady today is responsible for about 250 million cases and more than 880,000 deaths around the world each year. Humans get malaria when they are bitten (by mosquitoes) rather than when they bite (into food).

A few pathological protists have evolved to infect humans through our food. Either the live organisms or, more likely, their oocysts can contaminate (primarily via the fecal–oral route) food and water that people use to wash or to prepare food, and exposure to these contaminants may lead to an infection. An invasive protist infection in human gut tissue generally causes diarrhea, and occasionally more serious symptoms.

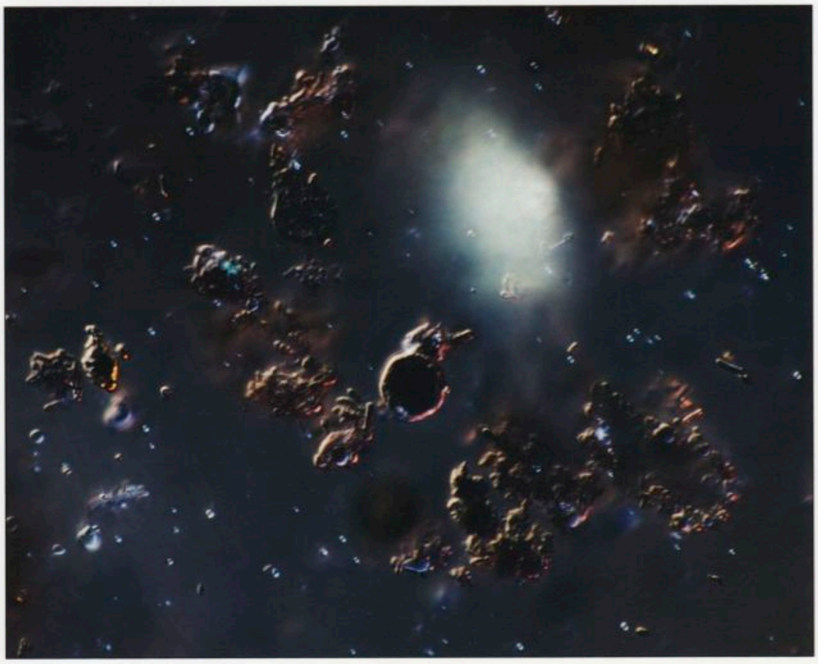
Toxoplasma gondii, which is the worst of the bunch, features in addition a rather bizarre life cycle that depends in large part on cats and mice or other rodents (see illustration on next page). This single-celled creature may not be the best-known protist, but it dominates the category in terms of the number of foodborne illnesses and deaths it causes. *T. gondii* sickens an estimated 112,500 people through foodborne transmission every year and leads to 2,500 hospital admissions and 375 fatalities annually in the United States alone. The CDC considers the disease the nation's third-leading cause of death due to foodborne illness, ranking behind only salmonella and listeria bacterial infections.

The good news is that protists such as *T. gondii* are relatively easy to kill through heat or chemical means. The bad news is that their oocysts are considerably more robust. Once shed into the environment, the eggs can persist for months and are surprisingly resistant to disinfectants, freezing, and drying. Heating the eggs to 70 °C / 158 °F for 10 minutes kills them outright, and researchers have shown that exposing potentially contaminated water to shortwave ultraviolet light (UVC) can eliminate the oocysts.

Among both wild and domestic cats, including many household pets, *T. gondii* is a common parasite. Instead of simply waiting for a cat to eat an infected rodent, however, the protist does something rather diabolical to continue its life cycle: it uses mind control. Healthy mice instinctively fear the scent of cats, but *T. gondii* alters their brains to remove that protective instinct, which leads the hapless rodents to seek out what has become an irresistible odor—and thus offer themselves to cats as an easy meal.

Estimates of the number of cats infected with the protist are hard to come by. But the number of people so infected seems to be quite large: some startling calculations suggest that 60 million

A smear of human feces contains a Giardia cyst, the large round object in the center of the frame.

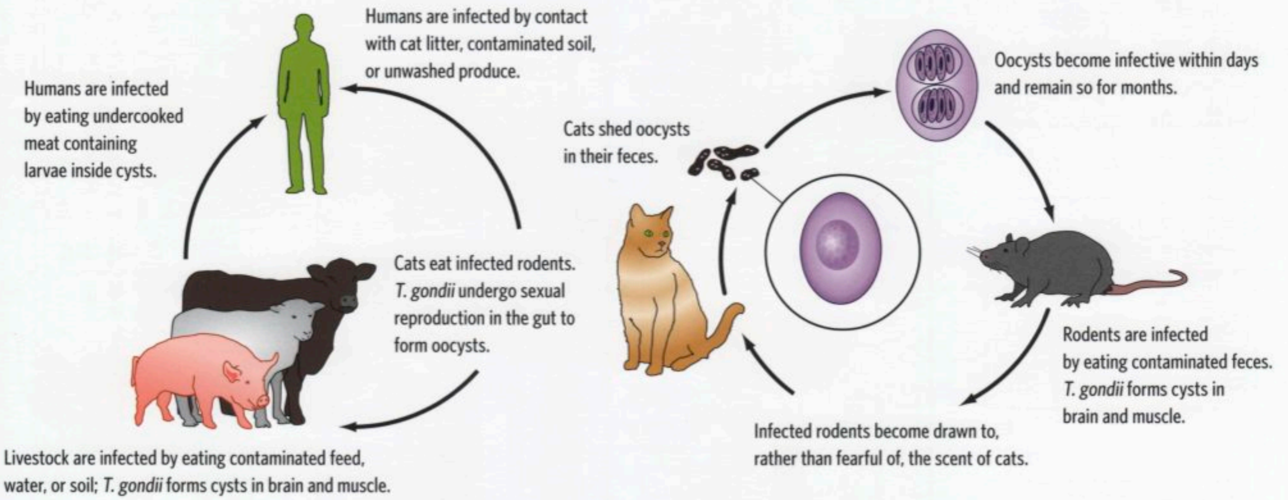


The Strange Life Cycle of *Toxoplasma gondii*

Toxoplasma gondii has a rather bizarre way of reproducing and maturing that involves a fiendish sort of rodent mind control. Cats—both wild and domestic—serve as the protist's main hosts, but infection with the protist rarely causes symptoms in them. Cats typically acquire the infection from the rodents they eat, who get it from unwittingly ingesting cat feces.

In mice and rats, *T. gondii* larvae invade white blood cells, which carry them through the bloodstream to muscle and brain tissue, where the larvae lodge within protective cysts. The devilish part occurs when the parasites somehow alter the brain chemistry of their host so that an infected rodent develops an unnatural attraction to cat odor.

When, inevitably, a cat ingests one of these deluded mice, the cysts in the rodent meat burst in the cat's intestinal tract, freeing the protists to begin reproducing and forming oocysts. For a few weeks after infection, cats defecate oocysts, which can be passed on to humans, livestock, or rodents through oral exposure to contaminated feces or water.



people in the United States may harbor the protist. The vast majority of infected people show no ill effects. But some fall sick with flu-like symptoms. Recovery is usually quick, although sometimes the disease manifests with more prolonged symptoms like those of mononucleosis.

T. gondii can, however, be deadly to a developing fetus. It can also leave newborns with lasting visual impairment or mental retardation, so pregnant women should avoid any exposure to cat feces. Likewise, the protist can lead to potentially fatal encephalitis, or inflammation of the brain, in people with underdeveloped or compromised immune systems. The very young, the very old, and those receiving chemotherapy or living with HIV/AIDS are most at risk.

Given the sinister behavioral effect of *T. gondii* on rodent brains, several research groups have explored a potential link between infection with this protist and neurological or psychiatric conditions in humans. Intriguing though inconclusive evidence suggests that the pathogen may cause at least some cases of schizophrenia. If that link is ever established, it would make toxoplasmosis perhaps the most debilitating of all foodborne illnesses.

With few reliable numbers and often asymptomatic cats, you should assume that all cat feces can be a source of contamination. Based on that assumption, the precautions for reducing the risk of cat-transmitted *T. gondii* are fairly straightforward: avoid cat feces, and never allow the animals or their litter boxes into a kitchen.

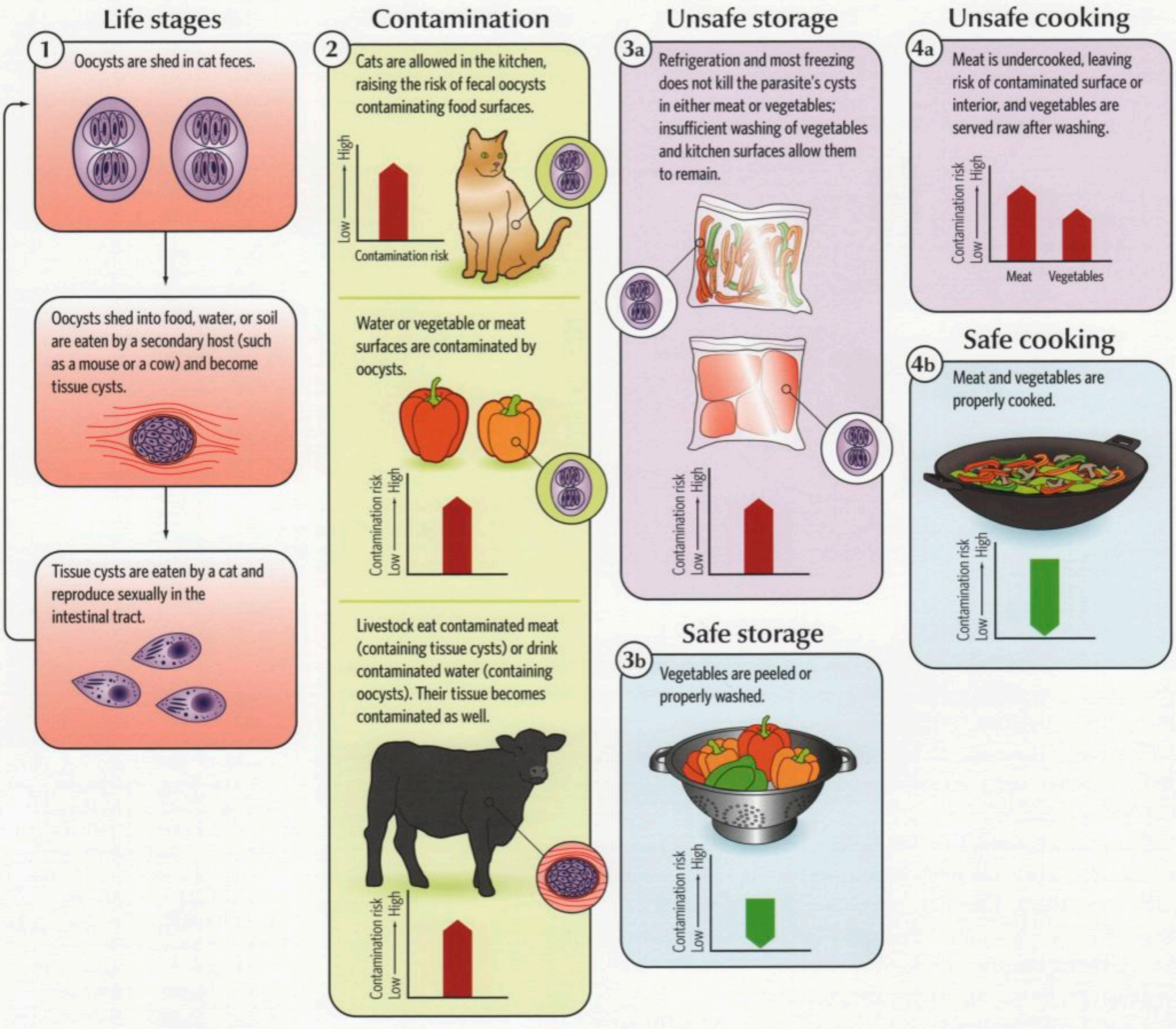
Milder but More Common

Compared with *T. gondii*, other protists such as *Giardia intestinalis* (also known as *G. duodenalis* or *G. lamblia*, or *Lamblia intestinalis* in Europe) lead a simple lifestyle. The *G. intestinalis* protist infects the gut, where it produces oocysts and sheds them into the host's feces. Ingesting eggs in food or water results in an invasive infection of the gut wall. It also causes acute diarrhea and stomach or abdominal pain lasting from two to six weeks.

Studies have linked *Toxoplasma* with a number of psychological conditions in humans. This connection is plausible because the parasite does migrate to the brain. Moreover, in rodents, it is known to affect dopamine, which is an important chemical mesenger in the human brain. In addition to indicating a possible link between *Toxoplasma* infection and schizophrenia, human studies have implicated the infection in changing the results of personality profiles, worsening psychomotor performance, lowering intelligence in men, and even doubling the likelihood that those infected will have a car accident. And, in expectant mothers, *Toxoplasma* infection seems to skew the sex ratio of their children towards many more boys than girls.

How *Toxoplasma* Infects Humans

Toxoplasma gondii usually infects rodents and the cats that eat them. Because most people do not eat cats or mice, the primary risk to humans comes by way of cat feces, which contain the oocysts of the parasite. In principle, a human could also become infected by eating beef, lamb, or other meat from animals that consumed the oocysts, but such routes of infection are very rare. Once in food, however, the oocysts are difficult to destroy with heat. The best precaution is to keep cat feces well away from food and the kitchen.



The *G. intestinalis* protist was the first pathogen ever diagnosed by microscopic examination when Dutch merchant and microscopy pioneer Antony van Leeuwenhoek spied it in 1681 while examining his own diarrhea. Ever since, the protist has been deemed primarily a waterborne rather than a foodborne pathogen.

The CDC estimates, however, that 10% of infections with this pathogen begin with food and lead to 200,000 giardiasis illnesses in the United States every year—nearly double the number of foodborne toxoplasmosis cases. FDA officials have traced outbreaks of giardiasis to food handlers. Fortunately, foodborne giardiasis is far less severe than toxoplasmosis and on average results in one death each year in the U.S.

The usual explanation for the high prevalence of giardiasis is that many animals carry it and foul water sources with their feces. Giardiasis is called "beaver fever" because these animals were thought to be a primary reservoir of the protist.

Recent research, however, shows that the *Giardia* pathogen that infects humans is genetically distinct from the *Giardia* pathogen that infects beavers; it is probably a separate species or subspecies. This finding suggests that most, if not all, giardiasis in humans results from contamination by human waste rather than by animal waste.

Hiking and backpacking guides often warn people to avoid drinking from streams that may support *Giardia,* and an entire industry has sprung up around protective filter units that sift the oocysts out of contaminated water—a necessary approach because the eggs are extremely resistant to heat or chemical treatments. Water that has been treated with enough chlorine or iodine can kill *Giardia,* but the chemicals leave a very strong taste and odor, and they take time to work. Iodine disinfection, for example, takes eight hours.

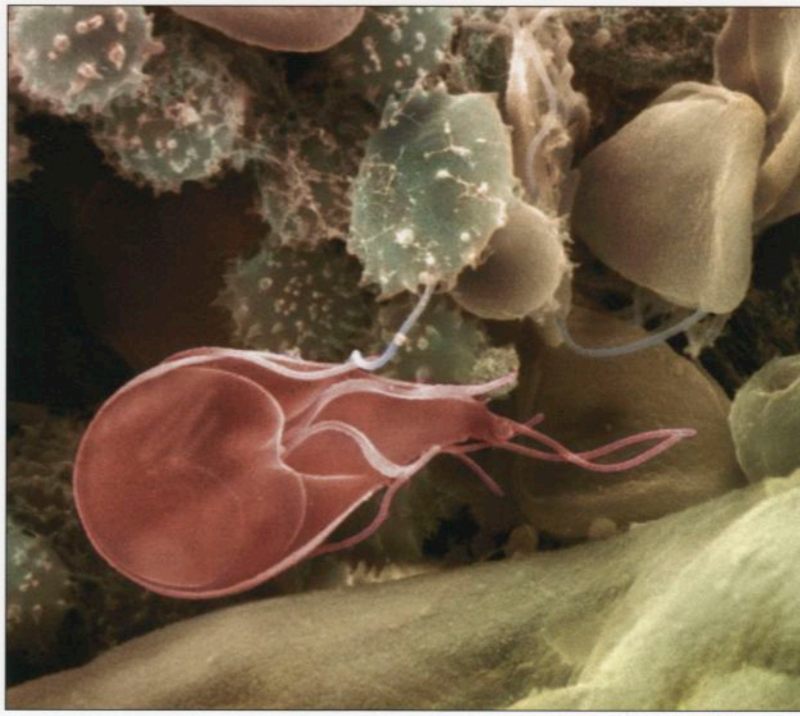
Swimming pools can easily get contaminated and remain so because insufficient chlorine levels or other sanitation measures fail to kill the oocysts. Boiling water also kills *Giardia* oocysts, and good hygiene practices in the kitchen and bathroom should help minimize the risk of infection.

Two other important protist parasites, *Cyclospora cayetanensis* and *Cryptosporidium parvum,* have a similar life cycle to that of *Giardia.* They too can produce hard oocysts that can abound in feces, which may then infect humans via the fecal-oral route.

C. cayetanensis is a good example of a so-called "new" foodborne pathogen. Although it has undoubtedly been infecting humans for ages, the protist was virtually unknown before scientists began studying it extensively in the 1990s. Health authorities consider the formerly obscure organism to be a chief cause of "traveler's diarrhea." Investigators have also traced two cyclosporosis outbreaks in the 1990s in the U.S. and Canada to fresh raspberries imported from Guatemala and to a salad mix of baby lettuce and basil.

Cryptosporidium, on the other hand, is a close relative of both *Plasmodium* and *Toxoplasma.* It has the dubious distinction of producing the most resilient oocysts of any genus of pathogenic protist. As a result, most water treatment plants and swimming pool sanitation systems are unable to eliminate it. Large outbreaks of cryptosporidiosis have occurred in Oslo and Sydney. A 1993 outbreak in Milwaukee, Wisconsin, ranks as the biggest outbreak of waterborne disease in the U.S.; it resulted in more than 400,000 cases. Smaller outbreaks that were linked to apple juice and green onions highlight the protist's potential as a foodborne pathogen. So far, shortwave ultraviolet (UVC) light and very heavy concentrations of ozone are about the only practical methods found to eliminate the oocysts.

At least six species of an amoeba genus known as *Entamoeba* can colonize the human gut, but only one, *E. histolytica,* causes disease. Like *Giardia, Cyclospora,* and *Cryptosporidium* infections, *E. histolytica* infections develop after humans ingest oocysts, generally in contaminated water or food. Unlike most other pathogenic protists, *E. histolytica* can lead to a serious illness known as **amebiasis**, which can result in dysentery and liver abscesses as the organisms lodge in the gut wall or liver and destroy tissue. Amebiasis can be fatal if not treated. Cases are rare in most developed countries, although the disease can become chronic, and infected food workers can contaminate kitchens.



Protists such as Giardia (above) and Entamoeba parasites may be considered waterborne pathogens, but beware: they can also contaminate food. Good kitchen and bathroom hygiene should greatly reduce the risk of contamination.

BACTERIA

Bacteria are perhaps the most adaptable life forms on earth. The tiny microbes survive and thrive in virtually every environment—from the black abysses of the oceans to the icy deserts of Antarctica to the thin upper atmosphere. Scientists have even found bacteria living miles underground, where they feed on radioactive rocks.

Their amazing capacity to adapt and carry on helps explain why these microscopic, single-celled organisms make up a good chunk of the biomass on Earth. On a more personal level, bacteria not only live all around us but on us and inside us as well; they also inhabit our food.

The vast majority of bacterial species are harmless to humans. But given their extraordinary variety of forms and survival strategies, it's little wonder that a few bacterial species are human pathogens and that some of those can be transmitted by food. To understand how the more important malefactors, such as *Salmonella*, *Listeria*, and *Escherichia coli* O157:H7, can sicken you and those you cook for, it helps to have a good working knowledge of the major kinds of bacteria and their life cycles.

In the late 1970s, DNA studies by Carl Woese and other biologists revealed that a huge part of the tree of life—long thought to be bacteria—is actually a distinct domain, which they named Archaea. Although they look much like bacteria, Archaea are as distant from bacteria in their genetic makeup as humans are. Archaea typically live in extreme environments, such as hot springs and geysers, inside oil-bearing rocks, or near volcanic vents at the bottom of the sea. But some live happily in the digestive tracts of cows.

Tiny, Fast, and Highly Adaptive

An individual **bacterium** is so small that (with only a few exceptions) it is invisible to the naked eye; you need a microscope to see one. *E. coli* is typical in measuring from two to three microns (millionths of a meter) long and about one micron across. Thus, it would take something like a million *E. coli* laid end to end to equal the height of a tall person. Bacteria don't weigh much individually, either—perhaps 700 **femtograms** each. You'd need to assemble about 1.5 trillion of them to tip the scale at 1 g / 0.04 oz.

But what they lack in girth and mass, they make up for in numbers. Under the right conditions, bacteria can multiply overnight by a factor of one thousand, one million, or even one billion.

People sometimes liken bacteria to microscopic plants, but in truth these minute organisms have no direct analog in the macroscopic world. They really are a distinct form of life. Unlike viruses (discussed in more detail later), bacteria are fully alive: they absorb nutrients from the world around them and secrete chemicals back into it. And many species are **motile**, or able to travel under their own power.

Bacteria that move often do so by spinning one or more tail-like appendages, called **flagella**, that contain complex molecular motors. The coordinated rotation of these motors propels the bacteria at surprisingly fast speeds. Other common adaptations, such as the ability to form protective cell walls and spore cases, as well as the capacity to aggregate in large groups, have contributed to both the ubiquity and the staying power of these ancient organisms.

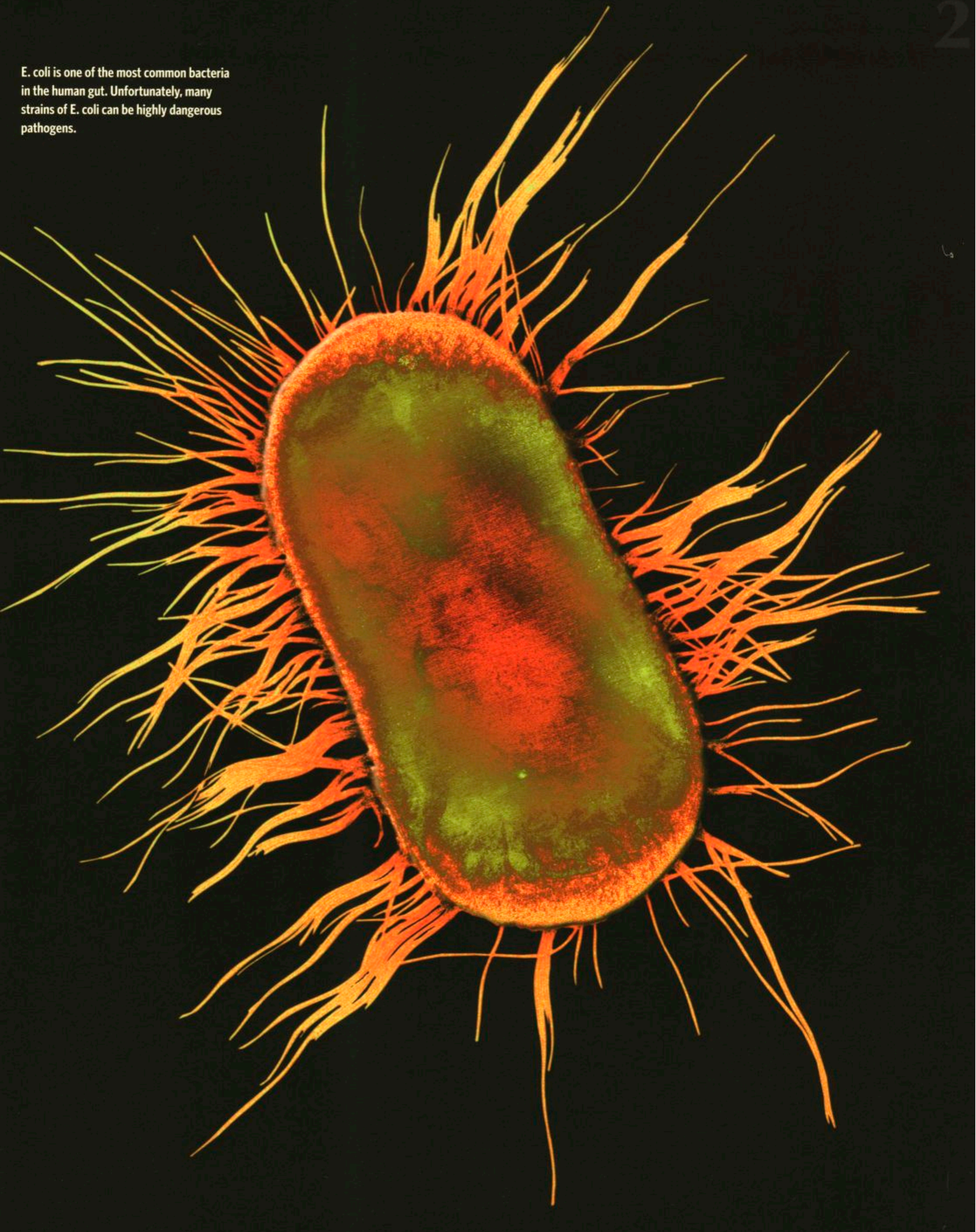
Some species, called **aerobic bacteria**, need oxygen to survive just as we do. Surprisingly, oxygen can be a deadly poison for many others, known as **anaerobic bacteria**, which have evolved to live in air-free environments. Some bacteria tolerate oxygen, but only so much; scientists refer to them as **microaerophilic.** Yet another category of bacteria can live in either anaerobic or aerobic conditions; specialists call them **facultative anaerobes**.

Apart from the microbe's living arrangements, researchers classify bacteria by their physical, chemical, or genetic properties. In the early days of microbiology, bacterial classification relied mainly on visual characteristics—rod-shaped bacteria were distinguished from spherical (coccal) or spiral varieties, for example.

Later on, investigators began using chemical dyes, such as Gram's stain, to distinguish different classes of bacteria by the makeup of their cell walls (see Microbial Staining as a Form of ID, page 106). These days, scientists classify bacteria primarily through their genetic properties by sequencing their DNA.

Because a typical bacterial **genome**—the microbe's entire collection of DNA—is much smaller than that of a plant or an animal, researchers had by the end of 2009 already completely sequenced the genomes of more than 1,000 bacterial species, far more than for any other kind of organism. But given suspicions among some scientists that millions of bacterial species share the planet with us, that's only a drop in the bucket.

The astounding diversity of bacteria is particularly relevant when you consider the ways in which the ones that are pathogenic can cause illness.



E. coli is one of the most common bacteria in the human gut. Unfortunately, many strains of E. coli can be highly dangerous pathogens.

THE CLASSIFICATION OF

Bacterial Subspecies

Beyond the conventional genus–species naming system for organisms, scientists often group members of a single bacterial species into smaller divisions that reflect genetic similarities or other shared features. These advanced classifications provide progressively finer criteria for distinguishing one microbe from another.

A **subspecies** is a genetically distinct population that is often geographically isolated from other members of the same species. The common food pathogen *Salmonella enterica,* for example, has seven subspecies, including *S. enterica arizonae* and *S. enterica enterica.* The latter is the most common kind that is found in people and warm-blooded animals with food poisoning.

Scientists can further divide closely related species or subspecies by identifying distinguishing characteristics, such as specific molecules or genetic elements in the cells or their outer surfaces. They refer to bacterial variants grouped this way as a **serovar** (or **serotype**).

The relationship among bacterial serovars resembles that which exists among different tomato varieties. The Sweet 100 cherry tomato cultivar, whose fruit weighs a mere 28 g / 1 oz, for example, differs markedly from the Goliath beefsteak tomato variety, which can yield fruits weighing 1.4 kg / 3 lb. Yet both types are readily identifiable as tomatoes: *Solanum lycopersicum.*

Small genetic differences can likewise impart significant variation among bacterial serovars, including the ability of some to withstand multiple antibiotics. Sometimes those differences are not even part of the microbe's heritable genome but are conferred when unrelated plasmid DNA is transferred from one bacterium to freeload on another (see Plasmids, next page).

Researchers have identified several thousand serovars of *S. enterica,* nearly all of which belong to the *enterica* subspecies. Common serovars associated with foodborne illness include Agona, Hadar, Heidelberg, and Typhimurium, which as a body hint at *Salmonella*'s outsized role in human disease.

All those subdivisions typically generate especially long formal names, such as *Salmonella enterica* subspecies *enterica* serovar Heidelberg, which is a variety that has shown enhanced resistance to antibiotics in the United States. Specialists commonly shorten the name to *Salmonella* Heidelberg. Investigators have linked another serovar, *Salmonella* Typhimurium, to a major outbreak in the United States in 2008 and 2009, in which contaminated peanuts and peanut-containing foods sickened hundreds.

Many other bacteria owe their ill repute to virulently pathogenic serovars. A particularly potent example is *E. coli* O157:H7. In this subgroup of what is a normally benign species, a relatively small number of genetic changes have occurred that enable it to cause severe illness, gastrointestinal bleeding, and even death. Yet in the gut of a typical person, 10 billion to 1 trillion *E. coli* of other serovars coexist quite harmlessly with their host.

Vibrio cholerae has 139 serovars, of which only two are pathogenic. Researchers have tied both to foodborne illnesses that were associated with contaminated shellfish.

At an even more refined level of classification, specialists sometimes refer to bacterial strains, which are usually isolated from a particular source, such as an infected animal or a human patient. No uniform naming convention exists for strains, but scientists often give them numbers or other designations based on the results of the tests they use to distinguish among them. They labeled, for example, a multidrug-resistant strain of *S. enterica* that belongs to the Typhimurium serovar "definitive type 104." Known as *S. enterica* serotype Typhimurium DT104, the strain was first isolated in 1984 from patients in the U.K. Within several years, *Salmonella* Typhimurium DT104 became common there, and in the mid-1990s it appeared throughout the U.S.

Most bacteria that infect the human body are aerobic for the simple reason that we have oxygen in our blood and that oxygen keeps the growth of anaerobic bacteria in check. A few kinds of anaerobic bacteria, such as *Clostridium perfringens,* can cause severe infections (tetanus and gas gangrene), but normally only when they get into deep wounds or dead, oxygen-starved tissue.

Anaerobic foodborne pathogens, including others within the *Clostridium* genus, have developed infection strategies that rely on hosts eating foods contaminated with their spores. Some anaerobes, however, can do their worst damage without ever inhabiting our bodies: foodborne botulism is a relatively uncommon but potentially deadly form of food poisoning in which *Clostridium* *botulinum* releases a potent nerve toxin as it grows in canned vegetables or other foods. Even heating the food enough to kill the bacteria doesn't destroy the toxin they've already produced.

As cooks, we're most interested in the three main groups of bacteria that are associated with food. The first group, sometimes called **spoilage bacteria**, aren't harmful on their own, but they can produce rot and foul odors that make food unappealing. Hard as it may be to believe, you almost never get sick from consuming these types of bacteria. Their presence does, however, often signal contamination with other aerobic bacteria that are pathogenic.

The second group includes both **invasive infectious bacteria**, such as *Salmonella* and *E. coli*, which can sicken humans by penetrating intestinal or other body tissues, and **noninvasive infectious bacteria**, such as *Vibrio cholerae*, which can cause illness even without a full-blown invasion by secreting toxins during their stay in our intestines.

Finally, we'll examine **food poisoning bacteria**, including *Bacillus cereus* and *C. botulinum*. In addition to these three groups, other kinds of bacteria can infect a wide range of body tissues through the blood, respiratory system, and other access routes. But, by definition, those infections are not related to food.

Spoilage Bacteria

Not all bacteria in food are dangerous; some are merely annoying. Spoilage bacteria produce liquids and gases that let us know that food has become rotten. Vegetables and fruit may become slimy or mushy, whereas meat usually starts to stink. As disgusting as spoiled food can be, most of the smell, color, and texture changes that people associate with food gone bad are actually medically harmless. With few exceptions, you rarely get sick from spoilage bacteria. Food in which spoilage bacteria have been very active, however, is likely to be contaminated with other bacteria that *are* pathogenic and could make you very sick.

Unfortunately, this situation can fool people into thinking the reverse is true—that if no sign of spoilage is present, then the food must be safe. This assumption is emphatically not true and is a great example of how misinformation can kill you. *People can get very sick or even die from food that shows no signs of spoilage.* Furthermore, as we noted, spoilage is not always so safe (see Spoiled Fish and Cheese, page 139).

Interestingly, although most other chemicals released by spoilage bacteria are not toxic to us, they can often harm other bacteria. The toxins either poison or repel species that might otherwise

THE BIOLOGY OF

Plasmids

A **plasmid** is not a living thing but rather a self-copying piece of roving DNA, typically circular, that can reproduce only inside a bacterium or some other organism. Plasmids differ from viruses, which have fairly complicated protein structures around their DNA or RNA; plasmids are just naked DNA. When a plasmid infects a bacterium, it supplements the normal genetic blueprint of the microbe, often bestowing on the host bacterium dramatic new capabilities, such as the power to cause disease, live in a new environment, or resist antibiotics.

Plasmids are passed on during the normal replicative division of a bacterium, which ensures that any plasmid-dependent traits persist in future generations. In fact, bacterial strains are sometimes defined by the plasmids they incorporate.

Cell division is not the only way plasmid DNA transfers from one microorganism to another, however. Those who monitor foodborne illnesses must stay aware of one aspect of plasmids' ability to pass from one bacterium to another: a process known as conjugation, which can occur during cell-to-cell contact. Amazingly, the donor and recipient of the plasmid transfer can belong to different species, creating the possibility, for instance, that a plasmid from *S. enterica* could spread to *E. coli* and vice versa. The details are beyond the scope of this book, but it's worth noting that some deadly bacterial strains acquire their pathological power from the promiscuous proclivities of simple plasmids.

Although spoilage and pathogenic bacteria often contaminate food simultaneously, you can never assume that the absence of spoilage bacteria means the absence of pathogens.

compete for limited food resources. This strategy is, in fact, the basis of **fermentation**, the process by which food-dwelling microbes break sugars down into acids or alcohols.

A great example of a bacterium that uses this tactic is *Lactobacillus bulgaricus*, a species that emits large quantities of lactic acid, preventing the growth of most other bacteria. *L. bulgaricus* thrives in the acid, which gives the food it inhabits a distinctive odor and flavor. In certain contexts this spoilage is, however, desirable.

For example, this is how yogurt is made. Makers inoculate milk with a particular strain of *L. bulgaricus* (or other related *Lactobacillus* species or the lactic acid-producing bacteria *Streptococcus thermophilus*) and incubate it for a time at a suitable temperature. As a side effect of the bacterial growth, the milk thickens into yogurt.

The preparation of fermented foods invariably involves cultivating bacteria, yeast, or fungi that secrete chemicals that are poisonous to other microorganisms. Food processors use related *Lactobacillus* species such as *L. plantarum* to produce fermented foods including sauerkraut, pickles, and Korean kimchi. San Francisco-style sourdough bread derives its characteristic tangy flavor from *L. sanfranciscensis*.

Nevertheless, not all *Lactobacillus* species are beneficial. Specialists consider some to be spoilage bacteria, particularly when they grow on meat.

A Toxic Invasion

The secretions of some other foodborne bacteria are not nearly as benign as those of their spoilage-causing cousins. Although some invasive infectious bacteria can cause disease without emitting a toxin, most pathogenic ones release an associated **bacterial toxin**. Intriguing evidence suggests that a bacterium can communicate with its kin by emitting chemical signals, which allow a group of microbes to gang up and coordinate their invasion. This process, called **quorum sensing**, enables the bacteria to build up their numbers before starting toxin production. Some researchers suspect this is why the onset of certain infections is so sudden.

Bacteria often secrete toxins specifically to harm us. It's nothing personal; it's just part of their life cycle. A common strategy among gastrointestinal bacteria is to release toxins that bring on diarrhea, in which a gram of fecal matter can contain millions of copies of the bacterium. The fact that diarrhea is hard to control and often messy boosts the probability that the bacteria will contaminate food or water and spread to other people, thereby continuing their life cycle. Over millions of years, bacteria have evolved this mechanism for dispersal. Unfortunately for us, their drive to survive means we may face discomfort, illness, and even death.

Common infectious foodborne bacteria include *Campylobacter jejuni*, *E. coli*, *Listeria monocytogenes*, *Yersinia enterocolitica*, and several species of *Salmonella*, *Shigella*, and *Vibrio*. Some of these pathogens, such as *Listeria*, prey upon susceptible people with undeveloped or compromised immune systems who eat contaminated food.

Every year in the United States, about 2,500 people fall seriously ill from a *Listeria* infection, also known as **listeriosis**. Of those sickened, about one in five ultimately dies; this is among the highest mortalities for any foodborne infection.

But the risk is far from uniform. Pregnant women, in whom one-third of all such infections occur, are 20 times more likely to get listeriosis than other healthy adults. Listeriosis places each such patient and her unborn baby or newborn at grave risk. Those living with AIDS are even more vulnerable; according to the CDC, they are nearly 300 times more likely to contract listeriosis than people with normal immune systems are.

Other pathogens, including *V. cholerae*, are better known as agents of waterborne disease—cholera in particular. A few species of *Vibrio* live in saline environments, such as salt-marsh mud. Nevertheless, food also can transmit a *Vibrio* infection; researchers have cited raw or undercooked seafood from the Gulf of Mexico, Latin America, and Asia as culprits, for example.

Despite their differences, the detailed properties of these infectious pathogens are less important to a cook than the big picture: each microbe can contaminate food and infect those who eat it, and nearly all can be transmitted by the fecal-oral route.

Poison Left Behind

Many bacteria produce harmful toxins. Infectious bacteria secrete those toxins inside your body, where the chemicals cause various forms of cellular damage that can make you ill. Some bacteria, however, synthesize toxins well before you eat them. Even though the bacteria typically cannot survive in the human body and do not produce an infection, their toxins can still wreak havoc inside you.

Toxin production is typical of anaerobic pathogens such as *Clostridium*, but aerobic bacteria also can release poisons. One such pathogen, *Staphylococcus aureus*, is ubiquitous in nature—it even grows on your skin. Although people know *Staphylococcus* more commonly as the source of staph infections and toxic shock syndrome, the bacterium can also taint food with a toxin that it secretes. The illness that results from this and other foodborne toxins is known as food poisoning.

Because the toxins are already present, food poisoning is characterized by an abrupt onset of symptoms. Commonly, someone leaves out susceptible food at an improper storage temperature (often room temperature) long enough for bacteria to multiply and produce toxins. If the microbes remain undisturbed for extended periods of time, dangerous levels of bacteria and their toxins can accumulate even in refrigerated food, although this happens less often.

In some instances, when a bacterial toxin is susceptible to heat, or **heat labile**, it breaks down readily at elevated temperatures. If you heat or reheat contaminated food to a high enough temperature, it will destroy some toxins, leaving the food safe to eat. Other bacterial toxins tolerate heat very well, however, which thwarts this strategy unless you heat the tainted food to excessive temperatures.

Bacteria have yet other ways to evade our attempts to kill them. Anaerobic bacteria have

The contamination of food alone is often insufficient to create a bacterial infection. An infection can be abetted by poor hygiene, improper food storage, or inadequate cooking safeguards.

THE ORIGIN OF
Microbial Taints and Off-Flavors

Everyone knows the archetypal odor of sour milk, perhaps the most readily recognizable sign of bacterial food spoilage. More research has gone into investigating the sources of tainted and off-tasting milk than those of perhaps any other food, and the list of ways in which it can be fouled is extensive. *Pseudomonas* bacteria, for example, produce an enzyme that can leave milk tasting fruity. Other bacteria give milk malty, acidic, rancid, or musty off-flavors.

Many other foods go bad through similar bacterial action. A fermentation process gone wrong because of the presence of uninvited *Bacillus* microbes, for instance, can create bitter-tasting cheese. The bacterial secretions indole and skatole produce not only bad breath but also the reek of rotting potatoes. *Streptococcus* can produce a cheesy off-flavor in canned hams. Everybody likes the earthy smell after a good rain, but the actinobacteria that release geosmin, which contributes to that pleasant aroma, add the same chemical to produce the more disagreeable smells of tainted fish, bread, flour, navy beans, and clams.

Fishmongers' and butchers' shops provide clear olfactory confirmation that fish and meats are especially prone to invasion by microbes that secrete odoriferous chemicals. *Vibrio*, *Achromobacter*, and *Pseudomonas* bacteria can all generate off-putting "fishy" flavors or smells. The growth of spoilage bacteria in meat, fish, and cheese can yield a pungent bouquet from the chemicals putrescine, cadaverine, histamine, and tyramine. This odor is a telltale indicator that hygienic practices may be absent in a kitchen.

Microbes don't like to share their food, so many of them emit chemicals like acids or alcohol that they can tolerate but that their competitors can't. Human chefs use this trait to their advantage to prepare fermented foods, to which the emitted chemicals provide flavor and texture. Yogurt, kimchi, sauerkraut, and sourdough bread are all examples.

responded to a fundamental challenge to their survival—the fact that there is a lot of oxygen in the world—by evolving the ability to form **bacterial spores.** The microbe grows a cocoon-like protective covering that encases the dormant bacterium, shielding it from oxygen, dehydration, and other potentially lethal environmental conditions. By forming spores, bacteria can hide out for months or years until conditions improve.

This is such an effective strategy that some aerobic bacteria also produce spores to cope with unfavorable environs. Many bacteria that live in seasonal ponds can produce spores when the ponds dry up, for example. The tough spore coverings can even protect some *Bacillus* bacteria from exposure to the extreme cold, hard vacuum, and harsh radiation of outer space.

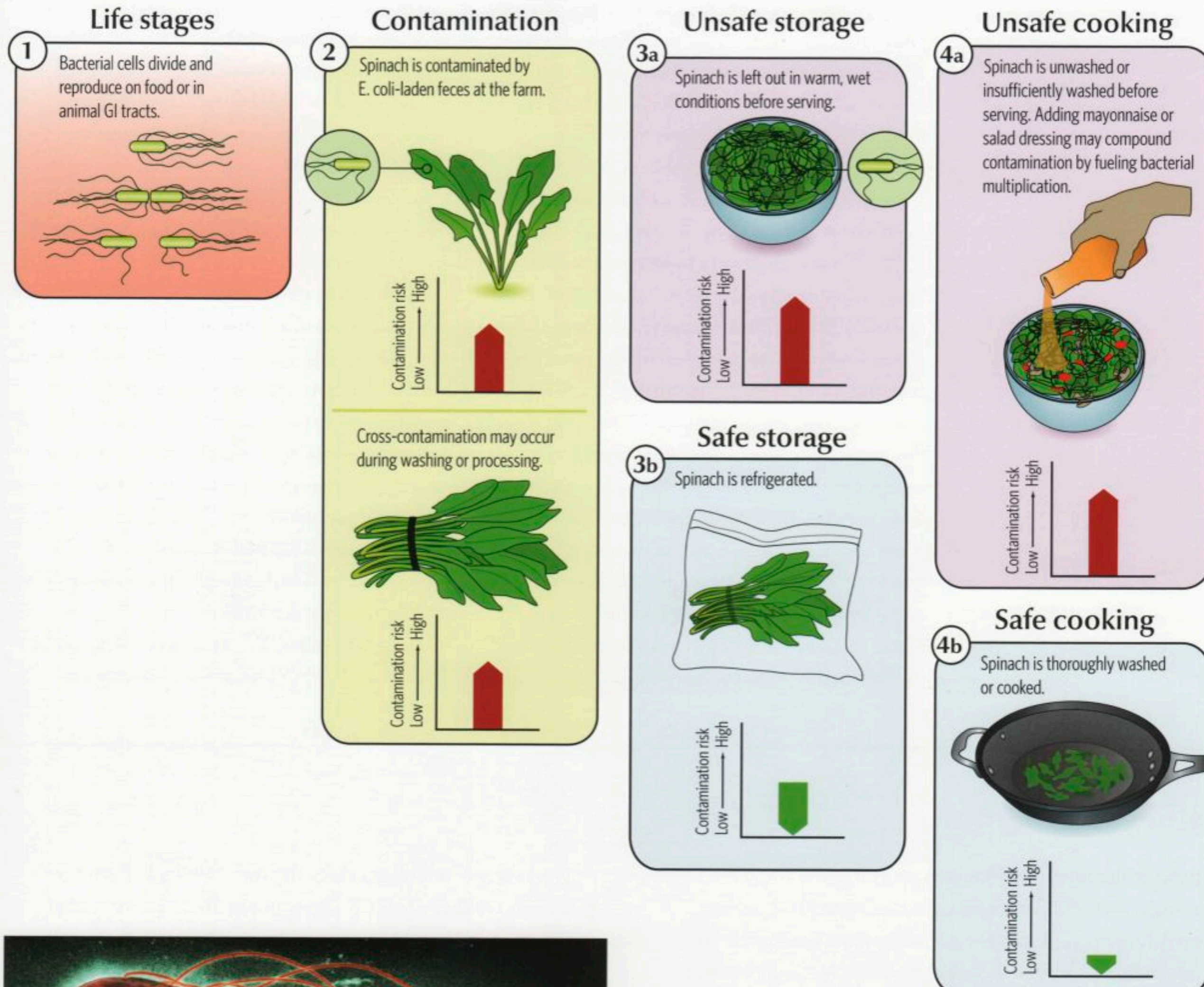
Understandably, bacterial spores are problematic in the kitchen because they are much harder to kill or inactivate than normal bacterial cells are. Unfortunately, throughout history human cooks have unintentionally provided invaluable assistance to anaerobic bacteria. Because most spoilage bacteria are aerobic, people have invented many schemes for preserving food for long periods of time by limiting its contact with oxygen. A layer of fat seals oxygen out of traditional French duck confit, for example, just as it prohibits oxygen from reaching pemmican prepared by North American Indians. The same preservation method is part of traditional sausage making—particularly the preparation of dry, preserved sausages. An airtight seal is fundamental to canning food and, more recently, the concept has been expanded to include cooking sous vide (see chapter 9). But these well-meaning techniques have a nasty side effect. They improve the growing conditions for anaerobic bacteria, which makes the food more susceptible to contamination by bacterial spores.

And because spores can survive heat or other measures that kill most bacteria, fully cooked food can be full of viable spores. If spore-containing food is eaten quickly after its preparation, the still-dormant spores are unlikely to cause any trouble. But if the spores are allowed time to revert into active bacteria, they can quickly reproduce and produce toxins.

Canning can prove to be a particular problem because people store canned food at room temperature for many months. If the canning is done

How Pathogenic *E. Coli* Can Get into Food

Most varieties of *E. coli* bacteria, which live in the gastrointestinal (GI) tracts of humans and other warm-blooded animals and are shed through their feces, are either beneficial or harmless. The same cannot be said for pathogenic strains such as *E. coli* O157:H7, which has been blamed for multiple foodborne outbreaks linked to contaminated milk, meat, and produce such as spinach and alfalfa. Infections with pathogenic strains cause painful cramping and bloody diarrhea. They are particularly dangerous for young children and the elderly, in whom life-threatening anemia and kidney damage can develop. Fortunately, good kitchen practices—including safe storage and cooking— can minimize the risk of infection.



An E. coli bacterium uses its long flagella to move around.

Food poisoning from bacterial spores is typically a concern only if food has been held at a temperature that allows them to germinate and multiply. Foods that are eaten promptly after cooking or quickly chilled to low temperatures generally do not cause problems.

For more on how to can food safely, see Canning, page 2·75.

incorrectly, it creates conditions that are ripe for toxin production. One solution is to heat canned food to more than 100 °C / 212 °F long enough to kill all the spores. Recommended heating times vary by type of food.

When food is cooked sous vide, it never reaches temperatures that high. So, after cooking, the food must instead be frozen or, if possible, held just above freezing temperatures. To avoid bacterial growth and subsequent creation of toxins, the food should be eaten soon after it is warmed.

B. cereus, *C. botulinum*, and *C. perfringens* count among the most common sources of food poisoning from spores. Each has different properties.

B. cereus is one of those facultative anaerobes, which can live with or without oxygen. It is also one of the few foodborne bacterial pathogens that is not closely linked to fecal contamination; the microbe is widespread in soil and dust and is often found on dried grains and beans. One study found that more than 50% of dried bean and cereal samples contained *B. cereus*. The bacterium often contaminates dried herbs, spices, and potatoes.

Although heat kills *B. cereus* fairly easily, the spores of this species are highly resistant to heat, and they get even harder to kill in the presence of fats or oils. The pathogen's hazard is complicated by the fact that it makes two different toxins. The first, a compound that causes diarrhea, is slow to act; symptoms of this poison may take 8–16 h to develop. Thankfully, the diarrheal toxins that *B. cereus* produces are heat labile at a relatively low temperature (56 °C / 133 °F); cooking for only 5 min will destroy them.

The second toxin, which is encoded by a plasmid, is known for causing vomiting and thus functions as an **emetic**, an agent that induces nausea and vomiting. Emetic toxins act more quickly, typically within 1–6 h of ingestion. Unfortunately, the *B. cereus* emetic toxin is not heat labile; studies suggest that deactivating the toxin in contaminated food requires heating to 126 °C / 259 °F for more than 1½ h.

C. botulinum stands as one of the most infamous food pathogens of all. Its effects, though relatively rare, are extremely severe. Researchers have found multiple bacterial strains in soil samples, in lake and stream sediments, and inside the intestines of fish and mammals. A large part of the pathogen's notoriety derives from the fact that it produces the most toxic protein known: the LD_{50} in mice (the amount that will kill half of them) is only 1–5 nanograms (billionths of a gram) per kilogram, or as little as one part per trillion.

Despite its potency, botulism's poison is fatal in fewer than 10% of cases in the United States

THE RISKS OF

Eating Wild Rabbit

Although the fecal-oral route is probably the most common way that bacterial pathogens contaminate food, some harmful microbes can gain access to their human victims through food infected by other means. One well-known example is salmonellosis acquired by eating raw or undercooked eggs that were contaminated before even being laid, through infections in the mother hens' ovaries. Although far less common, tularemia, or "rabbit fever," offers another example of a highly infectious and potentially fatal bacterial hazard for both chefs and their customers—in fact, public health officials have expressed concern over the microbe's potential as a bioterrorism weapon. Fortunately, after a correct diagnosis, a physician can treat the disease effectively with antibiotics.

The disease, which is caused by the species *Francisella tularensis*, sickens about 200 people in the U.S. every year, mostly in southern and western states. Researchers have linked most cases to handling infected rabbits or rodents and to tick or fly bites. Rabbit fever can also be delivered via the dinner plate, as suggested by a recent clinical report on an infected couple who ate roasted wild rabbit cooked to a medium state of doneness in a Berlin restaurant.

Wild rabbit must be cooked well-done to kill any tularemia bacteria; for rare or medium-cooked rabbit dishes, chefs can substitute farm-raised rabbits that have been kept segregated from their wild relatives by trustworthy breeders. In the kitchen, cooks who handle raw wild rabbit can protect themselves by wearing latex or vinyl gloves.

THE RISKS OF
Spoiled Fish and Cheese

As a general rule, spoilage bacteria do not cause illness themselves, but there are rare exceptions. Scientists have linked scombroid poisoning, otherwise known as histamine poisoning, primarily to eating spoiled fish such as tuna, mahi mahi, and bluefish. Spoilage that occurs during the production of Swiss cheese can also cause the illness.

The symptoms of scombroid poisoning–an itchy rash; a tingling, burning, or peppery sensation in the mouth; nausea and vomiting–are often confused with those of an allergic reaction (which involves histamines made by the human body itself). The entire course of an episode may last only a few hours, although the poison can initiate a dangerous drop in blood pressure and can hit the elderly or those with preexisting illnesses particularly hard.

The bacteria that form histamine are ubiquitous in salt water and live harmlessly in the guts and gills of fish. When fish die, however, the bacteria quickly invade their flesh, especially if the fish have been left out in warm weather. The resulting chemical cycle leads to an overabundance of enzymes that form histamine. According to the FDA, cooking, canning, and freezing have no effect on the integrity of the histamine molecule. Likewise, salting or smoking affected fish will not protect eaters from histamine because the bacteria that have been implicated in scombroid poisoning are salt-tolerant.

Carefully removing fish gills can reduce the amount of histamine-producing bacteria, but it can actually make the contamination worse if it is done incorrectly. And the sniff test is not a reliable way to detect histamine–only a chemical test can do that. The best way to reduce the risk is to chill fish immediately after they are caught in order to prevent the formation of histamine.

because few victims consume even that minuscule amount. Amazingly, some people actually want the toxin. Tiny amounts of the botulinum neurotoxin are used to temporarily paralyze muscles for the purpose of reducing wrinkles. It is sold under the name Botox.

C. botulinum is very sensitive to pH—it does not grow well in highly acidic conditions—and is strictly anaerobic. So contamination is an issue mainly in low-acidity foods that get little oxygen. Proper growth conditions, for example, exist at the centers of sausages (the word *botulus* is Latin for sausage), chopped garlic in oil, and other dense foods. Botulism is a particular concern in canned foods or dishes cooked sous vide because these preparation methods exclude oxygen by design.

C. perfringens is a fecal bacterial species that normally resides in the guts of both animals and people. Like other members of the *Clostridium* genus, however, it can be deadly if it gains access to susceptible body tissues, where it can provoke diseases as varied as gas gangrene and pig-bel. When necessary, it makes especially hardy spores.

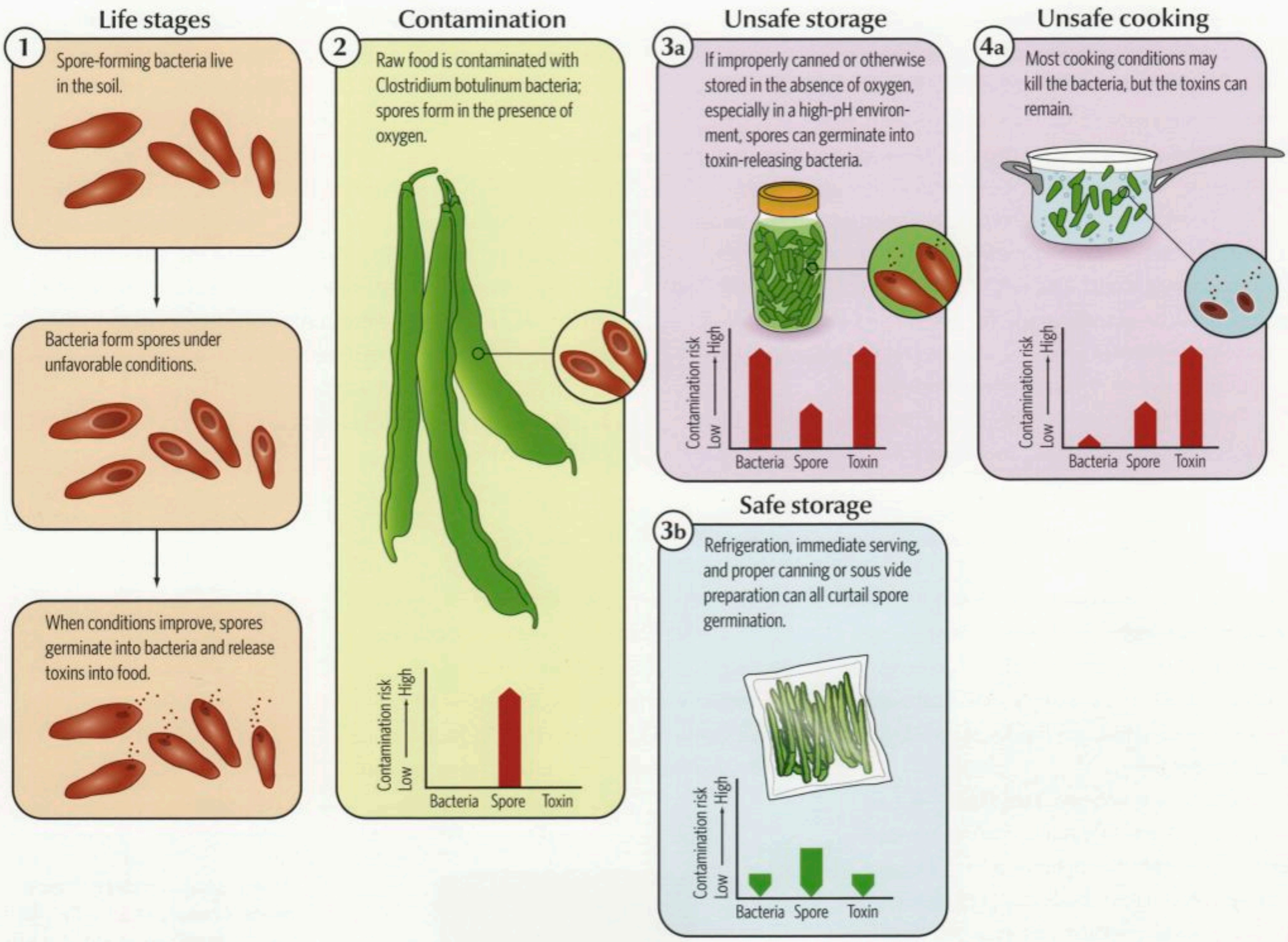
Alarmingly, the spores of many *C. perfringens* strains remain active at temperature ranges of 70–75 °C / 158–167 °F. If the initial cooking period does not kill the spores, it may instead just stimulate the germination of the spore-encased bacteria, which could then grow, multiply, and produce their potentially lethal toxins.

Imagine a scary but all-too-possible scenario in which spores of *C. perfringens* from human or animal feces contaminate a turkey. Say you stuff

Botulism is both a dreaded toxin and a miracle of cosmetic medicine. The toxin is used to paralyze muscles, which can relax facial wrinkles. The toxin is produced by bacteria that form hard-to-kill spores, which are the principle reason canned food must be pressure-cooked to be safe.

How *Clostridium Botulinum* Can Poison Food

C. botulinum, commonly found in soil, grows best when oxygen and acid levels are low. In an unfavorable environment, the bacteria can form protective cases, thus becoming spores that survive in a dormant state until conditions improve. Botulism, or botulinus poisoning, although rare, can be a special concern for sous vide or canning processes that eliminate oxygen. If the procedure is done incorrectly, the spores can germinate within the food. The resulting bacteria quickly multiply and produce a potent neurotoxin that is among the most deadly known.



and roast a turkey that somehow has become contaminated. If you follow the usual temperature guidelines, the bird will be cooked to an internal temperature of 74 °C / 165 °F. The high temperature will kill the bacteria, but it also encourages the germination of the remaining spores, which leads to more toxin-producing bacteria.

If the turkey is eaten right away, there is no problem. If the turkey is allowed to sit for too long, however, bacteria from the germinated spores could produce toxins that will sicken people who eat it. This is true even if the turkey is refrigerated whole because the center of the bird could take hours to cool down.

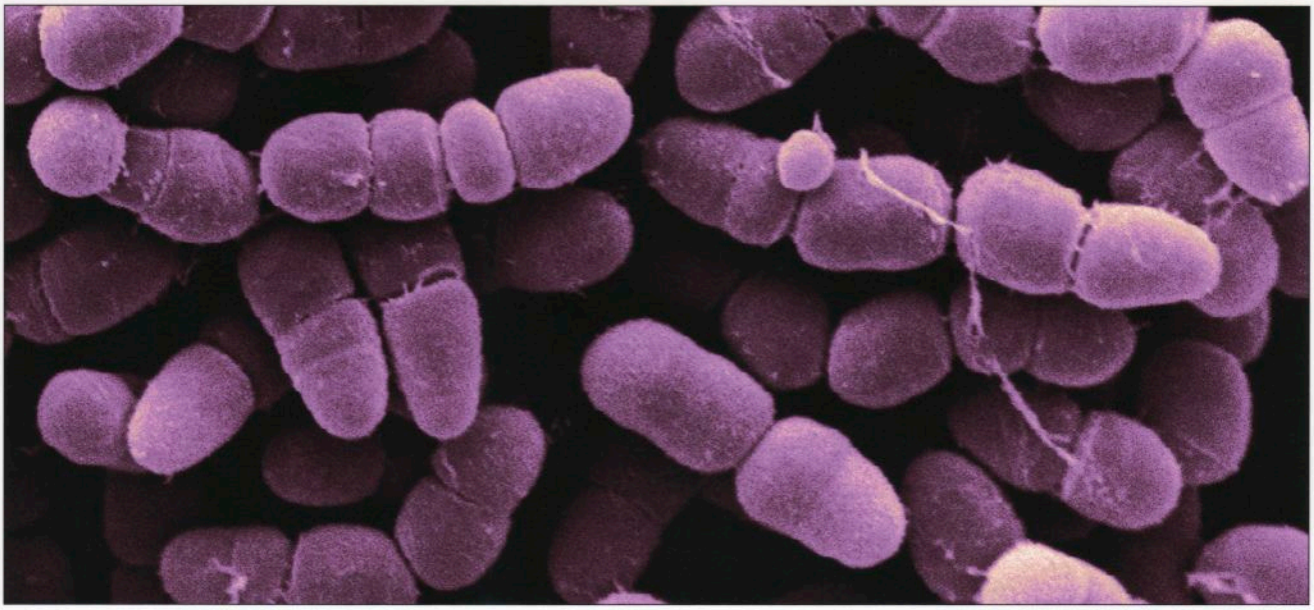
Unless you take active steps to cool the turkey quickly—in a blast chiller, for example—the temperature of the stuffing-filled body cavity drops very slowly. And once the temperature falls below 50 °C / 122 °F, *C. perfringens* can begin to grow. If the interior temperature stays below that threshold but above standard refrigeration temperatures for even a few hours, toxins can begin to accumulate. Because *C. perfringens* tolerates exposure to salt fairly well, similar outcomes can result from inadequate cooling of cooked hams, corned beef, and other cured meat products.

The neat categories of invasive infections, noninvasive infections, and food poisoning cover most cases, but some modes of food poisoning combine several mechanisms. A few bacteria have become particularly adept at this combined strategy, though much depends on the relative health of their human targets and the particular way they encounter the pathogen. In the typical scenario, *C. perfringens* produces a toxin that causes food poisoning. But if a victim ingests a sufficiently large dose, say about 100 million cells, the bacteria can noninvasively infect the victim's gut and begin secreting toxins there.

Under the right conditions, a person infected with the type C strain of *C. perfringens* can fall ill with a rare but very serious disease known as pig-bel, enteritis necroticans, or necrotizing enteritis. Under these circumstances, the dose of toxin is high enough that intestinal tissues begin to die (necrotize), which can lead to a very severe and often fatal blood infection.

Physicians first diagnosed and named pig-bel in New Guinea, where it sickened people who feasted on whole pigs cooked in pits in the ground. Those pigs went through the same heating and slow cooling cycle described for turkey, although the larger size of the pigs meant that the cycle was extended even longer. A contributing factor in the New Guinea cases may have been one of the other dishes on the menu: sweet potatoes. Unfortunately, the sweet potatoes probably contained a protein that blocks the action of a stomach enzyme that otherwise would help kill *C. perfringens*.

Clostridium perfringens bacteria (shown below) make spores (shown on page 110) that can get into a deep cut or a wound with dead tissue, where they can germinate and grow to produce the condition called gas gangrene. Because C. perfringens is anaerobic, it cannot invade living tissue that is properly oxygenated, so gas gangrene is a noninvasive infection. This type of infection, of course, is not foodborne, illustrating the diverse ways that one organism can cause trouble.



BACTERIAL GROWTH

All bacteria multiply by cell division. When an individual bacterium reaches a certain point in its growth, it splits into two separate cells. The time required for a new cell to begin dividing depends on local conditions—primarily, the availability of nutrients, the acidity (pH), and the temperature. Bacterial cell division is not as regular as clockwork, but under the right circumstances, it can happen in minutes.

Mathematically speaking, the process is known as **geometric growth** or **exponential growth**. It can be extremely rapid, doubling a bacterial population with every round of cell division. If you start with a single bacterial cell, the growth sequence would be one, two, four, eight, 32, 64, and so on. After 10 doublings, that single bacterium would become 1,024. After 20, the population would exceed one million.

Clostridium perfringens currently claims the record for fastest known bacterial replication: in one study, it reached a doubling time of less than eight minutes in ground beef, meaning it could theoretically grow by a factor of one million in less than three hours. Other foodborne pathogens replicate more slowly in food, but many can still double in 30 to 50 minutes, resulting in a potential millionfold increase in 10 to 17 hours.

The ability of bacterial populations to grow exponentially if food is improperly handled makes pathogenic bacteria particularly dangerous. One of the principal goals in food safety, then, is taking measures when food is stored, prepared, or served to prevent this kind of rapid bacterial replication. Although simple geometric formulas illustrate the enormous potential for bacterial multiplication, we can make better mathematical models to predict replication more accurately over time. Most chefs will never use these models, but looking at the calculations can give you a better idea of how the process works.

Bacterial replication rates depend strongly on temperature; below a critical threshold, bacteria simply do not reproduce. The same holds for replication above an upper threshold. These critical temperatures vary for different species and environmental conditions. Some bacteria multiply at temperatures just above freezing, albeit slowly. More often, microbe species begin to replicate somewhere between 3 °C and 12 °C / 37 °F and 54 °F. As the temperature rises above that range, bacterial reproduction generally accelerates until it reaches a maximum value.

This temperature dependence is the main reason that foods are stored in refrigerators and

THE TERMINOLOGY OF

Measuring Bacterial Reproduction

Researchers measure bacterial reproduction by counting either individual cells or **colony-forming units** (CFUs). CFU is the more general category because it accounts for cases in which the starting point of an infection or outbreak is not a single cell but rather a connected pair or a chain of cells. A CFU can even be a bacterial spore.

Because microbe numbers can increase so quickly, most studies measure the bacterial population by calculating the base-10 logarithm of the CFUs per gram, or $\log_{10}$(CFU)/g. (For liquids, the measurement is typically given in $\log_{10}$(CFU)/ml.) If just 10 CFU (10^1) are present per gram of food, the population size is 1 $\log_{10}$(CFU)/g. If one million (10^6) cells are present per gram, the population is 6 $\log_{10}$(CFU)/g. The numeral before the unit thus represents the population expressed as a power of 10.

An E. coli cell photographed in the late stages of cell division has nearly split to become two.

freezers, where the low temperatures can halt or dramatically slow the replication of pathogenic and spoilage bacteria.

If the temperature rises past a certain point, the bacteria stop reproducing, and at higher temperatures still they start to die (see The Limits of Bacterial Reproduction, page 145). As a general rule, most pathogenic bacteria multiply fastest at temperatures just below their lethal upper limit, which leaves a fine line between rapid reproduction and death. Foodborne pathogens typically reach their optimal reproductive rate between 37 °C / 98.6 °F—the normal body temperature of humans—and 43 °C / 109 °F. This is the case for *Escherichia coli* O157:H7, for example, as shown in the chart on the next page. Most pathogens cannot grow above 55 °C / 131 °F.

Just like any other form of life, bacteria need to eat, and the availability of nutrients also affects how fast they reproduce. Once bacteria have multiplied a millionfold, they can exhaust their local food source, which causes replication to slow or even halt. In most food safety scenarios, however, food provides ample nutrients, so this limiting factor rarely becomes a practical consideration in the kitchen.

The pH of food also can greatly affect bacterial reproduction. Most bacteria multiply fastest in foods that have a pH near 6.8 (close to the neutral value, 7.0), but may reproduce in acidic foods with a pH as low as 4.0 and in alkaline foods with a pH as high as 8.0. And a few pathogenic species can multiply at extreme pH values outside this range.

In the chart on the next page, which depicts the reproduction of *E. coli* O157:H7 as a function of both temperature and pH, note the dramatic effect that a small change in pH, in temperature, or in both parameters can have on the doubling time of the population. At lower temperatures, a shift in pH can extend the required interval for doubling from 30 minutes to six hours. Put another way, it can reduce the amount of replication that occurs in a single day from a factor of some 280 trillion to a mere factor of 16!

The addition of nitrates to cured meats raised concerns in the 1970s because the compounds can form into nitrosamines, many of which are carcinogenic in animals. In response to this concern, meat packagers reduced nitrate levels and began adding vitamin C (ascorbic acid), vitamin E (alpha-tocopherol), and other compounds that greatly reduce nitrosamine formation without detracting from nitrates' preservative functions.

For more on water activity and the role it plays in food preservation, see Water Activity, page 307 and Drying, page 2·428.

The concentrations of salt, sugar, and alcohol influence bacterial reproduction as well. Raising the concentrations of these lowers the **water activity**—the fraction of water available for microbes to use—in the food, which can hinder bacterial metabolism. This phenomenon explains why syrup, molasses, and salted meats can be stored with little or no refrigeration. Even though sugar can provide food for many bacteria, its concentration in syrup, for example, is so high that they cannot take advantage of it. Very dry foods, because of their inherently low water content, also are poor media for bacterial replication.

Chemicals as Preservatives

For more on the use of curing salts in meat curing, see page 3·158.

Various chemicals other than salt, sugar, and alcohol suppress bacterial reproduction, and some have been a mainstay in food preservation for thousands of years. Humans have long been curing meat with saltpeter (sodium and potassium nitrates) and sodium nitrites, for instance, and these chemicals are still found in most ham, bacon, and sausages. For many present-day meat producers, the characteristic taste of cured meat has become more important than the antimicrobial properties of the curing process, but cooks long ago adopted the practice because nitrates inhibit the reproduction of bacteria, particularly that of the botulism-causing *Clostridium botulinum*. From a historical standpoint, sodium nitrite has saved many lives by reducing the incidence of botulism associated with the consumption of cured meats.

Some researchers are testing the preservative for its potential to treat sickle-cell anemia, heart attacks, and even brain aneurysms. But evidence suggests that nitrites might cause respiratory problems when consumed in large quantities. Many cured meat products today contain only limited quantities of the chemical, primarily to retain the well-loved taste of cured meat.

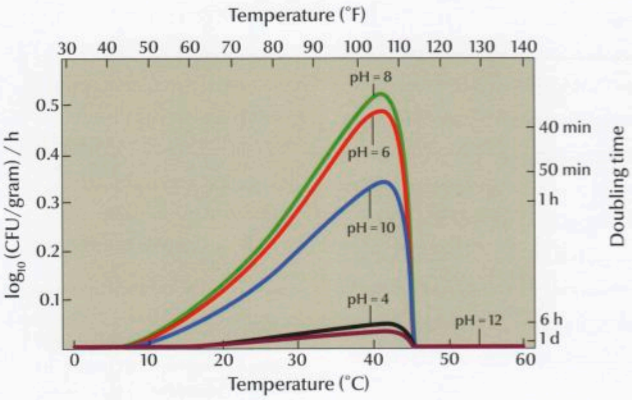
Processed foods, particularly ready-to-eat ones, contain many added preservatives. Some combat spoilage bacteria and mold and other kinds of fungus; others suppress the replication of pathogens. Most can halt all bacterial reproduction.

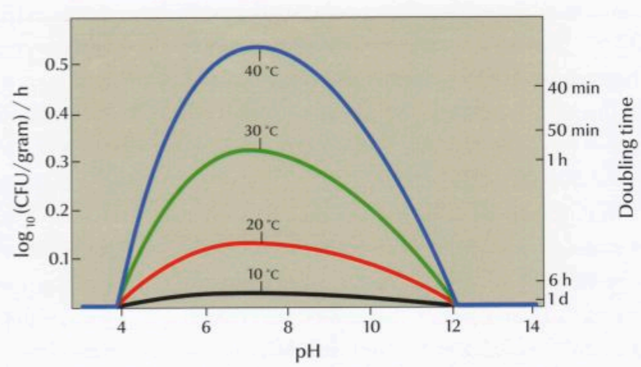
Many of these preservatives have a natural origin. Nisin, for example, is a protein produced by *Lactococcus lactis*, a bacterium naturally found in milk. Food processors manufacture the protein by fermenting milk and extracting the nisin from it. The FDA, which recognizes nisin as safe, lists it as a natural food additive that can control bacterial reproduction. Nisin is highly effective against Gram-positive bacteria, including food pathogens such as *Bacillus cereus*,

How Temperature and pH Affect Bacterial Reproduction

The reproductive rate of *Escherichia coli* O157:H7, like that of most foodborne pathogenic bacteria, varies tremendously in response to both temperature (below left) and pH (below right). Food safety rules typically define the general "danger zone" as running from 5–60 °C / 40–140 °F. Specialists adopted this definition mainly because it reflects the temperature range in which most pathogenic bacteria can reproduce.

Regrettably, however, simplistic rules about the danger zone are misleading at best. Inside the zone, the higher temperatures are exponentially riskier than the lower temperatures. It takes several days for *E. coli* O157:H7 to multiply at 5 °C / 40 °F as much as it does in mere minutes at 38 °C / 100 °F, for example. For more on this subject, see chapter 3 on Food Safety.





The Limits of Bacterial Reproduction

Pathogenic foodborne bacteria stop reproducing below a certain minimum temperature and above a certain maximum temperature—and replicate fastest within an optimal temperature range. The acidity, or pH, of the food also places limits on bacterial multiplication.

	Lower temp. limit		Upper temp. limit		Fastest growth		Lower pH limit	Upper pH limit
Species	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(pH)	(pH)
Bacillus cereus	4	39	55	131	28–40	82–104	4.3	9.3
Campylobacter jejuni	30	86	45	113	37–43	99–109	4.9	9.5
***Clostridium botulinum* Type A**	10	50	48	119	30–40	86–104	4.6	9
***C. botulinum* Type B**	10	50	48	119	30–40	86–104	4.6	9
***C. botulinum* Type E**	3	38	45	113	25–37	77–99	5	9
C. perfringens	10	50	52	126	43–47	109–117	5	9
***Escherichia coli* (pathogenic)**	6	43	50	121	35–40	95–104	4	9
Listeria monocytogenes	−1	31	45	113	30–37	86–99	4.4	9.4
***Salmonella* spp.**	5	41	47	116	35–37	95–99	3.7	9.5
***Shigella* spp.**	6	43	48	117	37	99	4.8	9.3
Staphylococcus aureus	7	44	50	122	35–40	95–104	4	10
Vibrio cholerae	10	50	43	110	37	99	5	10
Yersinia enterocolitica	−2	29	42	108	28–30	82–86	4.2	10

Listeria monocytogenes, *C. perfringens*, *C. botulinum*, and *Staphylococcus aureus*. The protein has also proved able to suppress reproduction of a few Gram-negative pathogens and several important species of food spoilage microbes. Food manufacturers commonly add nisin to cheese and other products to extend shelf life and fight pathogens.

Many foods have natural antimicrobial properties, which chefs can exploit. In 2007, a California-based research group at the U.S. Department of Agriculture that had previously studied the bacteria-killing effects of more than 200 plant essential oils tested a variety of wine-based marinade recipes. Research has suggested that, when added to oregano or thyme leaves, wine acts as a solvent to the antimicrobial compounds carvacrol or thymol (an ingredient in some antibacterial sprays), respectively. Other research suggests wine can kill some bacteria on its own.

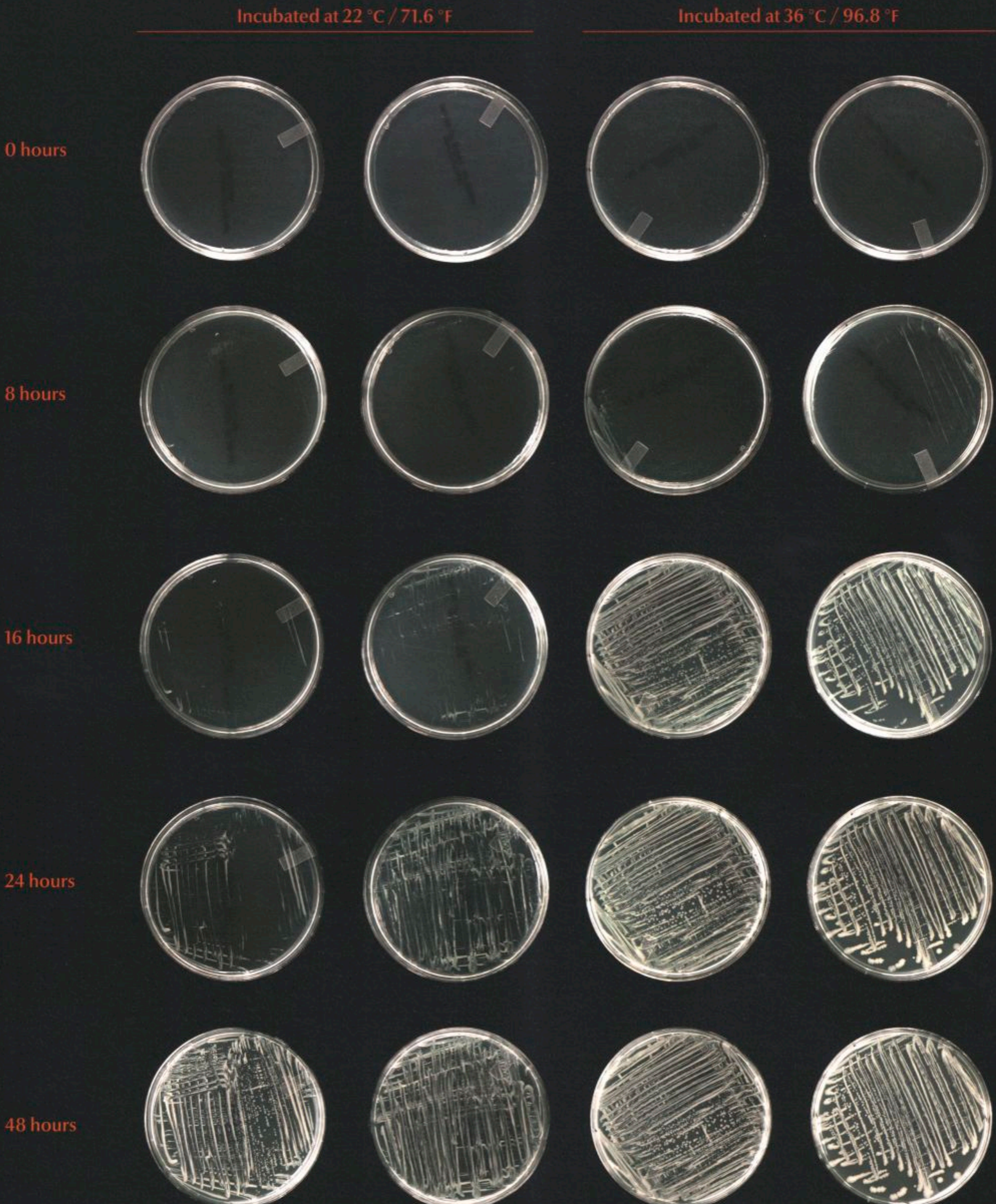
The 2007 USDA study confirmed the antimicrobial potency of a wine marinade with oregano against the pathogenic bacteria *E. coli* O157:H7, *Salmonella enterica*, *L. monocytogenes*, and *B. cereus*. The study found that red wine alone at 4 °C / 39 °F killed *L. monocytogenes* but required at least a half hour to do so. Adding oregano leaves, oregano oil, and garlic juice made the killing nearly instantaneous.

When *B. cereus* bacteria were added to either red or white wine and incubated at room temperature for an hour or more, the wine easily killed the bacteria, although red wine was about eight times more deadly than white. Red wine and oregano leaves were particularly effective against *E. coli* O157:H7 and *S. enterica*, but only when the bacteria were marinated for an hour at 21 °C / 70 °F or higher.

Combining either Pinot Noir or Chardonnay with oregano leaves, garlic juice, and oregano oil proved effective against all four bacteria. Again, increasing the incubation temperatures raised the potency.

Although bacterial populations can multiply exponentially on stored food, they typically reproduce more slowly inside a living plant or animal. The immune system of the host checks their replication to some extent. Vaccines, which boost the effectiveness of the immune response, therefore offer another way to improve the safety of the food supply. In 2009, American farmers began vaccinating cattle against *E. coli* O157:H7. The inoculation will not completely eliminate this dangerous strain of bacteria from beef, but it could reduce the number of infected cattle by perhaps two-thirds.

E. COLI CULTURES



THE MATHEMATICS OF

Modeling Microbial Multiplication

No prediction of microbial behavior can ever be completely accurate. Numerous variables—too many, in fact—make it a difficult problem to model. During the last few decades, however, the science of modeling and estimating bacterial reproduction and inactivation processes has blossomed into a major area of research that has been dubbed "predictive microbiology."

Part of the field's rapid expansion has come from the realization that researchers need to develop more complex models to account for the effects on microbial multiplication of factors including temperature, pH, preservatives, food structure, water activity, and the presence of other organisms. Quick, reasonable estimates of bacterial reproduction and survival, although not infallible, have enabled researchers to determine the shelf lives of foods, create new products, highlight potential points of concern in production and distribution processes, intelligently assess the influence of environmental factors, and help formulate better safety guidelines.

The specifics of the models that researchers and commercial food processors use lie beyond the scope of this book, but generally they try to predict the classic sigmoid or S-shaped curve that describes the lag, exponential, and stationary phases of bacterial reproduction over time (the onset of bacterial death adds a downward slope to the sigmoid curve).

These predictive models fall into three main classes: primary, secondary, and tertiary. Primary models seek to explain the response of bacteria to a single set of conditions over time. The oldest and simplest of these models, the log-linear model, is based on the concept that for a specific temperature, the rate at which bacteria die off remains constant over time. The builders of more recent models, including versions that are called (after their authors) the Baranyi, Buchanan, and modified Gompertz models, have sought to refine their predictions of bacterial replication curves by using experimental data.

Secondary models predict environmental relationships, such as the effect of temperature on the bacterial reproductive rate, or more complicated interactions including how the combination of salt and water activity affects the replication rate as the temperature increases. Tertiary models are more complicated still and combine aspects of primary and secondary models. They typically require spreadsheets or dedicated software programs to perform the calculations involved.

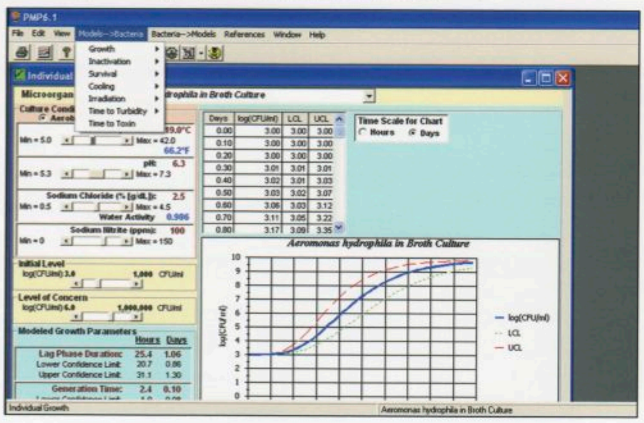
Some of these software programs can be very useful to chefs who design a particular food or food process. A company that is creating a ready-to-eat food product that has multiple ingredients and cooking steps can use the software to find out if the process provides enough of a safety margin.

A firm that makes precooked corned beef, for example, might predict the replication of *Clostridium perfringens* at a given cooling rate. The software's prediction might persuade the company to change the mix in the corned beef curing formula or to increase the cooling rate. In most cases, of course, chefs will not care about this level of detail, but particularly complex processes might be worth the trouble.

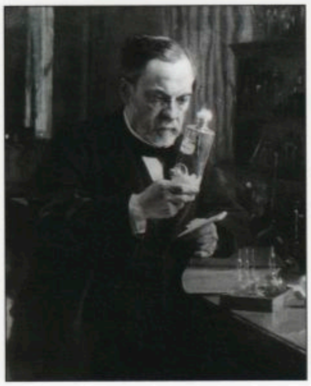
Many such food-pathogen software programs exist, but two stand out. The Pathogen Modeling Program, or PMP, is distributed for free by the U.S. Department of Agriculture. As of 2010, the software was available online at http://ars.usda.gov/services/docs.htm?docid=11550.

The second program, Growth Predictor, is distributed for free by the U.K. Institute of Food Research at http://www.ifr.ac.uk/Safety/GrowthPredictor. A version of Growth Predictor can be used with a web interface as part of the ComBase Initiative (a collaboration of agencies from the U.S., the U.K., and Australia) and is available by filling in an e-mail form at http://www.combase.cc/toolbox.html.

The Pathogen Modeling Program (PMP) is distributed for free.



BACTERIAL DEATH



The 19th-century French scientist Louis Pasteur is best known for developing a technique that makes milk safe to drink, but he also created the first rabies vaccine. Pasteur's interest in preventing disease was inspired by the tragic deaths of three of his five children from typhoid.

For more on pasteurization techniques and the history of Louis Pasteur, see page 2·84.

For more on measuring the pH of food, see How to Use a pH Meter, page 2·316.

For bacteria, death is very similar in some ways to reproduction: it, too, is exponential. When environmental conditions become lethal, bacteria start to die—slowly at first, and then with increasing speed as conditions worsen.

In the kitchen, temperature—high temperature in particular—provides the primary means of killing bacteria. Refrigeration or even freezing slows or stops the division of most bacteria of concern to cooks, but it does not kill them as it does many parasites. Instead, high temperature is what destroys bacteria.

As we have seen, however, an increasing temperature can also promote faster bacterial reproduction—but only up to a certain point. Above a critical threshold, the higher the temperature, the faster the bacteria expire; see The Limits of Bacterial Reproduction on page 145.

Too often, presentations on food safety oversimplify how this works and give the misimpression that the critical temperature alone is what matters. That is just not true. The process of bacterial death is a function of both time and temperature. *Do not trust any food safety rule that discusses temperature only.* Such rules can be dangerous, an issue we cover in more depth in chapter 3 on Food Safety.

Time is so important because killing bacteria is, by its nature, a statistical process. If you start with millions of bacteria, you will kill some fraction of them in any given period of time. Eventually, you may reach a certain probability that all of the bacteria have died. The usual way of describing this probability is to note the proportion killed in powers of 10. If you kill 90% of the bacteria, 10% (or 1/10) are left, so you have thus reduced their numbers by a factor of 10. Food scientists often refer to a tenfold reduction as a **1D (for decimal) reduction**. You may also see a tenfold reduction referred to as one order of magnitude or as a 1-D, 1-log, or 1-$\log_{10}$ reduction.

The canning industry enforces the most stringent requirements of any segment of the food-processing business. Canned food must last months or years without being refrigerated; it does so mainly by staying encapsulated in an anaerobic environment. During that time, any remaining anaerobic bacteria—perhaps left in the food in the form of spores—could multiply by many orders of magnitude and begin producing toxins. Even a single bacterium could multiply over a period of months to millions or even billions. Reflecting that danger of bacterial buildup if the food is incorrectly processed, the reduction standard recommended for low-acid canned foods is a **12D drop**, which means bacterial numbers must be cut by a factor of 10^{12}, to one-trillionth of their initial size.

Authorities differ on the proper reduction standards for other contexts. For fresh food, various sources recommend 4D, 5D, 6D, or higher levels of bacterial reduction (see chapter 3 for details). The difference of opinion reflects the fact that, for many circumstances, no single right answer exists. Any bacterial reduction, even a 12D drop, can prove unsafe if the contamination is great enough. Conversely, uncontaminated food does not require *any* bacterial reduction process before you can eat it. Unfortunately, there is no surefire way to guarantee that uncooked food is free of contamination, although washing certainly helps. So people eat their salad greens without heating them first, and every once in a while a fresh salad makes someone sick.

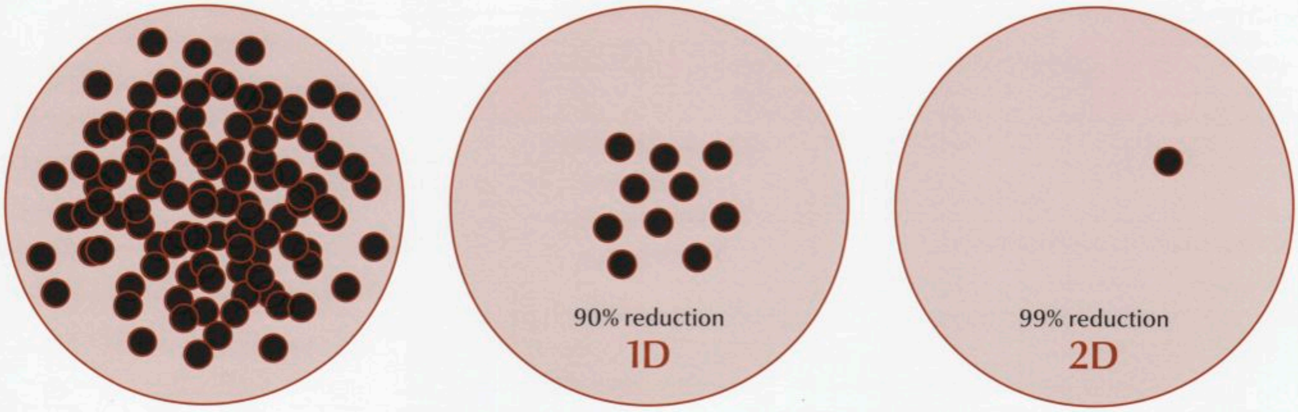
Pasteurization and Sterilization

The oldest approach to heat-sanitizing food is **pasteurization**, a technique named after French scientist Louis Pasteur. The pioneering chemist and microbiologist began developing his pasteurization technique only a few years before publishing the first of his landmark studies on the role of bacteria in disease—research credited with offering the first convincing proof for the germ theory of disease.

Many people think pasteurization applies only to heating dairy products to thwart pathogenic bacteria, but practitioners use the term in other contexts as well. Pasteur, in fact, first developed the technique for storing wine and beer.

Sterilization is another widely used term. Although sterilization techniques are often assumed to kill all microorganisms, they typically do not. More often, the heat treatment is designed

Demystifying Logarithmic Reductions



If the notion of a logarithmic reduction in bacteria seems confusing, it might help to think of the decrease in terms of percentages. A 1-log, or 1D, drop reduces a bacterial population (left petri dish) by a factor of 10, meaning that you're killing 90% of the population and leaving 10% alive (middle dish). A 2-log, or 2D, drop would equal a 99% die-off and leave 1% alive (right dish), and a 3-log, or 3D, drop would be equivalent to a 99.9% decrease. So what does this mean for the mother of all drops, the 12-log, or 12D, bacterial reduction suggested for low-acid canned foods? The bacterial numbers would be diminished by 99.9999999999%.

to kill the most dangerous pathogens, but it can spare other kinds of bacteria.

The combination of temperature and time required to kill 90% of a particular population (for a 1D reduction) depends on several factors. The most important is the type of bacteria; heat tolerance varies widely among species. The pH and the presence of salt, sodium nitrite, or other additives can also make a big difference, as can the presence of certain proteins or fats. Fats can either help shield bacteria from heat or make them more sensitive to elevated temperatures.

Because the rate at which bacteria die rises with temperature, 15 minutes may be needed to kill 90% of them at 54 °C / 130 °F, whereas only a few seconds are required at 100 °C / 212 °F. A graph known as a **thermal death curve** provides the time-and-temperature combinations necessary to achieve a given reduction in the number of bacteria; see Visualizing Thermal Death Curves on the next page. The shape of the graphs varies with bacterial species and with environmental conditions such as the pH and kind of food. In general, specialists model a thermal death curve mathematically as an exponential function that, when plotted as shown on the next page, yields a straight line that makes it easy to extrapolate to higher or lower temperatures.

The exact position of a thermal death curve doesn't matter as much as the principle that many combinations of times and temperatures can kill the same proportion of bacteria and therefore achieve the same level of food safety. You thus almost always have a choice: you can cook at high heat for a short time, or you can cook at low heat for a longer period. It makes no difference to the bacteria (or to the safety of the food). But, as we discuss throughout the book, different choices of times and temperatures can make huge differences in the appearance and taste of the dish.

Food microbiologists calculate thermal death curves by culturing bacteria under various conditions, subjecting them to heat, and then counting how many live or die over time. The results are routinely published in scientific journals such as the *International Journal of Food Microbiology*.

Commercial food handlers apply a variety of other methods to kill bacteria, including ultrahigh pressure, gamma-ray irradiation, strong electric fields, and ultraviolet light. These approaches may have some potential for use by chefs because they can kill bacteria without altering flavor and texture. Further research is required, however, before these techniques can expand beyond laboratory and industrial use to smaller kitchens.

If you know the time (D_{ref}) required to achieve a 1D drop at a reference temperature (T_{ref}), then you can use an equation to calculate the 1D cooking time (t) at any other temperature (T) above the minimum lethal temperature (T_{min}):

$$T_{kill} = D_{ref}10^{(T-T_{ref})/Z}, \text{ where } T_{min} \le T \le T_{max}$$

A typical value for the parameter Z is 10 °C / 18 °F, meaning that if you change the temperature by 10 °C / 18 °F, the time required to kill the same fraction of bacteria increases or decreases by a factor of 10.

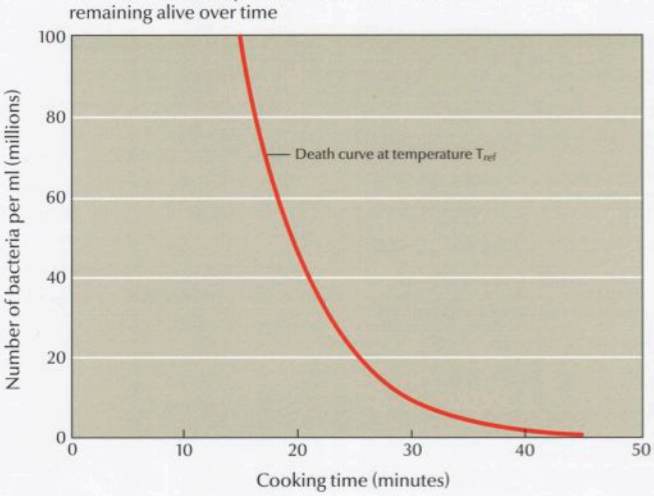
Visualizing Thermal Death Curves

A common assumption in food science is that the same fraction of the bacteria in a particular food held at a particular temperature dies off each minute. That means, for example, that if 90% of the bacteria die in the first 7 min at 58 °C / 136 °F, then 90% of those that remain die in the next 7 min, and so on. In other words, the population falls exponentially over time, as shown in the top left chart below. The shape of this "thermal death curve" can be summarized by a power of 10 (a logarithm) called D, which is the number of minutes needed at a given temperature to knock the population down to one-tenth its starting number. That time falls as temperature rises, and when the time D is plotted against temperature on a graph that has powers of 10 on the vertical axis, the result is usually a straight line (top right chart below). The rate of killing can then be summarized with just the four parameters defined in the table Thermal Death Curve Parameters immediately below.

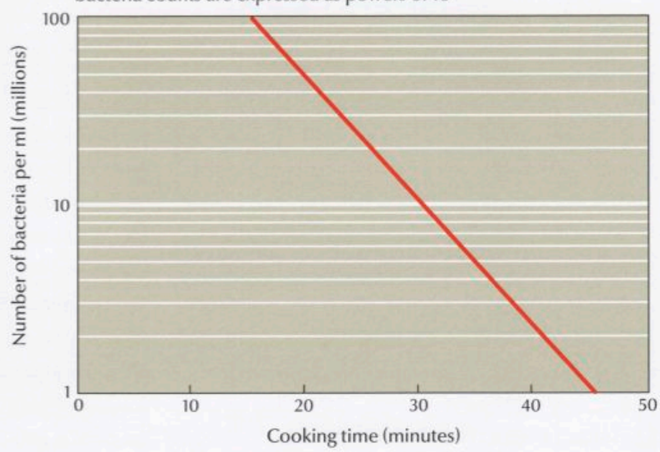
Thermal Death Curve Parameters

Parameter	Definition
T_{min}	minimum temperature needed to kill the organism (at least within the boundaries of the study)
D_{ref}	time needed to kill 90% of organisms at the reference temperature (for a 1D drop)
T_{ref}	reference temperature at which D_{ref} is measured
Z	change in temperature required to reduce the D value by a factor of 10

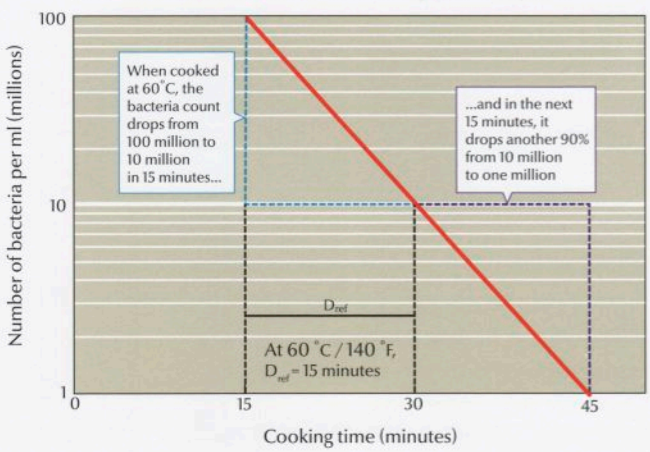
Bacteria die at an exponential rate; the curve shows the number remaining alive over time



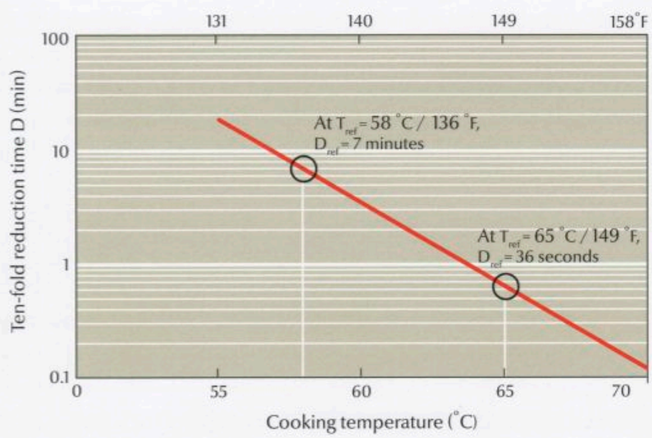
The death curve becomes a straight line when bacteria counts are expressed as powers of 10



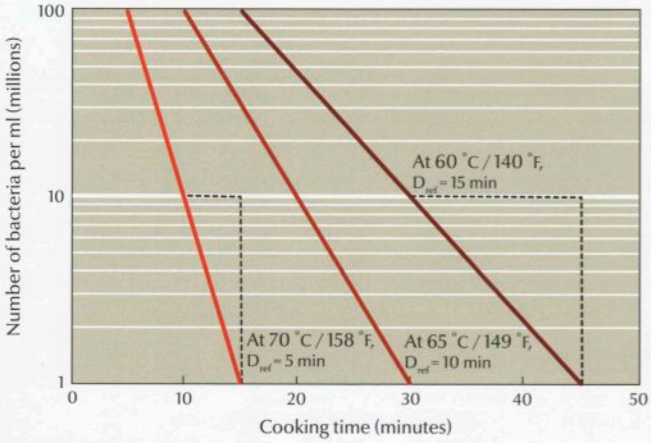
The time D is the number of minutes needed to reduce the bacteria count to one-tenth the starting number (by 90%)



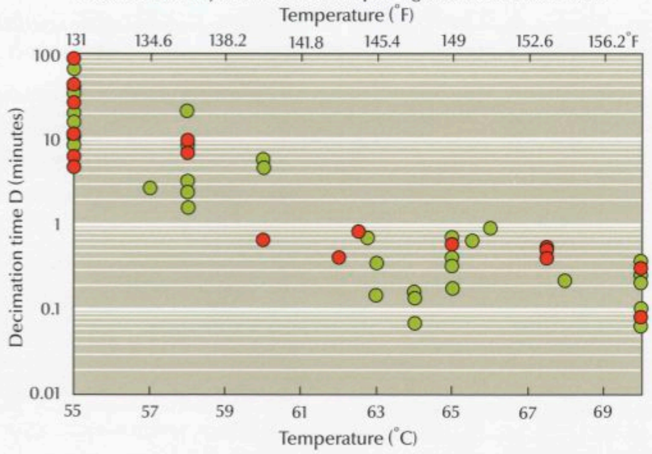
A graph of D vs temperature reveals how long you must hold food at a given temperature to achieve a tenfold (1D) reduction in bacteria



The higher the cooking temperature, the faster bacteria die, and the shorter the D time

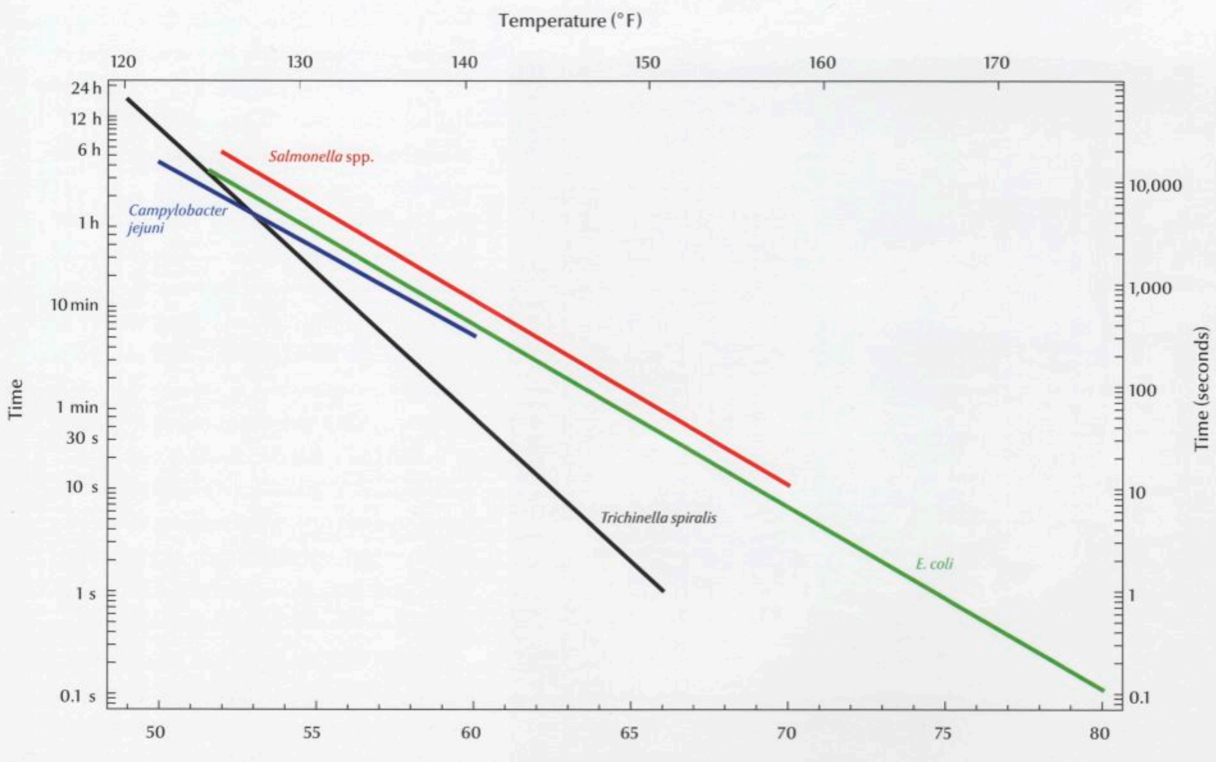


As the actual data points from scientific studies show below, thermal death curves vary from one kind of pathogen and food to another



The graph below shows thermal death curves from the scientific literature for a 6.5D reduction of various pathogens: Salmonella spp. (red, a composite), Campylobacter jejuni (blue), E. coli (green), and Trichinella spiralis (black). The lines cover the range of temperatures tested; the typical assumption is that one can extrapolate the line to higher temperatures, but it may not be valid to extrapolate to lower temperatures. If one line lies below another, that means the pathogen indicated by the lower line is more heat-sensitive.

For example, E. coli is more heat sensitive than Salmonella. The Salmonella curve in red is the basis for FDA cooking guidelines for many foodborne pathogens (see chapter 3) because it is a serious threat in its own right and its thermal death curve lies above those of most of the other pathogens. So by the time Salmonella is reduced to the 6.5D level, most other pathogens will have been reduced to an even greater extent. Note, however, that some bacteria produce spores that are very heat-resistant.



VIRUSES

Viruses have developed many ways to invade their targets. A virus can fuse with a cell, poke a hole in its protective membrane, or try some other tactic to get its genetic information inside, such as injecting that information into the host cell or tricking the cell into engulfing its attacker. Whatever method the virus uses, the successful delivery of DNA or RNA moves the cycle of infection into high gear.

Bacteria are tiny living things. Viruses are quite different, so much so that they blur the distinction between what is alive and what is just a complex chemical.

A virus consists of at least two main components: a biological information molecule—either **DNA** or **RNA**—on the inside and a viral protein coat, or **capsid**, on the exterior. A few varieties of virus include a third component called an **envelope**, which surrounds the capsid.

Think of a virus as a nanometer-scale syringe or hypodermic needle. The "syringe" is the viral protein coat, which is a complicated structure that usually has a geometric shape. Its function is to infect a host cell by injecting or otherwise inserting the DNA or RNA into that cell, where it mingles with the DNA and RNA of the host.

The information molecules of the virus contain the blueprints for building more identical viruses. Once inside the cell, the viral DNA or RNA hijacks the cell's own molecular machinery for building proteins and forces it to makes copies of the virus, thus effectively converting the cell into a virus factory. The virus may also cause its host cell to make toxins.

None of this activity is good for the cell, which usually dies, sometimes bursting in the process to release lots of new copies of the virus. As the human immune system cleans up the dead cells and responds to the virus, it produces inflammation and other symptoms. Many viruses can block their hosts from mounting an effective defense, and some actually trick the host's immune system into attacking healthy cells.

A computer-generated model of rotavirus particles shows proteins that protrude from the surface of the virus particles and bind to target cells to help the virus gain entry.

Dangerous but Not Exactly Alive

Viruses differ from bacteria in many fundamental ways that matter to food safety. Unlike bacteria, which can increase their numbers dramatically on or in food—even precooked food—viruses can reproduce only within the cells of *living* hosts. So viral contamination levels, at worst, remain constant in prepared food or ingredients; the contamination does not increase over time.

Even though viruses do not reproduce independently the way that bacteria do, they do reproduce in a parasitic way, so they are subject to natural selection. They co-evolve with their host species and, over time, become quite specialized. Although most viruses infect just a single species, some adapt and cross over to infect other species. The rabies virus, for example, can infect most mammals, including humans. Meanwhile, the influenza virus can infect humans and a few other animals—notably pigs and birds—and the West Nile virus can infect humans, birds, and horses, among other animals.

Many viruses specialize in infecting human cells, and those that do are either neutral or pathological. Unlike bacteria, which sometimes benefit humans, no natural human viruses are known to be beneficial. Nearly all viruses that cause foodborne illness are specialized to live in humans and do not infect plants or other animals.

Perhaps the most important way in which viruses differ from bacteria is how they die. Because viruses aren't alive in the same way that bacteria are, you can't kill them: instead, you must **inactivate** viral pathogens. Refrigeration or freezing do not inactivate viruses, but heat can do so. The **thermal inactivation curve** for a virus is very similar to the thermal death curve for bacteria that we discussed in the previous section on bacterial death. Like thermal death, thermal inactivation is an exponential phenomenon that depends on time and temperature.

Unfortunately, much less is known about how heat inactivates viruses than about how heat kills bacteria. Unlike many bacteria, most viruses are hard to grow in a laboratory. The problem is particularly acute for foodborne viruses that infect human gut cells; those cells can themselves be difficult and expensive to culture.

Notorious Noroviruses

The noroviruses aptly illustrate the conundrum that many viral pathogens pose to science. Although noroviruses are among the most common foodborne pathogens, thought to collectively cause more than nine million cases of foodborne illness each year in the United States—and to sicken many millions more around the globe—few details have emerged about the mysterious microbes.

Noroviruses have been infecting humanity from time immemorial, yet they were unknown to science until an outbreak of foodborne gastroenteritis, or intestinal inflammation, in 1968, at a school in Norwalk, Ohio. Following that episode, related viruses were found in similar outbreaks worldwide. Microbiologists originally lumped the burgeoning group under the name Norwalk virus. They subsequently became known as Norwalk-like viruses (NLVs) then, in 2002, were officially classified under the genus *Norovirus.*

It took some 40 years after noroviruses were discovered for researchers to successfully cultivate the viral particles in a laboratory—a feat not accomplished until 2007. In the meantime, investigators learned what they could from genetic sequencing of noroviruses' viral RNA, epidemiological studies of infected humans, and research on related viruses that infect cats and mice.

Noroviruses mainly sicken humans, and contamination occurs chiefly via the fecal–oral route. Investigators of outbreaks have implicated foods, such as salad dressing, raspberries, sandwiches, and cake frosting, served in a wide range of places, from schools to cruise ships to some of the world's best restaurants (see Food Poisoning at The Fat Duck, page 155). According to CDC estimates, infected food handlers are responsible for half of all norovirus outbreaks. The viruses can also affect people who eat foods that were

Noroviruses are among the most common foodborne pathogens, but they were only recently discovered, and their mechanism of action remains unclear.

THE MATHEMATICS OF

Spreading an Infection Around

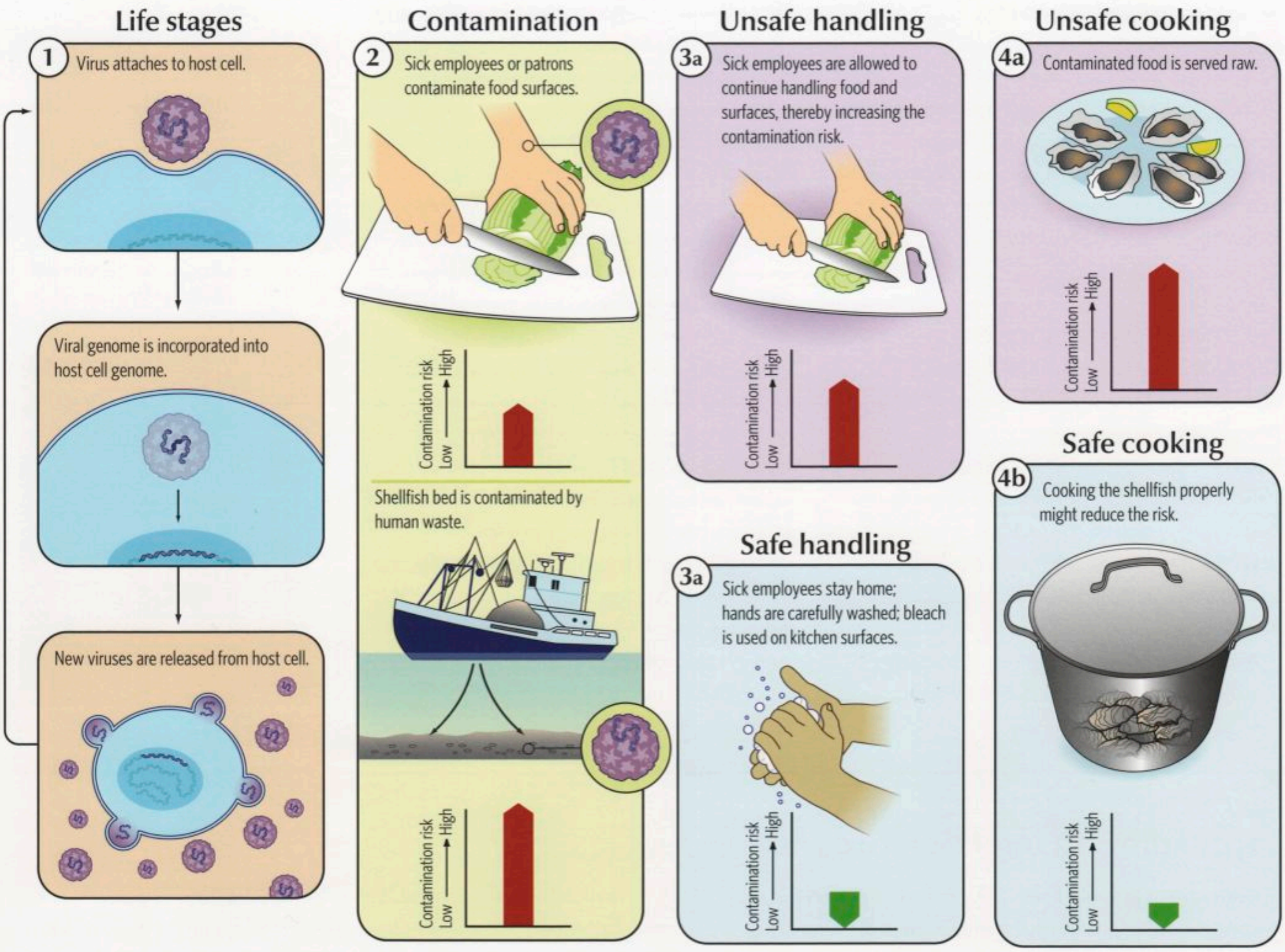
A little math demonstrates how easy it is for noroviruses to infect people. One study by researchers in Hong Kong suggests that 1 g / 0.04 oz of feces from an infected patient can harbor 300 million particles of norovirus genotype II, the strain that accounts for most outbreaks. If that small amount of feces were to get dispersed in an Olympic-size swimming pool (about 2.5 million l / 660,000 gal), the resulting dilution would still leave one viral particle per 8 ml / 1½ tsp of water. A vegetable rinsed in that water could be infectious.

Contamination can build up at the source of the food as well. Oysters or clams routinely become contaminated from the discharge of raw sewage coming from the boats that harvest them. One study showed that 85% of boats operating in a productive oyster area in the U.S. in 1993 lacked proper sewage-holding facilities, meaning that they instead discharged their sewage directly into the sea—despite laws forbidding the practice. Investigations of three separate gastroenteritis outbreaks suggested that a single crew member who is stricken with a norovirus can contaminate miles of oyster beds through fecal discharge into the water.

That may seem incredible, but consider that a single adult oyster can suck in and spit out as much as 230 l / 60 gal of seawater a day as it feeds on microorganisms that it filters out of the water. Norovirus-contaminated feces that discharge into the ocean and are diluted to a concentration of one virus per 100 ml / 3.4 oz of water (12 times more dilute than in the swimming pool example above) could theoretically expose an oyster to some 2,300 viral particles every day. Because oysters grow over a period of months or years, they filter a tremendous amount of seawater, meaning that the virus can survive and accumulate within oysters (or clams), then infect a person who eats the shellfish.

How Noroviruses Can Contaminate Food

The highly infectious noroviruses multiply only within the cells of their hosts—typically humans. Nevertheless, they can persist in the environment, such as in shellfish beds, until consumed by an unsuspecting victim. The CDC estimates that half of all norovirus outbreaks are due to infected food handlers, highlighting the necessity of good kitchen hygiene and of keeping sick employees at home. The hardy particles often resist disinfection and chlorination attempts, but the risk can be reduced by carefully washing fruits and vegetables, properly cooking oysters and shellfish, cleaning potentially infected surfaces with bleach, and washing contaminated linens in hot water and detergent.



It is not known what time and temperature combinations are enough to thermally inactivate norovirus because, as of this writing, the studies have not yet been published. Cooking may or may not be able to reduce the risk.

contaminated at the source, such as shellfish tainted by human feces (see Spreading an Infection Around, previous page).

Once inside a person, the pathogens can spread rapidly. One 2008 study estimated that a single **virion** (infectious virus particle) of Norwalk virus is 50% likely to produce an infection—the highest infection rate of any known virus. No surprise, then, that specialists attribute half of all foodborne gastroenteritis outbreaks to noroviruses.

Recovery from a norovirus infection does not produce long-term immunity, which means that people can get reinfected repeatedly. No one knows whether this lack of immunity is caused by diverse viral strains or by some other feature of the virus. Intriguing research, however, has indicated that people with certain blood types may be resistant to norovirus infection.

Norovirus infections are generally mild and are only rarely lethal. Symptoms occur after a typical incubation period of one to two days and include nausea, vomiting, diarrhea, and abdominal pain; they usually ease in a few days. But viruses can be shed for as long as two weeks after recovery.

Rotavirus and Hepatitis

Two other kinds of foodborne viruses, rotavirus and hepatitis, are worth mentioning. The former is a wheel-shaped virus that primarily affects children; health officials estimate that most children have been infected at least once by the age of four. The *Rotavirus* genus includes seven species so far—each denoted by a letter of the alphabet. Rotavirus A causes 90% of all rotavirus infections in humans. Only about 1% of the estimated 3.9 million annual cases of rotavirus infection in the U.S. are thought to result from foodborne contamination, but that still translates to 39,000 incidents annually.

Rotaviruses can cause fever and vomiting, and they constitute the leading cause of severe diarrhea among children, a condition that requires hospital admission in one out of every 40–80 cases. Although deaths from rotavirus infection are uncommon in developed countries, rotaviruses kill nearly one million people annually.

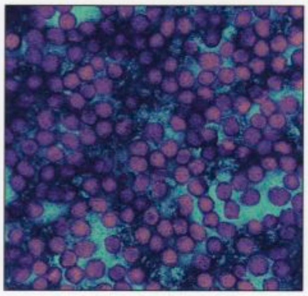
Adults who experience repeated exposure to the same rotavirus strain can develop partial immunity, which results in less severe infections. Even asymptomatic adults can shed infectious particles, however. Hijacked intestinal cells can rapidly release as many as one billion viral particles per milliliter (0.2 teaspoon) of feces. And because rotaviruses require only 10 particles to be infectious, their next victim is usually not far off.

Hepatitis A, another highly infectious viral pathogen that propagates primarily through fecal contamination, is foodborne in about 5% of cases. It makes a few thousand Americans ill each year. The resulting liver disease is usually mild but seems to intensify with age. Infected children are generally symptom-free. In other victims, symptoms can include sudden fever, nausea, appetite loss, and abdominal pain, followed by jaundice. Severe infections can persist for up to six months.

Hepatitis A is transmitted by direct contact, usually with those who have poor hygiene—commonly, infected restaurant workers. The disease's relatively long incubation period makes tracing the virus to contaminated foods—often fresh produce, shellfish, and ice—difficult.

Fortunately, researchers introduced a hepatitis A vaccine in 1995, and hepatitis A rates have since dropped considerably in developed countries. In addition, people who recover from an infection develop antibodies against the virus that protect them for life. In many areas, regulations require vaccination of all food workers. Even where this is not required, it is an excellent idea.

Like rotavirus infections, astrovirus infections are foodborne in about 1% of cases. Health agencies estimate rotaviruses and astroviruses cause a comparable number of infections annually in the U.S. But astroviruses tend to produce less severe symptoms than rotaviruses do, and the rate of hospital admissions for astrovirus infection is about a quarter that for rotavirus infection. Astroviruses, named for their star shape, cause gastroenteritis and diarrhea; they primarily infect the young. Childhood infection can confer long-lasting immunity.



Rotaviruses are some of the less common foodborne pathogens, but they still sicken tens of thousands of diners in the United States each year.

THE HISTORY OF

Food Poisoning at The Fat Duck

In early 2009, more than 40 people reported falling ill after dining at Heston Blumenthal's three-Michelin-star restaurant The Fat Duck. Immediately after the incident, Blumenthal closed the restaurant to figure out what had gone wrong. Initial inspections focused on ingredients that could cause food poisoning, such as shellfish, and on the staff, who could have potentially spread a virus to diners. Some commentators began to worry that the illness was caused by one of Blumenthal's famously unconventional cooking techniques. Authorities even began investigating the possibility of sabotage.

Months later, the U.K. government's Health Protection Agency determined that the cause of the illness was an outbreak of a norovirus. Sewage-tainted oysters and razor clams carried the pathogen into the restaurant kitchen, infecting both staff and guests. Subsequent testing confirmed that oyster and razor-clam beds harvested by two different suppliers to The Fat Duck from coastal waters near two different parts of Great Britain tested positive for norovirus, as did stool samples from the ill guests and staff.

Symptoms of food poisoning were ultimately reported by 529 customers, which makes this episode by far the largest such event in memory to have affected a high-end restaurant. Officials said that, although the restaurant could have taken greater steps to prevent this outbreak, there was not enough evidence to press charges. Indeed, there is very little that a restaurant can do if its suppliers send it contaminated oysters, which are generally served raw (as occurred here).

The financial hardship and negative press were perhaps punishment enough: Blumenthal had to close the restaurant for nearly three weeks for a top-to-bottom disinfection at a cost of roughly £160,000 ($240,000).

PRIONS

Prions—protein molecules that can take on a misshapen, pathogenic form—are among the strangest foodborne causes of disease yet discovered. For many years, prions filled a highly exotic and arcane corner of biological research, and their uniqueness led to tremendous scientific excitement, as well as two Nobel prizes. Despite this attention, the curious molecules remained mostly unknown except to specialists because they had little relevance to the world at large.

That all changed in 1986 with the sudden emergence of mad cow disease, or bovine spongiform encephalopathy (BSE), first in Great Britain and, later, in other parts of the world. Hundreds of thousands of cows eventually became infected. A decade afterward, health officials began seeing a similar disease in people who had eaten infected beef. After dwelling for so long in near-obscurity, prions abruptly morphed into a hot topic for both the media and politicians.

Protein molecules, the basis of prions, make up the normal cellular machinery of living organisms. After each long protein molecule is produced, it undergoes a process called **protein folding**, in which it kinks into a characteristic shape, or **conformation**, which determines how it works. Although the analogy is imperfect, you can think of proteins as mechanical devices such as gears. The conformation of the folded protein, like the type of gear, determines what it does and how other proteins may interact with it (see Prion Diseases, page 158).

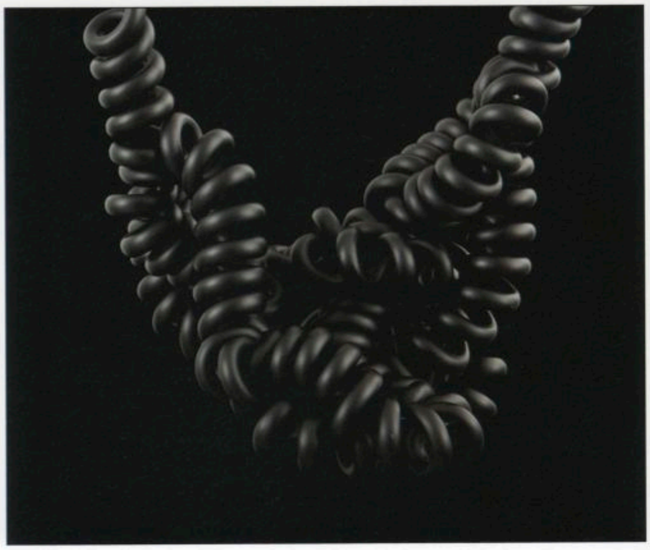
The idea that prion proteins can cause disease simply by shifting their normal three-dimensional conformation to an alternative, abnormal shape was highly controversial for many years. All other cases of microbial infection required an information molecule, such as DNA or RNA, to transmit building instructions for the pathogen. Prions, on the other hand, are more akin to a poison that spreads; apparently, only a single protein molecule is enough to start the chemical "infection."

After many years of pursuing the topic and countering critics, Stanley Prusiner of the University of California, San Francisco, won the 1997 Nobel Prize in Physiology or Medicine for this discovery. His prion theory of disease is now widely accepted.

Yet many mysteries remain about the class of prion-associated diseases known as transmissible spongiform encephalopathies. As of this writing, for example, no one has yet deduced the purpose of prions in their normal conformation, although some scientists believe the proteins may play a role in cellular communication. Details about exactly how and why the abnormal conformation causes disease are also lacking.

Despite this dearth of knowledge, an ominous pattern exists. All prion diseases known to date affect the nervous system, primarily brain tissue,

Proteins have helically coiled sections, much like a telephone cord. They tangle to form complex, three-dimensional shapes that allow them to perform their functions. When improper folding causes certain proteins to take on the wrong shape, as happens to prions, the molecules can become pathogenic.



where the misfolded proteins tend to clump together and leave tissue damaged and sponge-like in appearance. Normally, the brain is protected from incoming proteins and other large molecules by the blood–brain barrier, but the prions somehow manage to breach that blockade. Some researchers suspect that the brain disease may progress (albeit slowly) because nerve cells are not replaced the way other body cells are, although research has yet to explain clearly why symptoms do not appear elsewhere in the body.

In the absence of solid information, several myths have sprung up about prions. Many people order their beef well-done out of concern over mad cow disease, for example. Unfortunately, that is a pointless precaution because no reasonable amount of heat will destroy the incredibly stable prions. Autoclaves that operate at 121 °C / 250 °F, typically used to sterilize scientific equipment, seem to have little effect on the unique proteins, even after treatment for 48 hours. Likewise, the U.K. government cremated infected cows to contain the disease, only to discover that their ashes still harbored prion proteins.

Chemicals are ineffective as well, and prions easily resist exposure to both ultraviolet and ionizing radiation. Even acid treatments have not worked well; the concentration required to destroy prions also dissolves stainless steel. Researchers recently discovered that a common soil mineral can degrade prions and are still hoping to develop disinfectants and, eventually, therapeutic drugs for prion diseases, but as of mid-2010, no good method has been developed for inactivating or destroying prions in meat that is bound for the dinner table.

From Sheep to Beef to People

The discovery of prions emerged from research into scrapie, a degenerative brain infection that is inevitably fatal to sheep and goats. The disease was formally recognized by science in 1738—it has probably been around far longer—but only recently recognized as a prion-related illness.

Scrapie essentially dissolves the brains of affected sheep and goats before ultimately killing them. Scientists have not yet determined how scrapie passes among the animals, but some suggest that it may be transmitted when sheep eat grass contaminated with the blood of other sheep—for example, from the placenta remaining after delivery of a lamb by a sick ewe.

An experiment with scrapie-infected sheep in Iceland only deepened the mystery. Icelanders slaughtered entire flocks to eliminate the disease, and they left pastures that the sick sheep had grazed fallow for several years. When healthy sheep that the farmers knew to be scrapie-free were introduced to those pastures, they still contracted the disease—though no one could say where the prions infecting them had originated.

One of the great ironies about the intense media attention paid to mad cow disease is that "mad sheep" disease has been documented since the 18th century with little fanfare—probably because physicians have never noticed any scrapie-like illness in humans who ate lamb, mutton, or sheep brains. This species barrier suggests that scrapie prions in sheep cannot convert human proteins to the disease-causing conformation. Presumably, human proteins are too different for the scrapie proteins to exert their twisted influence.

Humans have their own scrapie-like diseases, however, including several forms of **Creutzfeldt-Jakob disease** (CJD), which was named after the two German neuropathologists who first reported it in the early 1920s. These very rare diseases affect about 200 people annually in the United States; the prevalence worldwide is about one in a million.

An inherited version of CJD and a related disease, fatal familial insomnia, have a clear genetic basis, but hereditary CJD is thought to account for only 5%–10% of cases in the U.S. By far the most common form is **"sporadic" CJD**, or sCJD, whose victims have no known risk factors. Sporadic CJD appears to result from an accidental or spontaneous shift in normal prion proteins, although extensive research has not yet shown any pattern.

No treatment for CJD exists; it is always fatal. Symptoms include dementia that progresses much faster than what is typical for Alzheimer's disease, often accompanied by impaired muscular coordination, vision, memory, and judgment, as well as personality changes. The disease can incubate for decades, so symptoms usually appear later in life.

Unlike scrapie, which has a long history in sheep, prion diseases were unknown in cattle until modern agricultural practices resulted in the addition of increasing amounts of processed ingredients to cattle feed, including protein supplements to help build muscle mass and bone-meal supplements as a source of calcium. All too often, those supplements came from the carcasses of other livestock, including cattle. This practice effectively turned cattle into cannibals—just like the New Guinea people whose ritualistic cannibalism at funerals helped to spread another prion disease known as **kuru** (see Why You Shouldn't Eat People, next page).

We do not know what caused the first case of mad cow disease, or BSE. One hypothesis is that cattle were given feed that included the ground-up carcasses of sheep that had been infected with scrapie. Some intriguing, although inconclusive, evidence suggests that BSE may occur sporadically, like sCJD. Either way, some cow, probably in the U.K., developed a prion disease. Its carcass was probably processed into feed eaten by more cattle, fueling a cycle of animal infections.

Then people started to die. Two of the earliest patients had all of the usual symptoms of CJD, except that one victim was a 16-year-old girl and the other was an 18-year-old boy; sCJD patients are typically older than 63.

THE GEOMETRY OF

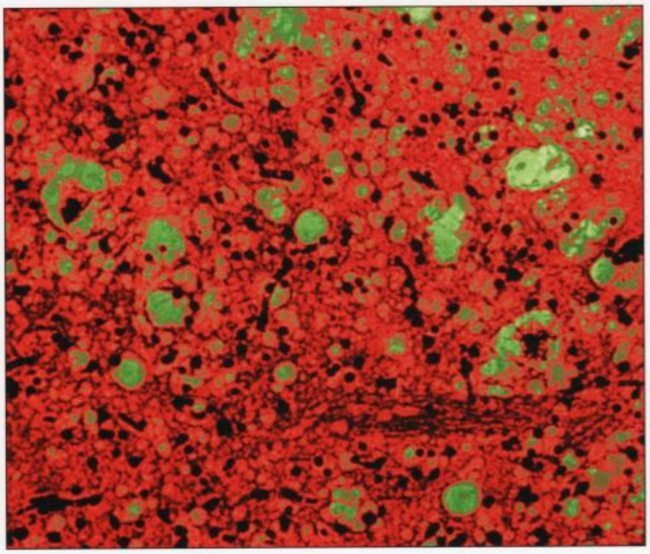
Prion Diseases

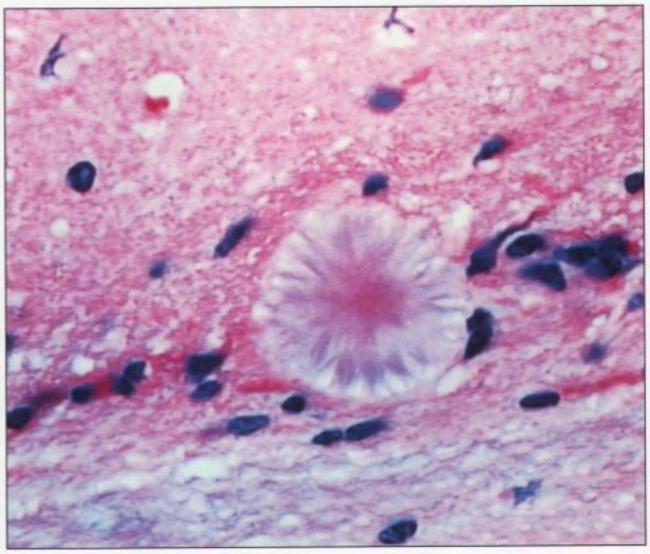
A prion is an unusual protein that has (at least) two different stable shapes, or conformations—call them C (for cellular) and Sc (for scrapie, the disease prions cause in sheep). Conformation C is the default mode, the normal state for the benign protein in the body. The alternative Sc conformation is associated with disease. Both forms comprise the same sequence of **amino-acid** building blocks; the only difference between them is their final shape, analogous to the difference between ice and liquid water.

If one of the harmless C-type prions encounters its abnormally shaped Sc-type counterpart, something strange happens: the protein in conformation C permanently switches its shape to that of conformation Sc. Prions in the Sc conformation essentially act like recruiters, and the switching process they initiate accelerates because each Sc prion can convert more than one C prion.

Unfortunately, the Sc conformation is stable and irreversible. The process may resemble an infection in the way it progresses, but the total number of protein molecules never increases—only their shapes change.

The prion disease kuru causes voids (black spots, below left) to form around the neurons (green spots) in the brain of an infected monkey, as seen through an electron microscope. In variant Creutzfeldt-Jakob disease, prions collect into amyloid plaques (light object at center, below right) in the brain of a mouse, as seen through an optical microscope.





THE BIOLOGY OF

Why You Shouldn't Eat People

In the late 1950s, researchers noted a strange new brain disease among the Fore people in the highlands of New Guinea. The disease resembled CJD but afflicted younger people and showed up in suspicious clusters. Years of field and laboratory work by American pediatrician D. Carleton Gajdusek, M.D. finally revealed the bizarre cause of the disease known as kuru: it came from ritual cannibalism—specifically, from the custom, practiced mostly by women and children, of eating the brain of a relative as part of the funeral ceremony. Gajdusek's finding made him a co-winner of the Nobel Prize in Physiology or Medicine in 1976. But Gajdusek could not name the infectious agent. We now know that kuru is an example of a foodborne prion disease, transmitted, in this case, through the consumption of infected brain matter. Once the ritualistic cannibalism stopped, so did the spread of kuru.

Autopsies of the young victims' brains showed a different pattern of damage from that of sCJD, leading researchers to label the new disease **variant CJD** (vCJD). By February 2009, 164 people in the U.K. had died of vCJD, and more than 40 more people died of the disease in nine other countries.

Although no one knows for sure how these people contracted vCJD, the evidence strongly suggests it was by eating beef or meat products from BSE-infected cattle (see Mad Cow Disease, next page). Since the British epidemic, cows with BSE have been found in nearly every cattle-raising nation, including the United States and Canada. In many of these countries, the problem of contaminated cattle feed, which may have contributed to the lethal infections of both cows and humans, has been addressed by new rules against feeding mammalian protein to ruminants.

Thankfully, vCJD has so far not brought the epidemic that some feared would come. Millions of people ate beef in the U.K. between 1986, when the BSE epidemic was first recognized, and 1996, when the first 10 cases of vCJD were announced. The lack of a broader epidemic suggests that the infection could indeed be very rare.

Alternatively, the disease may possess a highly variable latency between prion consumption and the onset of symptoms. If the latter is true, the cases reported to date could be the leading edge of a much larger problem—a possibility that has raised concerns over the potential for transmission through blood or organ donations. In the case of kuru, after all, an intensive surveillance program found that the latency between infection and symptoms could exceed 50 years. Only time will tell whether the same holds true for vCJD.

Crazy Cats and Mad Moose

Unfortunately, BSE is not the only worrisome prion disease. Another is **feline spongiform encephalopathy**, which is a disease of cats that were fed BSE-infected beef—primarily pet cats but also wild cats that are kept in zoos. This outbreak appears to have run its course as BSE-contaminated beef has become rarer.

A related disorder known as **chronic wasting disease** (CWD) affects deer, elk, and moose. It has spread in recent years across North America. Like other prion diseases, the origins of CWD are mysterious. And like scrapie and BSE, symptoms of CWD include disorientation, wasting, and inevitable death due to disintegration of the brain.

CWD was first recorded in 1967 among mule deer that were temporarily held at a wildlife research facility in northern Colorado as part of a nutritional study, although the true nature of the perplexing illness would not be known for another decade. By then, researchers were noting with alarm that the vast majority of deer housed at the facility for more than two years either died or had to be euthanized. In 1980, the disease appeared at a research station in Wyoming that had shared deer with the Colorado facility. A year later, researchers detected the disease in wild elk living in Rocky Mountain National Park.

The researchers realized that the disease was somehow propagating among captive animals and that, once returned to the wild (or perhaps after having escaped from their pens), those animals could be creating new focal points for the epidemic. In response, officials ordered all deer and elk at the Colorado facility to be slaughtered, the soil to be turned, and all pens and equipment to be repeatedly doused with chlorine.

THE POLITICS OF

Mad Cow Disease

Government officials in the United Kingdom initially sought to downplay reports of a widespread "mad cow" disease outbreak to protect the British beef industry, and a government-sponsored report in 1989 concluded "it was most unlikely that BSE would have any implications for human health." Ultimately, health officials ordered the slaughter of millions of potentially affected cattle to stop the disease "once and for all" and restore confidence in British beef. Ironically, this move prevented scientific study of how widespread the epidemic had become.

Meanwhile, other governments banned British beef, purportedly out of concern for their citizens, although cynics suspected the embargoes may have been imposed to help those countries' domestic beef industries. For a while, the situation took on the appearances of a typical trade dispute—until people began to die.

As a result of the outbreak, health officials in the U.K. banned restaurants, supermarkets, and butchers from serving beef on the bone, reasoning the ban would decrease the likelihood of variant Creutzfeldt-Jakob disease by preventing people from eating susceptible marrow and nerve tissue attached to the bone. No scientific evidence existed at the time (or since) to confirm that the same piece of meat would be safer off the bone than on it. Among the tissues at high risk for BSE contamination, however, the FDA lists a cow's skull, brain, part of the small intestine, and nerves attached to the spinal cord, brain, eyes, and tonsils. So far, milk and cow meat that haven't contacted the animal's central nervous system tissue have shown no infectivity in laboratory animals.

Health officials eventually pronounced British beef safe for consumption because the harmful conformation of the protein was not found in muscle tissue or blood. That negative finding, however, was subsequently shown to be meaningless because the tests available at the time were insufficiently sensitive. We now know that the dangerous conformation does exist in both blood and muscle.

Since the British epidemic, almost every new discovery of BSE elsewhere has been accompanied by political posturing—and, typically, by banning all beef from the home country of the BSE-affected cow. The contaminated cattle feed that may have contributed to BSE is largely a thing of the past thanks to new rules against feeding mammalian protein to ruminants. These rules were designed to prevent the perpetuation of the cannibalism cycle. Strangely, feed intended for pigs and chickens is not subject to such rules, provoking concern from consumer groups that we are risking the rise of future prion diseases. Could a massive scare over "mad pig" disease be next? The refusal to learn permanent lessons from the BSE crisis seems deeply ingrained in the agricultural system and its politics.

The best example of this refusal to learn can be found in the political posturing over testing. New technology enables rapid testing for BSE at the relatively nominal cost of $20 to $30 per animal carcass, or only a few pennies per pound of beef. Yet when several U.S. meat-packing companies began doing such tests, in part to become eligible to export beef to Japan, the U.S. Department of Agriculture (USDA) responded by outlawing them! The USDA argues that the testing is "unnecessary" because "no scientific proof" that it is required exists, but how can proof be obtained unless you look? We believe the real motive for preventing testing is likely to be political pressure from the beef industry. Perhaps beef lobbyists oppose the cost, nominal though it may be. More likely, beef-industry advocates suspect that widespread testing would turn up some sporadic cases (as it has in other countries) and undermine confidence in the U.S. beef supply.

Cooking beef until it's well done will not reduce the risk of "mad cow" disease; better safety rules for cattle feed, however, have greatly reduced the incidence of BSE over the past decade.

Nevertheless, new elk brought to the facility still developed CWD. The facility remains shuttered because of the presumption that contamination persists in some form—a scenario that bears a striking similarity to the results of the Icelandic scrapie experiments. As with scrapie, no one knows for sure how CWD is transmitted between the animals or what transmissible agent has contaminated the facility, although prions are the prime suspects, and other studies suggest the particles can persist in the soil for at least three years.

As of mid-2010, health authorities have found CWD in 16 U.S. states and two Canadian provinces. Ironically, CWD-infected deer lose their fear of humans, which makes them more likely to be shot by a hunter. CWD may yet be a human health issue; so far, a number of cases of a CJD-like disease have been reported among avid deer and elk hunters. Although this link remains controversial and no transmission has yet been confirmed in humans, eating deer, elk, or moose meat—and especially the internal organs, spinal cord, or lymph nodes—of animals shot in affected areas is not recommended unless they test negative for CWD.

The bad news is that few food-safety recommendations can be made for prion diseases because no amount of cooking or sanitation can eliminate the risk. The large gaps in our understanding are bound to make these diseases sound scary. The good news is that the tally of human cases even tentatively linked to vCJD or CWD remains quite low, especially when compared with those attributed to other foodborne pathogens. Although prions deserve our continued attention, then, it's important to remember that the likelihood of contracting a prion disease is still remote.

Take Culinary Risks, Safely

Taking risks at the table should be a matter of trying new dishes and sampling unusual flavors, rather than chancing the ingestion of any of the numerous tiny pathogens that can stalk unwary chefs and their guests. Attempting to rid your kitchen of all dangerous microbes is futile, of course. But now you know which ones can wreak the most havoc and how they do their damage.

Applying that knowledge in practical ways—the subject of the next chapter—can make a huge difference in your and others' health. Diseases like trichinellosis and botulism may still have fearsome reputations, but safe kitchen practices can help ward off even far more threatening bugs, whether notorious noroviruses, vicious listeria bacteria, or toxic toxoplasmas.

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3 FOOD SAFETY

3

FOOD SAFETY

Researchers establish the scientific basis for food safety in the laboratory, but it's up to cooks to apply that knowledge in the kitchen. To do so properly, we must ask ourselves two main questions: "How can I prepare food that is safe?" and "Am I following the appropriate laws and regulations?"

To answer the first question, you must learn how to apply a series of scientifically based—but often deceptively simple—techniques. Thorough hand washing, for example, is arguably the single most important way to improve food safety, yet it is so simple that many people take it for granted and either don't do it well or don't do it at all. In the preceding chapter, we discussed other simple steps that help to ensure safe food preparation; we'll discuss hygiene in this one.

To answer the second major question related to food safety, you must know what rules to follow. Laws and regulations govern a variety of kitchen practices because food safety is a matter of public health. It's not just a good idea for cooks in restaurants or other commercial settings to follow these rules; it's the law! Your kitchen will be shut down or you will face other punitive measures if you do not comply.

There's also a substantial set of informal food safety recommendations that carry less regulatory weight than laws but boast a far wider sphere of influence. You can't read a cookbook or food-related web site without encountering this well-meaning counsel. "You must cook chicken to 74 °C / 165 °F" or "Pork needs to be well-done to avoid trichinellosis." In many cases, the advice has been passed down for generations, and these word-of-mouth directives have become as influential as the official rules.

In a perfect world, the practical steps that make food safe would match those specified in the rules, regulations, and informal recommendations, and everybody would be able to learn and follow one clear set of guidelines. In reality, food safety regulations are often complicated, contradictory, and unsupported by scientific evidence. Rules in one part of the world can differ markedly from those in another, for example, yet it seems unlikely that pathogenic bacteria are really all that different in New York City, London, and Paris. The guidelines our mothers gave us may be no better. Some "commonsense" notions about keeping food safe are merely incomplete; others are outright wrong and dangerous.

To help make sense of all the conflicting, incomplete, unsound, or truly confounding regulations and advice, this chapter will explore the current state of food safety rules. We'll use the term "rules" to cover official regulations as well as informal recommendations. We'll review the source and scientific basis of some procedures and dispel misconceptions about others. We'll seek to illuminate the rule book for the U.S. Food and Drug Administration (FDA), and we'll also propose our own short list of food safety rules. Finally, we'll provide some instruction on how to comply with official regulations and follow other crucial tenets of food safety.

Cheeses made from raw milk are banned in many countries, yet millions of Europeans consume them without incident. The United States has a crazy patchwork of different raw cheese regulations. Federal government standards forbid raw milk cheeses aged less than 60 days to be imported into the United States or to cross state lines, but individual states have their own rules for cheese made and sold within their borders. As a result, 24 of the 50 states do allow raw milk cheese; the remaining 26 states ban it. Raw milk cheeses can be made and sold in New York, for example, but are banned in New Jersey. In Canada, most provinces ban raw milk cheese aged less than 60 days, but Quebec allows them. How can the same food be safe in one place and unsafe in another?

DISCLAIMER:

This book cannot and does not substitute for legal advice about food regulations in the United States as a whole or in any U.S. legal jurisdiction. Nor can we guarantee that following the information presented here will prevent foodborne illness. Unfortunately, the many variables associated with food contamination make eliminating all risk and preventing all infections virtually impossible. We cannot accept responsibility for either health or legal problems that may result from following the advice presented here. If you operate a commercial establishment and serve food to the public, consult the rules and health regulations in your area.

THE COMPLEX ORIGINS OF FOOD SAFETY RULES

Scientific research on foodborne pathogens provides the foundation for all food safety rules. Generally speaking, two kinds of research inform us about issues of food safety. The first is laboratory experimentation: for example, testing how much heat will kill a pathogen or render it harmless. Data from these experiments tell us the fundamental facts about pathogens of interest. The second kind of research is investigation of specific outbreaks of foodborne illness. This research is called epidemiology (from the root word "epidemic"); it tells us what happens in the real world.

Proper cooking can substantially reduce pathogens in food, but it won't ward off foodborne illness if you don't address the risk associated with cross-contamination of other foods and kitchen surfaces.

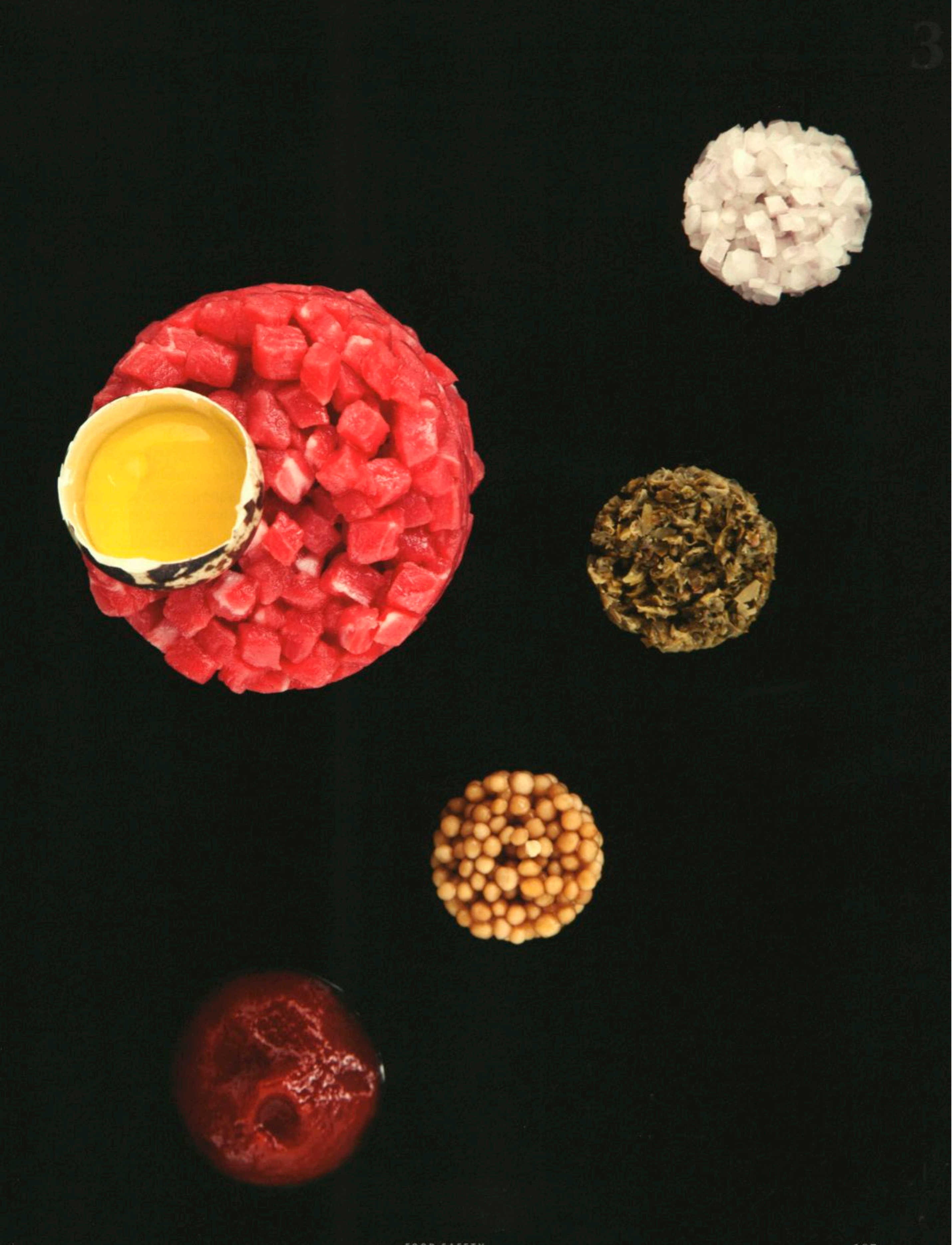
You might think that scientific evidence would constitute the "last word" when food safety rules are made, but in fact it's only the beginning. Policy makers take many other factors into consideration, including tradition, cultural trends, political expediency, and pressure from industry. To some extent, it's reasonable to apply these modifiers because public health, not scientific purity, is the ultimate goal of food safety regulations. But this approach sometimes imposes arbitrary and scientifically indefensible restrictions that limit food choices, confuse the public, and prevent cooks from preparing the highest-quality meals. We'll devote much of this chapter to explaining the cumbersome and sometimes dangerous fallacies engendered by these restrictions.

To complicate matters, some guesswork and compromise are inevitable in setting safety standards. Take, for example, the way in which health officials decide how much the pathogen count should be reduced when heating food. In the preceding chapter, we reviewed the terminology used to describe these reductions. Killing 90% of the pathogens within a specific food, for example, is called a 1D reduction (where D stands for "decimal," or factor of 10). Killing 99% of the pathogens is referred to as a 2D reduction, killing 99.99% is termed a 4D reduction, and so forth.

Cooks achieve these reductions by maintaining food at a given temperature for a corresponding length of time. The practical impact of an elevated D level is a longer cooking time at a particular temperature. If a 1D reduction requires 18 min at 54.4 °C / 130 °F, then a 5D reduction would take five times as long, or 90 min, and a 6.5D reduction would take 6.5 times as long, or 117 min. Clearly, the D levels targeted for food can have a profound effect on the manner and quality of cooking.

What D level should regulators choose to ensure food safety? If the food contains no pathogens to begin with, then it's not necessary to kill pathogens to *any* D level! Highly contaminated food, on the other hand, might need processing to a very high D level. Right away, you can see that

Most kinds of raw-cured Spanish hams (right) are banned in the U.S., even though there is no prohibition against serving raw beef such as steak tartare or the raw egg used to garnish it (far right).



decisions about pathogen-reduction levels are inherently arbitrary because they require guessing the initial level of contamination. That guess can be supported by the results of scientific studies measuring the number of foodborne pathogens present under the various conditions that cooks encounter. But it's still a guess.

Many people don't realize that authorities rely on guesswork to develop these standards. Chefs, cookbook authors, and public health officials often make dogmatic statements that food cooked to a standard is "safe," but food cooked less than the standard is "unsafe." That can never be literally true. No matter what the standard is, if the food is highly contaminated, it might still be unsafe (especially owing to cross-contamination). And on the other hand, if the food is not contaminated, then eating it raw won't hurt you.

All food safety standards deal in probabilities. Reaching a higher standard (i.e., cooking food longer or at a higher temperature) will make the food less likely to be unsafe, and targeting a lower standard will make it a bit more likely. But there are no guarantees and no absolutes. Deciding what level is enough is guesswork. There are no black and white standards; there are only shades of gray.

To compensate for this inherent uncertainty, food safety officials often base their policies on the so-called worst-case scenario. They reason that if you assume the absolute worst contamination levels and act to address that threat, then the public will always be safe. Setting relatively high D levels to account for a worst-case scenario establishes such a formidable barrier for pathogens that even highly contaminated food will be rendered safe. High D levels also offer a measure of insurance against an imperfect thermometer, an unevenly heated oven, an inaccurate timer, or an impatient chef. If real-world conditions miss the mark, slightly lower reductions will still suffice.

Not surprisingly, some food safety experts challenge this conservative approach. The required pathogen reductions or "drops" explicitly cited in U.S. federal regulations, for example, range from a 4D drop for some extended-shelf-life refrigerated foods, such as cooked, uncured meat and poultry products, to a 12D drop for canned food, which must last for years on the shelf. General FDA cooking recommendations for fresh food are set to reach a reduction level of 6.5D, which corresponds to killing 99.99997% of the pathogens present. Many nongovernmental food safety experts believe this level is too conservative and instead consider 5D to 6D pathogen reduction for fresh foods sufficient for real-world scenarios.

An expert advisory panel charged with reviewing the scientific basis of food safety regulations in the United States made just this point about standards developed by the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS). In a 2003 report, the panel, assembled by the U.S. Institute of Medicine and National Research Council, questioned the FSIS *Salmonella* reduction standards for ready-to-eat poultry and beef products. In devising its standards, the FSIS had established a worst-case *Salmonella* population for the precooked meat of each animal species, then calculated the probability that the pathogen would survive in 100 g / 3.5 oz of the final ready-to-eat product.

In the case of poultry, for example, the FSIS calculated a worst-case scenario of 37,500 *Salmonella* bacteria per gram of raw meat. For the 143 g / 5 oz of starting product necessary to yield 100 g / 3.5 oz of the final, ready-to-eat product, that works out to nearly 5.4 million *Salmonella* bacteria before cooking. To protect consumers adequately, the FSIS recommended a 7D drop in bacterial levels, equivalent to a reduction from 10 million pathogens to one.

The review committee, however, found fault with several FSIS estimates that, it said, resulted in an "excessively conservative performance standard." Even "using the highly improbable FSIS worst-case figure," the committee concluded that the ready-to-eat regulation should instead require only a 4.5D reduction.

The irony is that, although experts debate these matters, their rigorous analyses can be undermined by confounding factors such as cross-contamination. Imagine, for example, that a highly contaminated bunch of spinach really does require a 6.5D reduction in pathogens to be safe. Even if that spinach is properly cooked, it could have contaminated other food or utensils in the kitchen while it was still raw, rendering moot even an extreme 12D reduction during the cooking process. *A chain is only as strong as the weakest link, and in food safety, cross-contamination is often the weakest link.* One powerful criticism of food safety standards is that they protect against unlikely worst-case scenarios yet do not address the more likely event of cross-contamination.

Another conservative tactic used by health officials is to artificially raise the low end of a recommended temperature range. Most food pathogens can be killed at temperatures above 50 °C / 120 °F, yet food safety rules tend to require temperatures much higher than that. Experts may worry that relying on the low end of the range may be dangerous for the same reasons that moderate D levels cannot be trusted: vacillating oven temperatures, varying chef temperaments, and so on. Still, their solution belies the facts.

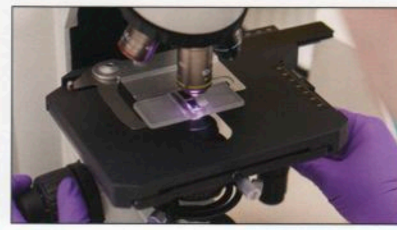
For Our Own Good?

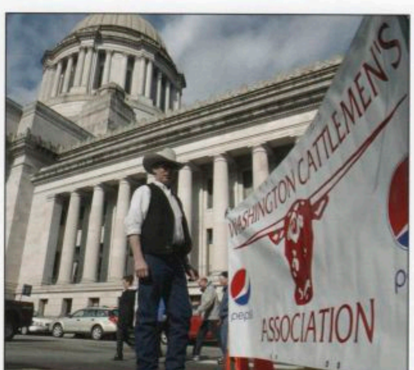
The public health goal of maintaining food safety and minimizing harm poses an interesting dilemma: when does the end justify the means? More specifically, is it justifiable to promote unscientific food safety standards in the name of public safety? Regulators seem to act as if it is.

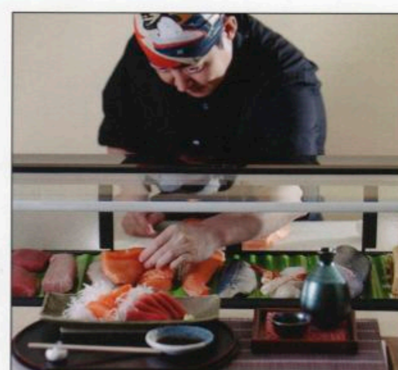
During a recent outbreak of *Escherichia coli* linked to contaminated fresh spinach in the United States (see The *E. Coli* Outbreak of 2006, page 172), public health authorities initially told consumers, retailers, and restaurants to throw out all spinach, often directly stating in public announcements that it could not be made safe by

Factors Influencing Food Safety Trends

Scientific data, political and industry pressure, tradition, and cultural factors are among the elements that can interact to influence how food safety rules are made.







Scientific data on pathogens

Allowance for safety factors

Traditional and cultural factors

Political and industry pressure

Simplification and rule making

Rules and regulations for professional chefs

Extreme simplification

Recommendations for consumers

cooking it. This assertion is scientifically incorrect: *E. coli* is very easy to kill with heat.

Evidently the officials decided that oversimplifying the public message was better than telling the truth. They may have feared that if people cooked contaminated spinach to make it safe to eat, but either didn't cook it sufficiently or cross-contaminated other food or kitchen surfaces in the process, more fatalities would result. The authorities must have decided that the benefits of avoiding multiple accidental deaths far outweighed the costs of simply tossing out all spinach. In this case they probably were right to make that decision. The cost of some spinach is small compared to the misery and expense of hospitalization.

Oversimplifying for the sake of public safety is a very reasonable thing to do in the midst of an outbreak or other health crisis. It may well have saved lives to lie to the public and announce things that, strictly speaking, are false (for example, that you can't kill *E. coli* with heat).

However, outside of a crisis situation, there is a pervasive danger that this philosophy leads to "dumbing down," oversimplifying, or fabricating food safety information. It is very easy for public health officials to adopt the paternalistic attitude that they can make scientifically incorrect statements with impunity, even in situations in which the balance of risks is nothing like that which occurs during a crisis. Who pushes back against nonsensical rules? The reality is that the only groups that push back are those that have political clout.

Because of this approach, culinary professionals and casual cooks alike have been grossly misled about a wide range of food safety issues and are often subjected to distorted, incomplete, or contradictory rules. When a political interest group exists, it is that group's opinion, rather than science, that shapes the rules. But when there is no political force to push back, the rules can be overstated and excessive.

For more on time-and-temperature reductions of pathogen populations, see Bacterial Death, page 148.

Consider the overstated risk of exposure to *Trichinella*, which has led to ridiculously excessive recommendations for cooking pork (see Misconceptions About Pork, page 179). This overkill is just one of many such examples. Cooking standards for chicken, fish, and eggs, as well as rules about raw milk cheeses, all provide examples of inconsistent, excessive, or illogical standards. To a public health official, mandating that pork chops or chicken breasts be dry and overcooked makes sense if it keeps even one person from getting sick. In this calculus, one less case of foodborne illness is worth millions of ruined chops or breasts.

That attitude becomes harder to defend, however, if you accept that overcooking food comes at a cost. A chef's livelihood may depend on producing the best taste and texture for customers. Home cooks who love food want it to taste the very best that it can. To a person who cares about the *quality* of food—or who makes a living based on it—excessive food safety standards don't come cheap.

A balance must be struck between the risk of foodborne illness and the desire for palatable food. In cases such as those of pork and chicken, misleading the public about a rarely occurring scenario (while ignoring other, larger risks) arguably offers little protection and comes at the cost of millions of unnecessarily awful meals.

Culture Clash

The excessive restrictions on cooking pork didn't come out of nowhere. In decades past, pork was intrinsically less safe than other meats because of muscle infiltration by *Trichinella* and surface contamination from fecal-borne pathogens like *Salmonella* and *Clostridium perfringens*. As a result, people learned to tolerate overcooked pork, and farms raised pigs with increasing amounts of fat—far more fat than is typical in the wild ancestors of pigs such as wild boar. The extra fat helped to keep the meat moist when it was overcooked.

Since then, research has sharpened our understanding of pork-associated pathogens, and producers have vastly reduced the risk of contamination through preventive practices on the farm and in meat-processing facilities. Eventually the FDA relaxed the cooking requirements for pork; they are now no different than those for other meats. The irony is that few people noticed—culinary professionals and cookbook authors included. Government information aimed at consumers from both the USDA and the FDA continued to promote excessive cooking standards for pork. Amazingly, even pork industry groups continued to do the same thing.

After decades of consuming overcooked pork by necessity, the American public has little appetite for rare pork; it isn't considered traditional. With a lack of cultural pressure or agitation for change by industry groups, the new standards are largely ignored, and many new publications leave the old cooking recommendations intact.

Clearly, cultural and political factors impinge on decisions about food safety. If you doubt that, note the contrast between the standards applied to pork and those applied to beef. Many people love rare steak or raw beef served as carpaccio or steak tartare, and in the United States alone, millions of people safely eat beef products, whether raw, rare, or well-done. Beef is part of the national culture, and any attempt to outlaw rare or raw steak in the United States would face an immense cultural and political backlash from both the consumers and the producers of beef.

Millions of servings of rare beef steak or completely raw steak tartare or carpaccio are served every day, so if that meat were inherently dangerous, we'd certainly know by now. Scientific investigation has confirmed the practice is reasonably safe—almost invariably, muscle interiors are sterile and pathogen-free. That's true for any meat, actually, but only beef is singled out by the FDA. The cultural significance of eating raw and rare beef, as much as the science, accounts for the FDA's leniency in allowing beef steak to be served at any internal temperature.

Cultural and political factors also explain why cheese made from raw milk is considered safe in France yet viewed with great skepticism in the United States. Traditional cheese-making techniques, used correctly and with proper quality controls, eliminate pathogens without the need for milk pasteurization. Millions of people safely consume raw milk cheese in France, and any call to ban such a fundamental part of French culture

THE POLITICS OF

Busting the Seasonal Ban on Oysters

A tussle between government officials and oyster enthusiasts in 2009 illustrates how pressure from industry and political constituencies can influence food safety rules. In the fall of that year, the U.S. Food and Drug Administration (FDA) announced plans to ban the sale of raw oysters harvested from the Gulf of Mexico between April and October. In those warm months, coastal waters are more likely to carry *Vibrio vulnificus,* a pathogen that can kill people who eat infected oysters. About 15 people die that way each year.

Vibrio can be treated by pasteurization and other antimicrobial measures, but industry advocates complained that the treatments are too expensive and ruin the taste and texture of fresh, raw oysters. Suppliers and consumers from Florida to Louisiana fiercely opposed the FDA plan, which would have restricted the sale of oysters to only the treated type during the seasonal ban. The protestors claimed a $500-million economy was at stake, and the agency quickly backed down, saying it would put the ban on hold until it had considered further studies on the cost and feasibility of antimicrobial treatments. But by spring of the following year Gulf fishermen had worse woes to contend with, as millions of gallons of oil spewing from a damaged offshore drilling rig contaminated coastal waters and put many shellfish beds off-limits.

THE POLITICS OF

The *E. Coli* Outbreak of 2006

A foodborne outbreak can readily test whether a government's epidemiological tools, consumer protection mechanisms, and regulatory systems are functioning properly. A major outbreak of the pathogenic bacterium *Escherichia coli* O157:H7 in 2006 provided a telling look at all three.

In the summer and fall of that year, foodborne *E. coli* O157:H7 sickened 205 people in the United States. Half of them had to be hospitalized, and three died. Epidemiologists were able to trace the outbreak back to fresh baby spinach that had been packaged at a California facility on August 15, but were unable to pinpoint the exact origins of the contamination. A joint investigation by the California Department of Health Services and the U.S. Food and Drug Administration (FDA), however, suggested that the contamination could have begun in one of four implicated spinach fields exposed to the feces of cattle or wild boar—or it could have stemmed from tainted irrigation water.

A subsequent multi-agency study published by the Centers for Disease Control and Prevention (CDC) concluded that a surprisingly high number of bacterial isolates from the wild boar, cattle, surface water, sediment, and soil at a ranch near the outbreak matched the implicated *E. coli* strain. It was the first time *E. coli* O157:H7 had been isolated from wild boar in the United States and the first indication that these animals were either sentinels of, or active participants in, a potentially overlooked mechanism of produce contamination.

Although it is difficult to know for sure what caused the outbreak, the most likely scenario is rather complicated. Herds of cattle in ranches near the spinach farms had members infected with *E. coli* O157:H7. This infection is not uncommon in cattle because it doesn't produce serious illness in them. But the cattle were isolated from the spinach fields, so how could they have caused the outbreak?

California, where the spinach was grown, is also home to European wild boar that were imported in the 1920s to be hunted but that broke free and interbred with feral pigs from domestic farms. It appears that the wild boar became infected from the cattle, probably by eating their feces. The boar then broke into the spinach fields and defecated on the spinach.

Ironically, the last stage in the infection chain resulted from conservation measures based on good intentions: facilities at the packing plant washed the spinach, but then reused the washing water, allowing contamination from only a tiny fraction of the spinach to be spread throughout the entire output of the plant.

Although the epidemiological investigation broke new ground, other governmental responses to the outbreak suggested ample room for improvement. In its first consumer warning, issued September 14, the FDA advised that "consumers not eat bagged fresh spinach at this time." The next day, the FDA added the important caveat that the real danger lay with raw spinach in particular, not cooked spinach. "FDA advises that people not eat fresh spinach or fresh spinach-containing products that are consumed raw."

Such nuanced advice lasted only a day, however. On September 16 and for the next full week, the agency issued variations on the same general (and oversimplified) warning: "FDA advises consumers not to eat fresh spinach or fresh spinach-containing products until further notice."

Arguably, the best advice came not from the FDA but from the CDC. Although it warned against selling, serving, or eating any spinach implicated in the outbreak, the CDC also correctly noted that "*E. coli* O157:H7 in spinach can be killed by cooking at 160° Fahrenheit [71 °C] for 15 seconds." The agency also warned against cross-contamination: "If consumers choose to cook the spinach, they should not allow the raw spinach to contaminate other foods and food contact surfaces, and they should wash hands, utensils, and surfaces with hot, soapy water before and after handling the spinach."

A 2008 report prepared for the U.S. House of Representatives Committee on Oversight and Government Reform took the FDA to task for its repeated failure to protect consumers from tainted produce. Titled "FDA and Fresh Spinach Safety," the report noted that the *E. coli* O157:H7 outbreak was only the latest of at least 20 linked to fresh spinach or lettuce in the last 12 years. The growing popularity of freshly cut produce undoubtedly factored into the surprising number of outbreaks, but the report also faulted the FDA's lack of oversight. "It appears that FDA is inspecting high-risk facilities infrequently, failing to take vigorous enforcement action when it does inspect and identify violations, and not even inspecting the most probable sources of many outbreaks," the report charged. Many of those faults may have been linked to a common denominator: a chronic lack of funding.

For chefs, the take-home lesson is that government agencies charged with safeguarding public health cannot entirely prevent foodborne outbreaks and often do not issue the most accurate advice during an outbreak itself. Arming yourself with scientifically sound food safety information is your best bet for minimizing the risk both to you and to your guests.

would meet with enormous resistance there.

The United States, however, lacks a broadly recognized culture of making or eating raw milk cheeses. Not coincidentally, health officials have imposed inconsistent regulations on such cheeses. Raw milk cheese aged less than 60 days cannot be imported into the United States and cannot legally cross U.S. state lines. Yet in 24 of the 50 states, it is perfectly legal to make, sell, and consume raw milk cheeses within the state. In most of Canada raw milk cheese is banned, but in the province of Quebec it is legal.

How can these discrepancies among and even within countries persist? It comes down to politics. In areas without a substantial local population demanding unpasteurized milk cheeses—a few gourmets, foodies, and chefs don't count for much politically—no backlash has ensued. So the seemingly conservative rule holds, banning anything that seems remotely suspicious.

Where artisanal cheese producers have more public support, the laws allow raw milk cheese. Raw milk cheese is a product of small-time artisans. As of this writing, no large, politically connected producers are making these cheeses in the U.S., so no movement has emerged to make laws on raw milk cheese more consistent and reasonable.

Producers and enthusiastic consumers did manage to prevail against a U.S. ban on Jamón Ibérico de Bellota, the great Spanish raw-cured ham made from free-ranging pigs that eat only acorns. Until late 2007, the ham was barred from importation into the U.S., even though millions of Spaniards have safely savored it. A Spanish processing facility and fans of the ham jointly spent a decade and millions of dollars to secure a special license that allows hams processed in that facility alone into the United States. This concession represents a small victory for ham connoisseurs. But it's an odd precedent, given that the officially licensed ham is no safer than the traditional Spanish product lacking the requisite paperwork.

More recently, bureaucratic forces seem to have begun conspiring against the ham. Traditionally, the hams come with the hoof attached to show that the ham really is from a black-footed (*pata negra*) pig, but in 2009 this practice was found to violate a USDA regulation. So off with the hooves.

In another development, a trade dispute between the United States and the European Union caused the U.S. government to slap a 100% tax on a variety of food products, including hams imported from Europe with an intact bone. That hams with a bone should be taxed while boneless hams are not is bizarre, but such are the ways of the government.

Bureaucracy affects food safety rules in more subtle ways as well. Changing a regulation is always harder than keeping it intact, particularly if the change means sanctioning a new and strange food or liberalizing an old standard. No one will praise public health officials and organizations for moist pork chops, but plenty will heap blame should someone fall ill after regulators relax a safety standard.

Cutting boards are prime territory for cross-contamination among different foods if they aren't properly sanitized between uses. Food on the cutting board can contaminate whatever food next comes in contact with the board's surface or the cutting knife. To prevent this, wash cutting boards and other tools between every use.

COMMON MISCONCEPTIONS

You may notice that some of the temperatures in this chapter are rounded up or down. For example, in an exact conversion, 130 °F = 54.4 °C, and 54 °C = 129.2 °C, but we have quoted them together as 54 °C / 130 °F. Throughout this chapter we often quote from the official FDA 2009 Food Code, and when we do we use exactly what it specifies. Some parts of the Food Code round temperatures to the nearest whole degree, whereas other parts round to a tenth of a degree. A nitpicker might observe that the requirements of U.S. law thus depend on whether you read your thermometer in Celsius or Fahrenheit.

Once upon a time, some well-meaning officials decided that food safety recommendations should include only temperatures instead of time-and-temperature combinations. This decision, perhaps the worst oversimplification in all of food safety, has led to years of confusion and mountains of ruined food.

Scientifically speaking, you need the right combination of both time and temperature to kill pathogens. Why give temperature-only rules when the science says otherwise? One can only guess at the reasoning of regulators, but they most likely thought that providing both temperatures and times would be too complicated. If you don't understand the meaning of time, however, you've got bigger problems in the kitchen than food safety.

Once you eliminate time from the standards, the strong tendency is to choose a temperature so hot that it can produce the required D level of pathogen reduction nearly instantaneously. This impractically high temperature invariably leads to overcooked meat and vegetables while preventing very few cases of foodborne infection in addition to those that would be prevented by less extreme heat. After all, once a pathogen is dead, heating it further doesn't make it any deader.

Unfortunately, the use of temperature alone in standards is only one of several sources of the confusion that pervades discussions of food safety. Another is the routinely invoked admonition that cooking temperature must be measured in the core or center of food or that "all parts of the food" must be brought to a recommended temperature for a specified time. Recall from the preceding chapter that virtually all food contamination is an external phenomenon; the interior of unpunctured, whole-muscle meat is normally considered sterile. This revelation often comes as a shock, but it's been verified in many tests: foodborne pathogens generally can't get inside an intact muscle.

There are a few notable exceptions, such as the flesh-dwelling parasites *Trichinella* and *Anisakis* and the hen ovary- and egg-infecting *Salmonella* bacteria. But these kinds of infections are relatively rare. The vast majority of cases of contamination can be linked to human or animal fecal matter that comes in contact with a susceptible surface.

The FDA acknowledges as much in the 2009 Food Code, which has the following to say about beef steaks:

> (C) A raw or undercooked WHOLE-MUSCLE, INTACT BEEF steak may be served or offered for sale in a READY-TO-EAT form if:
>
> (1) The FOOD ESTABLISHMENT serves a population that is not a HIGHLY SUSCEPTIBLE POPULATION,
>
> (2) The steak is labeled to indicate that it meets the definition of "WHOLE-MUSCLE, INTACT BEEF" as specified under ¶ 3-201.11(E), and
>
> (3) The steak is cooked on both the top and bottom to a surface temperature of 63 °C (145 °F) or above and a cooked color change is achieved on all external surfaces.

In effect, the FDA says it isn't concerned about the interior or core temperature of a beef steak; it cares only about the exterior temperature. So why doesn't the FDA see fit to apply the same criteria to *all* intact muscle foods? What is the difference, for example, between a beef tenderloin roast and a fillet cut from it, or between a thick rib-eye steak and a thin rib roast? There is no scientific basis, in fact, for treating beef roasts any differently than steaks.

More generally, no valid reason exists for handling other intact, cultivated meats like lamb or poultry any differently than beef steaks. Nevertheless, many laws and regulations still specify a core temperature for these meats—and these overly conservative rules are likely to remain in place until somebody lobbies for rare lamb or duck breast.

European chefs have long served red-meat poultry, including duck and squab breast, cooked rare like steaks. Searing the outer surface of these meats should be sufficient, just as it is for beef steaks. There is no more compelling reason for an interior temperature requirement for these meats than there is for beef.

This brings us to another common quirk of food safety rules: having completely different rules for

Ground beef, in which interior and exterior parts are thoroughly mixed, is particularly susceptible to contamination. During grinding, pathogens on the food surface can end up in the food interior, which doesn't get as hot as the surface does during cooking.

different foods. We have come to expect that chicken, for example, must be cooked differently than beef to make it safe. Why should there be any difference in cooking recommendations if most food contamination is external and most of that contamination is human-derived? Thankfully, as the rules have evolved, they have clearly trended toward greater uniformity across food types. The FDA 2009 Food Code, in fact, uses similar time-and-temperature combinations for most foods. But other codes still do not.

Poultry is an interesting case in point. Chickens, turkey, and ducks are typically sold whole with the skin intact. It's true that the risk of fecal contamination is higher if meat is sold with its skin or if it includes the abdominal cavity, from which fluids contaminated with fecal matter can leak during slaughter and processing. And chickens are notoriously prone to *Salmonella* infections. Consequently, past specifications treated chicken as high risk and urged cooking it to correspondingly high temperatures—higher than those recommended for beef, for example.

Research has since shown that *Salmonella* can be killed by temperatures as low as 49 °C / 120 °F if the heat is applied long enough. Some food safety rules better reflect the science and have lower time-and-temperature requirements for poultry. But other official standards still treat chicken as though nothing short of cremation will safeguard the consumer. The result is that government regulations end up contradicting one another (see Misconceptions About Chicken, page 180).

The Danger Zone

Another commonly oversimplified and misleading food safety standard concerns the "danger zone" between the maximum temperature at which cold food can be safely held and the minimum temperature at which hot food can be safely held. The typical "danger-zone" rule is that you can only leave food out for four hours when its temperature is between 4.4 °C and 60 °C / 40 °F and 140 °F before it becomes too hazardous to eat. Some so-called authorities reduce this even further, to

The concept of the "danger zone" is based on an oversimplification of microbial growth patterns. Not all temperatures within the danger zone are equally dangerous. Most pathogens grow slowly at temperatures below 10 °C / 50 °F. Their growth accelerates modestly with increasing temperature and is typically fastest near human body temperature, 37 °C / 98.6 °F. Beyond this optimum, higher temperatures sharply curtail the growth of most pathogens until they stop growing completely and start to die.

THE HAZARDS OF

Punctured Meat

Although contamination of intact muscle meat is almost always limited to the surface, it's important to recognize that poking, perforating, or otherwise puncturing whole pieces of meat can introduce pathogens into their interior. Sticking a temperature probe into the center of a piece of meat can contaminate it; injecting brines or marinades can, too. Gunshots also penetrate flesh, carrying any pathogens on an animal's skin or feathers into the muscle interior, so wild game should be considered to be at high risk of internal contamination and cooked accordingly.

Mechanical meat tenderizers such as the Jaccard, which are used increasingly in the commercial processing of beef, also carry contamination to the interior. Mechanically tenderized beef has been blamed for at least four outbreaks of foodborne illness in the past decade alone. In December 2009, for example, tenderized or "needled" steaks and sirloin tips from a processing company in Oklahoma caused *Escherichia coli*-associated illness in 16 states, moving the USDA to consider special labeling requirements for needled beef.

Cooks, beware: Jaccarding a steak (as described on page 3·50) poses the same risks because a Jaccard tenderizer perforates meat. The same is true for meat sold pretenderized, which is much more common than you might think. During tenderization, the tines carry pathogens into the meat, where they are less likely to be killed by heat if the meat is served rare.

If you are really concerned about the contamination of punctured meat, then you can dip the meat in a hot blanching bath for a short time or pass a torch over the meat's surface before tenderizing it with a Jaccard or other penetrating meat tenderizer. For more detail on blanching and searing strategies, see page 2·267.

Although it doesn't make sense to specify maximum and minimum temperatures for the "danger zone," it is perfectly reasonable to do so for holding temperatures, such as the maximum permissible temperature for a refrigerator.

two hours; USDA fact sheets say the limit is just one hour if the ambient temperature is more than 32 °C / 90 °F.

If you peruse the FDA 2009 Food Code, however, the "danger zone" turns out to be a much more complicated topic than simple fact sheets suggest. The general temperature range for foods is 5–57 °C / 41–135 °F, but there are several exceptions. Eggs, for some reason, are allowed to be stored at 7 °C / 45 °F. Food that is cooked at 54 °C / 130 °F can be held at that temperature.

The time duration is also complicated. Food that starts off cold (i.e., 5 °C / 41 °F or below) can spend four hours at 5–57 °C / 41–135 °F. Or you can apply an alternative standard that it can spend six hours at 5–21 °C / 41–70 °F. And many exceptions are given.

If you are cooling hot food, then it must spend no more than two hours in the range 21–57 °C / 70–135 °F and no more than six hours in total at 5–57 °C / 41–135 °F. Of course there are exceptions here, too, because the FDA allows some foods to be cooked at no more than 54 °C / 130 °F.

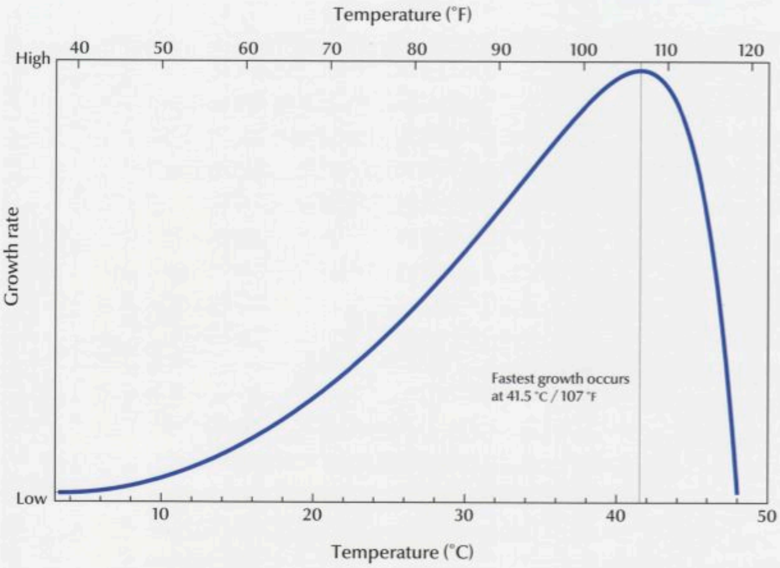
Many people try to avoid this complexity by simplifying the standard to "four hours in the danger zone." This can be a useful simplification, but we should all understand that it is just that—a gross simplification of the underlying dynamics of microbial growth.

On chicken meat, for example, *Salmonella* begins growing slowly at temperatures above 4 °C / 39 °F, reaches its peak growth rate at 41.5 °C / 107 °F, then declines sharply until it stops growing and begins to die at 49 °C /120 °F (see top graph on next page). Temperatures at which peak growth occurs are clearly the most dangerous. The "danger zone" limit of four hours is designed to ensure that, even at those temperatures, *Salmonella* bacteria would not grow in sufficient numbers to cause illness.

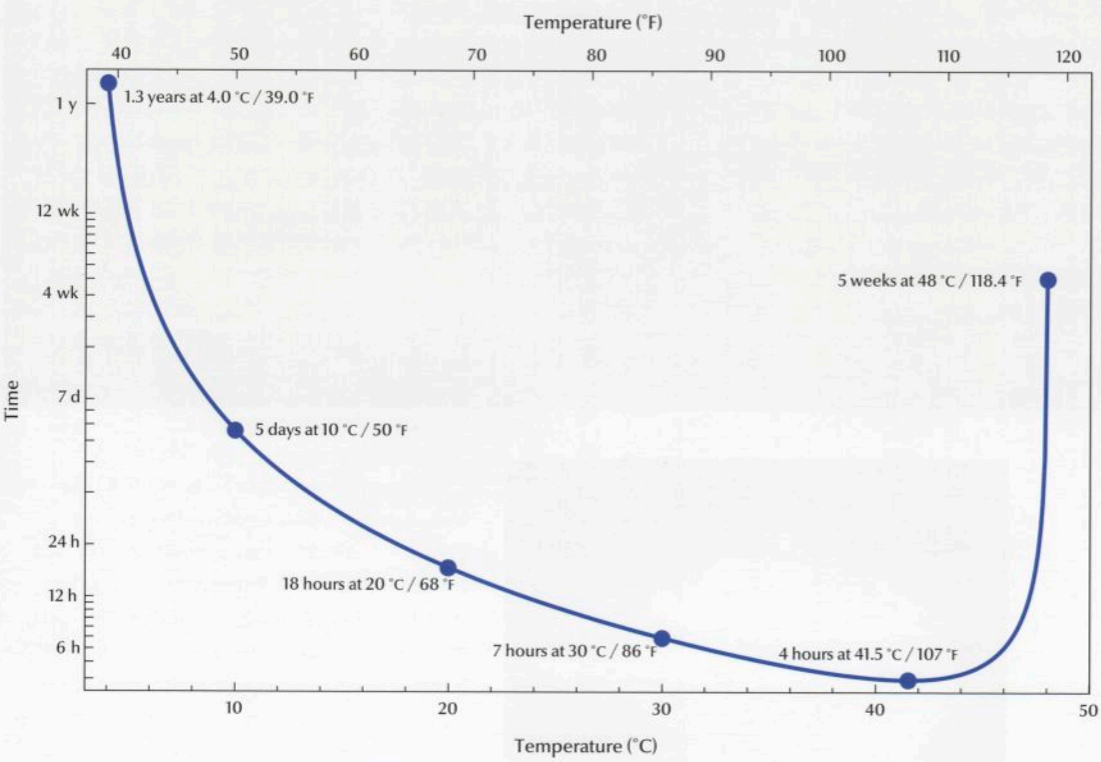
Some simple calculations reveal the varied risk within a broader temperature range. If four hours within the "danger zone" is taken as the upper safety limit, that means that, even at 41.5 °C / 107 °F, the temperature at which peak *Salmonella* growth occurs, four hours' worth of growth is still safe. We can plot the time required for the same amount of bacterial growth at other temperatures. The surprising result, as the bottom graph on the next page shows, is that four hours at the peak temperature produces the same amount of bacterial growth as 1.3 years at 4 °C / 39 °F!

In the Zone

Food safety rules typically specify a "danger zone" of temperatures from 4.4–60 °C / 40–140 °F at which food cannot be left out for more than four hours. But as these graphs show, all temperatures within the danger zone are not equally dangerous. The top graph shows the wildly different rates at which *Salmonella* bacteria grow at various temperatures within the danger zone. The lower graph gives a different perspective on this phenomenon by showing how long at each temperature the bacteria require to multiply as much as they do in four hours at 41.5 °C / 107 °F.



On chicken meat, Salmonella reproduce fastest at 41.5 °C / 107 °F. Notice, however, how much the growth rate drops at lower temperatures and plummets even more sharply at temperatures above the peak.



To offer another way to think about the differing risks posed by different temperatures, we calculated how long at each temperature Salmonella would need on chicken to achieve the same multiplication in number of bacteria that occurs in four hours at 41.5 °C / 107 °F. The bacteria could sit at 4 °C / 39 °F for more than year, or at 48 °C / 118 °F for five weeks. Salmonella bacteria begin to die at temperatures above 48 °C / 118 °F. At temperatures below 4 °C / 39 °F, the bacteria stop growing but do not die, even when frozen.

THE RULES OF

Food Safety Disclaimers

Most serious or fatal foodborne illnesses strike people with compromised immune systems: typically infants, the elderly, or people with underlying health issues. The U.S. FDA makes a sensible distinction between these "highly susceptible" people and the general population.

Requiring more stringent food safety standards for susceptible customers is perfectly reasonable. Other parts of the world may or may not make this distinction through law or regulation, but it is always a good idea to be more conservative when preparing food for susceptible diners. Catering at a hospital might necessitate a very different menu from that offered to healthy adults.

In many cases, you won't be able to tell which guests or customers are more vulnerable to contaminated food. Many restaurants address this problem with a short legal disclaimer on their menus, often with an asterisk marking certain menu items as containing raw or lightly cooked food that "might increase your likelihood of foodborne illness."

The FDA (FDA Food Code 2009 3-603.11) requires both a disclosure and a reminder with the following specifications:

(B) DISCLOSURE shall include:

(1) A description of the animal-derived FOODS, such as "oysters on the half shell (raw oysters)," "raw-EGG Caesar salad," and "hamburgers (can be cooked to order);" or

(2) Identification of the animal-derived FOODS by asterisking them to a footnote that states that the items are served raw or undercooked, or contain (or may contain) raw or undercooked ingredients.

(C) REMINDER shall include asterisking the animal-derived FOODS requiring DISCLOSURE to a footnote that states:

(1) Regarding the safety of these items, written information is available upon request;

(2) Consuming raw or undercooked MEATS, POULTRY, seafood, shellfish, or EGGS may increase your RISK of foodborne illness; or

(3) Consuming raw or undercooked MEATS, POULTRY, seafood, shellfish, or EGGS may increase your RISK of foodborne illness, especially if you have certain medical conditions.

The disclosure requires you to identify which dishes on a menu contain raw or undercooked food. The reminder tells the customer that health issues are a possible consequence of eating that food. Even in jurisdictions that don't require them by law, these labels and warnings could help limit your legal liability. At the very least, they warn people appropriately, and it is simply good common sense to let people decide for themselves whether they should eat food that might make them ill.

Of course, FDA requirements and European Union regulations do not apply to chefs at home. When cooking for friends or family in your own kitchen, you must use your own judgment based on your health status—and theirs.

Once again, the information supplied by this book and its authors cannot substitute for legal advice. If you are a restaurateur or commercial chef concerned about a legal requirement for labeling or for warning customers, consult the relevant authorities or retain legal professionals in your area.

Millions of pork chops have been overcooked to 71 °C / 160 °F, as this one has, in the name of safety. The dry white meat and contracted shape show that too much heat has been applied. Yet science suggests no reason to cook pork this way.

This result is specific to *Salmonella*, but the same kind of curve exists for every pathogen. Peak growth is *much* faster than nonpeak growth, and virtually no growth occurs at temperatures less than 4.4 °C / 40 °F for most pathogens. Not coincidentally, this is close to the upper temperature limit recommended for refrigerators by the FDA.

As with D levels, there is no one right answer for ensuring safety within the "danger zone." If the food is not already contaminated, leaving it out at room temperature for more than four hours (or six hours, depending on which standard you use) is unlikely to cause problems. On the other hand, highly contaminated food isn't safe to leave out for any duration. Like other food safety rules, the so-called "danger zone" directive is not a strict rule—it is a subjective simplification of a complicated issue. That simplification is a useful way to get a rule of thumb, but it isn't some deep scientific truth.

Misconceptions About Pork

The "safe" temperature for cooking pork is one of the most misunderstood—and most distorted—aspects of food safety. Numerous so-called authorities or experts recommend massively overcooking pork, as is evident from the table on this page. Why pork? The usual reason given is the danger of contamination with the roundworm *Trichinella spiralis*.

This assertion is misleading for several reasons, as discussed on page 120. Most importantly, improvements in pork farming and processing practices have virtually eliminated *Trichinella* contamination in commercially produced pork in developed countries. One study showed that only eight cases of trichinellosis (also called trichinosis) could be attributed to pork grown commercially in the United States between 1997 and 2001. During that same period, the American population consumed about 32 billion kg / 70 billion lb of pork. That's an awful lot of pork to generate only eight cases of trichinellosis.

Trichinellosis from wild game (mostly from bear meat) and from noncommercially raised pork was also very rare: just 64 cases over five years, for a total from all sources of 72 cases. This is such a low incidence for a country of more than 300 million people that trichinellosis ranks among some of the rarest diseases known to medicine. When it does occur, the disease is neither fatal nor serious, and it is easily treatable. It is hard to see what all the fuss is about; there are far more common and more serious public health threats than trichinellosis.

The alarmism also ignores two other points. First, most commercial pork is frozen to kill the parasite. Second, and perhaps more surprising, *Trichinella* is very easy to kill with low heat.

The FDA cooking regulations for eliminating *Trichinella* include temperatures as low as 49 °C / 120 °F, albeit maintained for 21 hours. (The main reason to cook at temperatures that low is to process ham in the style of a "raw" ham). The regulations do not even bother to list temperatures higher than 62 °C / 144 °F because the time required to eliminate the parasite would be less than a second.

Officially Recommended Times and Temperatures for Cooking Pork

Some food safety rules have evolved to reflect that pork cooked at lower temperatures is safe; others have not. Most cooks and cookbook authors insist that the higher temperature is the only one that will eliminate contamination. They are wrong.

Source	Temperature (°C)	Temperature (°F)	Time
USDA Food Safety and Inspection Service website, "Safety of Fresh Pork ... From Farm to Table"	71	160	no time given
FDA 2009 Food Code example times (including pork but not specific to it)	54	130	112 min
	60	140	12 min
U.S. Code of Federal Regulations 9CFR318.10 (specific to pork and *Trichinella*)	49	120	21 h
	54	130	30 min
	61	142	1 min

For more on roundworms, see page 120.

The FDA 2009 Food Code makes no special recommendations at all for cooking pork. Instead, it suggests using the FDA's time-and-temperature table for whole-meat roasts for all meats (see FDA-Specified Oven Temperatures for Roasting Whole-Meat Roasts, page 186).

Other pathogens that can infect pigs, such as *Salmonella*, are not unique to pork—another reason why the FDA Food Code does not require a different standard for it. The cooking recommendations in the FDA time-and-temperature table will destroy *Salmonella* to the 6.5D level in any meat, including pork. Yet most information sources for consumers, including the USDA web site and the National Pork Board, recommend a cooking temperature of 71 °C / 160 °F, which is laughably high. Dry, overcooked pork is the inevitable result, particularly when leaner cuts are cooked at this temperature.

Why does this mistake persist? Exaggerated concern about *Trichinella* is clearly one factor. So is the failed strategy of relying on temperature only. A desire to maintain the status quo may also play a role; once you've taught people that pork needs to be overcooked, it takes some courage to change course, particularly if it means admitting you've made a mistake.

The growing popularity of free-range pork has spurred debate over whether eating such meat might increase the risks of trichinellosis. In a 2009 op-ed in *The New York Times*, a free-range opponent pointed to a study reporting that, among pigs sampled from three states, two free-range animals had potential *Trichinella* exposure, compared with none of the conventionally raised pigs tested. "For many years, the pork industry has been assuring cooks that a little pink in the pork is fine," he noted. "Trichinosis, which can be deadly, was assumed to be history." The study, however, turned out to be financed by the National Pork Board, no friend of the free-range movement.

In the authors' experience, convincing chefs that pork has no special cooking requirements compared with those for beef or other meat can be a difficult feat. Showing them the FDA Food Code provokes statements such as, "But that must be wrong!" Cookbook authors have less of an excuse for perpetuating this travesty. Many have repeated the silly claims about 71 °C / 160 °F for years without bothering to check technical sources to verify the facts.

Misconceptions About Chicken

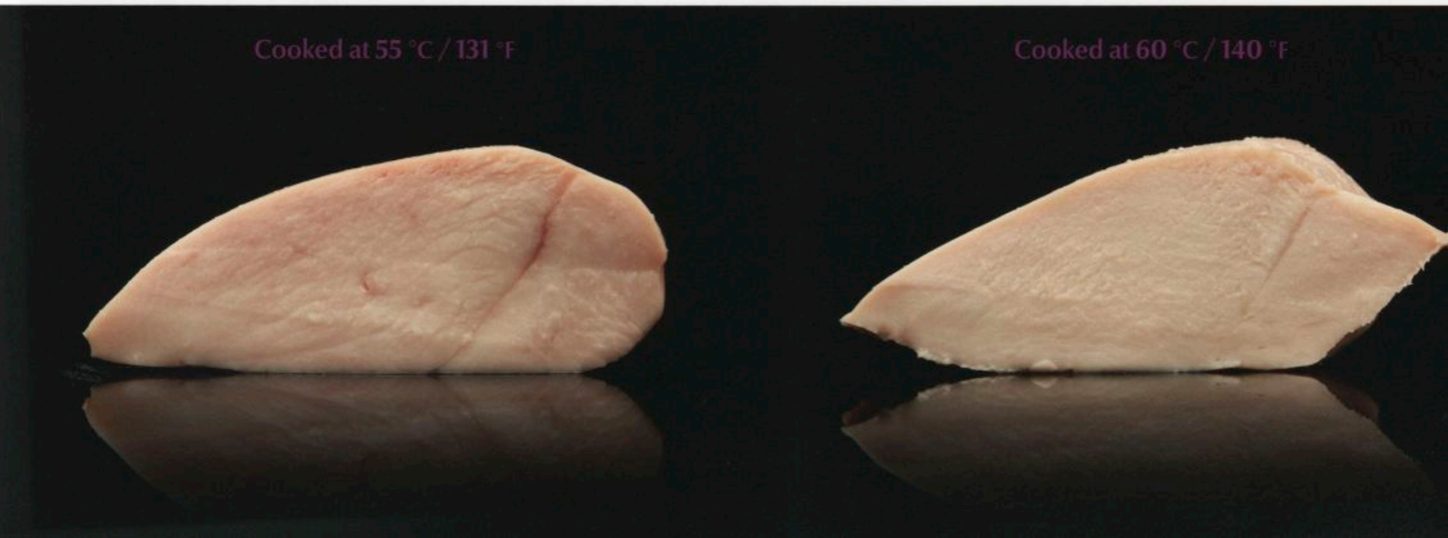
The misconceptions surrounding chicken are in some ways similar to those that plague pork but are arguably even more confusing because of conflicting standards and widespread blurring between fact and fiction. First, the facts: chickens can indeed host asymptomatic *Salmonella* infections, and it is not uncommon for chicken feces to contain high levels of the pathogenic bacteria. Moreover, chickens are typically sold whole, which means that they may carry remnants of any fecal contamination of the skin or interior abdominal cavity that occurred during slaughter and processing. That's why chicken and chicken-derived products are considered such common sources of foodborne *Salmonella*.

As with *Trichinella* and pork, however, the link between contaminant and food has been exaggerated. Many people believe, for example, that chicken is the predominant source of *Salmonella*. That's not necessarily the case. In a 2009 analysis by the CDC, *Salmonella* was instead most closely associated with fruits and nuts, due in part to an outbreak linked to peanut butter in 2006. Indeed, the tally of outbreak-linked foodborne illnesses attributable to produce was nearly double the tally of such illnesses associated with poultry, and the foodborne pathogen most commonly linked with poultry was not *Salmonella* but the bacterium *Clostridium perfringens*.

If the link is overblown, the cooking standards for chicken are truly convoluted. As the table on the next page shows, the FDA 2009 Food Code lists the same cooking standards as the USDA's Food Safety and Inspection Service (FSIS) web site, and both concord with conventional wisdom: the meat should be cooked to a minimal internal temperature of 74 °C / 165 °F for 15 seconds. Unbelievably, the FSIS notes: "For reasons of personal preference, consumers may choose to cook poultry to higher temperatures." That ridiculous recommendation is far from the final word on the subject.

For ready-to-eat food products, including rotisserie and fast-food chicken, the FSIS calls for a 7D reduction in *Salmonella* levels. In 2001, the FSIS developed a corresponding set of time-and-temperature tables for chicken and turkey products according to their fat content. The tables, based on the research of microbiologist Vijay K. Juneja, Ph.D. and colleagues at the USDA Agricultural Research Service, include fat contents as high as 12% and recommended temperatures as low as 58 °C / 136 °F. As we've previously discussed, that set of standards has been challenged as overly conservative by an advisory panel, which instead suggested a 4.5D reduction, allowing a 36% decrease in cooking times from the FSIS 7D standard.

In 2007 Juneja's team published the results of



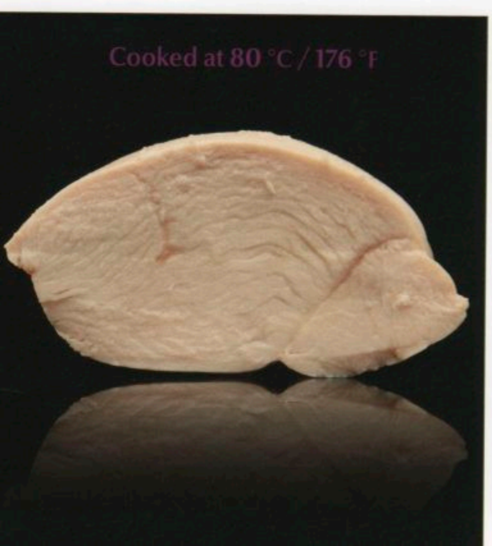
Identical chicken breasts show the changes in color and texture that occur with overcooking. At 55 °C / 131 °F, the breast meat has a slight pink cast and is tender and moist. By 60 °C / 140 °F, the additional heat has caused some contraction of muscle proteins, and the pink cast has disappeared. In our taste tests, we preferred chicken in this temperature range. At 80 °C / 176 °F, the chicken is tougher, and contraction of muscle proteins has forced the juices out of it.

a study directly examining *Salmonella* growth in ground chicken breast and thigh meat. The data show that cooking chicken meat at temperatures as low as 55 °C / 131 °F for much shorter times produces a 6.5D reduction. The researchers' curve is quite similar to the FDA's 6.5D reduction curve for whole-meat roasts, except for a sizeable divergence in time at the 60 °C / 140 °F temperature point (see What to Believe?, page 189).

So who's right? Technically, destruction of *Salmonella* can take place at temperatures as low as 48 °C / 120 °F given enough time. There is no scientific reason to prefer any one point on the reduction curve, but the experts who formulated the FSIS ready-to-eat standards arbitrarily decided to go no lower than 58 °C / 136 °F. Likewise, officials preparing the FDA Food Code and other reports chose 74 °C / 165 °F as an arbitrary cut-off. The choice seems to have been based not on science but on politics, tradition, and subjective judgment.

Health officials have admitted as much. In a January 2007 report published in the *Journal of Food Protection*, a panel called the National Advisory Committee on Microbiological Criteria for Foods conceded that, on the basis of preconceived notions of consumer taste, the FSIS recommended higher cooking temperatures to consumers than to makers of processed chicken products:

> The temperatures recommended to consumers by the FSIS exceed those provided to food processors, because poultry pieces cooked to 160 °F are generally unpalatable to the consumer because of the pink appearance and rubbery texture.



Officially Recommended Times and Temperatures for Cooking Chicken

Source	Temperature (°C)	Temperature (°F)	Time
USDA Food Safety and Inspection Service website, "Focus on: Chicken"	74	165	no time given
FDA 2009 Food Code	74	165	15 s
U.S. Code of Federal Regulations, ready-to-eat chicken; example times for 10% fat content	58	136	81 min
	60	140	35 min
	63	145	13 min
	74	165	<10 s
FSIS recommendations (based on Juneja, 2001) for 7.0D reduction in *Salmonella* for ready-to-eat chicken; example times for 10% fat content	58	136	76 min 42 s
	60	140	32 min
	63	145	11 min 18 s
	74	165	<10 s
Juneja, 2007 6.5D reduction in *Salmonella* for ground chicken breast meat	55	131	39 min 31 s
	57.5	135.5	31 min
	60	140	19 min 30 s
	62.5	144.5	4 min 17 s
Juneja, 2007 6.5D reduction in *Salmonella* for ground chicken thigh meat	55	131	1 h 15 min
	57.5	135.5	34 min 8 s
	60	140	20 min 56 s
	62.5	144.5	5 min 28 s

Elsewhere in the same report, the authors suggested that a final temperature of 77 °C / 170 °F for whole-muscle breast meat and 82 °C / 180 °F for whole-muscle thigh meat "may be needed for consumer acceptability and palatability."

These are amazing admissions! In effect, the authors are saying that FSIS consumer regulations, which are ostensibly based on safety considerations, are in reality based on bureaucrats' beliefs about consumer preference. That is hardly their charter! Shouldn't chefs and consumers be the ones to decide what they would prefer to eat?

Perhaps the most galling aspect of this stance is that the advisors are just wrong about the culinary facts. Chicken cooked at 58 °C / 136 °F and held there for the recommended time is neither rubbery nor pink. In our opinion its texture and flavor are far superior to those of chicken cooked at the extremely high temperatures the experts recommend. Regulators' misguided and patronizing attempts to cater to consumer preference have served only to perpetuate the tradition of overcooking chicken.

UNDERSTANDING THE FDA RULE BOOK

Broadly speaking, health officials take two approaches to food safety rules. One approach is to make specific rules for various food types—in particular, to specify time-and-temperature combinations for cooking. The other, more general approach is simply to say, "Cook sufficiently to destroy pathogens."

The FDA takes the first approach, giving very detailed standards for a wide range of foods. Indeed, the FDA's Food Code constitutes the most detailed list of food safety specifications in the world as of this writing. The European Union and most of its member states tend to take the opposite approach, requiring restaurants and other commercial food establishments to serve food that is safe without giving much guidance about how to achieve that safety.

For more on the cooking, storage, and freezing temperatures specified by FDA rules, see the tables on pages 184 and 186.

One can argue the merits of either approach. The FDA Food Code has some entries that are rather puzzling and seemingly not supported by science. In those cases, the detailed approach requires U.S. cooks to follow rules that may be unwarranted. Chefs in Europe must satisfy the health department, but they can decide how to achieve compliance on a case-by-case basis.

Although many chefs associate frozen seafood with poor quality, proper handling and quick freezing can preserve taste and texture.

You could counter that the FDA rule book is more useful and informative because it gives the chef very specific guidelines and imposes a national standard that, ideally, prevents local authorities from running amok with their own discordant rules. In practice, however, local regulations commonly depart from the national standard, and local authorities do run amok from time to time (see The New York Sous Vide Hysteria, page 188).

We've reproduced many of the FDA's time-and-temperature standards in the pages that follow. The principal set of rules, reproduced on page 184, is remarkably detailed and covers even uncommon foods such as baluts, a Southeast Asian specialty that consists of cooked chicken or duck eggs that each contain a partially developed embryo.

The FDA has special requirements for whole-meat roasts: in addition to the temperature of the food, the air temperature for dry still and dry convection ovens must meet certain specifications. Humidified ovens, including combi ovens, steamers, and cook-and-hold ovens, are not required to meet any air-temperature specifications, although the FDA still provides a temperature recommendation as well as suggestions for relative humidity.

Sous vide cooking is covered by special FDA rules. Although the basic time-and-temperature regulations are the same as those for more conventional cooking, the sous vide-specific rules include further requirements for storage.

Raw foods are also governed by FDA regulations. In the case of raw fish, the FDA requires that susceptible species be frozen to kill anisakid nematodes and related parasites before being served. You can legally serve most other foods raw, but not to susceptible people and not without a warning. Oddly, raw plant-based foods are exempt from these requirements—an unfortunate distinction given that plants can be just as contaminated as food of animal origin.

Analysis of FDA Regulations

Although the FDA does not give a rationale for most of its standards, we can gain a better understanding of them with the aid of some basic scientific principles. One in particular is the basic assumption in virtually all food microbiology that thermal death curves for bacterial pathogens are straight lines on a semilog graph.

In plain English, this means that, when a specific amount of bacterial reduction is plotted logarithmically against the combinations of temperature and time required to achieve it, the resulting line should be straight. For an example, look at the thermal death curve for *Salmonella* shown on page 187. Such lines offer a consistent basis of comparison for the parameters that produce a desired reduction in bacteria numbers.

As that figure shows, if you plot a curve from the data in the FDA's cooking table for whole-meat roasts, you get essentially the same curve as the 6.5D thermal death curve for *Salmonella* in beef.

The FDA Food Code for 2009 is an exhaustive but imperfect attempt to prevent foodborne illness with detailed regulation.

In principle, this plot should be a straight line, but the FDA's decision to round off to the nearest minute and nearest degree has made the line a bit bumpy. And one point on the graph is much more problematic than the others: the last one.

At 70 °C / 158 °F, the FDA 2009 Food Code lists a corresponding cooking time of 0 seconds, and other FDA documentation lists it as "< 1 second." The previous temperature in the code, 69.4 °C / 157 °F, corresponds to a cooking time of 14 seconds, so there's a sizeable decrease in time between that point and the last one for a temperature difference of just 0.6 °C / 1 °F. In fact, the final data point is downright wrong if it's meant to represent actual reductions in populations. The real cooking time for a 6.5D drop for *Salmonella* at 70 °C / 158 °F is 11 seconds.

This error is potentially dangerous because cooking meat for less than a second at 70 °C / 158 °F does not produce anything close to a 6.5D reduction in *Salmonella*. On the other hand, even the true value of 11 seconds is quite brief; one could argue that the relative difference in time is not important. Indeed, this is exactly what FDA officials told us when this discrepancy was brought to their attention. They had basically "rounded down" from 11 seconds to 0 seconds. But then why not round 14 seconds or other values in the table down to zero also?

We point out this error to remind cooks that the "experts" don't get everything right. Anybody can make mistakes, including government bureaucrats, so it behooves a cook to have an understanding of food safety that goes beyond the specifications in the rule book. Unfortunately, there are many other examples of inconsistencies, inaccuracies, and caprice in the official regulations that govern food safety.

The data curve in the FDA time-and-temperature table for egg dishes and for ground, minced, injected, or mechanically tenderized meats (red line in FDA Time-and-Temperature Curves, page 187) also follows the 6.5D *Salmonella* curve. For reasons that aren't clear, however,

FDA-Specified Cooking Times and Temperatures

	Temperature			
Food	**(°C)**	**(°F)**	**Time**	**Note**
fish farmed meat, including that from commercially raised game animals eggs broken and cooked to order	63	145	15 s	for raw eggs, see below
ratites (e.g., ostriches, emus, kiwis) injected or marinated meats eggs other than those cooked to order ground or minced fish or meats, including commercially raised game animals	63	145	3 min	for more complete cooking standards, see red line on FDA Time-and-Temperature Curves, page 187
	66	150	1 min	
	68	155	15 s	
	70	158	<1 s	
poultry baluts wild game animals stuffed meat, fish, poultry, pasta stuffing containing meat, fish, poultry, or ratites	74	165	15 s	
whole-meat roasts from: pork beef corned beef lamb cured pork roasts such as ham	54.4	130	112 min	for more complete cooking standards, see blue line on FDA Time-and-Temperature Curves, page 187. Time-and-temperature combinations yield an approximate 6.5D reduction for *Salmonella*. If meat is cooked in an oven, that oven must meet certain temperature standards (see FDA-Specified Oven Temperatures for Roasting Whole-Meat Roasts, page 186)
	55.0	131	89 min	
	56.1	133	56 min	
	57.2	135	36 min	
	57.8	136	28 min	
	58.9	138	18 min	
	60.0	140	12 min	
	61.1	142	8 min	
	62.2	144	5 min	
	62.8	145	4 min	
	63.9	147	134 s	
	65.0	149	85 s	
	66.1	151	54 s	
	67.2	153	34 s	
	68.3	155	22 s	
	69.4	157	14 s	
	70.0	158	0 s	
whole-muscle, intact beef steak	63	145	no time given	surface brought to this temperature to achieve "cooked color change"; no core temperature required
any raw food of animal origin cooked or reheated in a microwave oven	74	165	no time given	
food reheated in other oven for hot holding	74	165	15 s	
reheated ready-to-eat food taken from hermetically sealed commercial container	57	135	no time given	
plant foods (fruits and vegetables) for hot holding	57	135	no time given	
fruit or vegetable juice packaged on-site	5D reduction of "most resistant microorganisms of public health significance"			

FDA-Specified Cooking Times and Temperatures (continued)

milk pasteurization for making cheese	63	145	30 min	or any point in the FDA dairy table (see FDA Time-and-temperature Curves, pink line)
	72	162.1	15 s	
	89	191.2	1 s	
	96	204.5	0.05 s	
	100	212	0.01 s	
pasteurization of high-fat or sweet dairy foods such as ice cream	69	155.6	30 min	or any point in the FDA ice cream table (see FDA Time-and-temperature Curves, orange line)
	80	175.6	25 s	

the FDA version begins at 63 °C / 145 °F instead of at 54.4 °C / 130 °F. The seemingly arbitrary decision to start at a higher temperature is puzzling because all points along the curve yield the same 6.5D reduction and thus all provide the same level of safety.

To make matters worse, this curve contains the same apparent timing error at 70 °C / 158 °F that bedevils the curve for whole-meat roasts, compounded by an absence of intermediate data points between 65 °C / 150 °F and 70 °C / 158 °F. As we noted before, the final time point of less than one second cannot be scientifically correct for whole-meat roasts—or for any other food.

Similarly puzzling is the single data point for fish and for eggs cooked to order (green dot in graph on page 187). At the specified cooking temperature of 63 °C / 145 °F, the time requirement of 15 seconds is dramatically less than the 240 seconds required for the same temperature point in the FDA's time-and-temperature table for cooking meat. Instead of a 6.5D reduction in *Salmonella*, 15 seconds of cooking time would yield only a 0.41D reduction.

As discussed previously, many food safety experts think that the 6.5D standard is excessive and that 4.5D would be more reasonable, but nobody is in favor of 0.41D—that is simply ineffective and useless. Even if it did accomplish something, another question remains: why should eggs cooked to order require such a slight D-value reduction when the same eggs, if not cooked to order, require a 6.5D pathogen reduction?

We asked the FDA, and they could not give us an answer. Their rationale appears to be simple pandering to common practices. If you order eggs "sunny side up" with runny yolks, the typical cooking temperature will be about 63 °C / 145 °F. The FDA appears to have observed common practice then codified it, even though the practice carries essentially no food safety benefit.

Recall that the FDA does allow you to serve raw or lightly cooked eggs—you just need to warn your customers in writing on the menu or elsewhere. But the warning is not required if you follow the 63 °C / 145 °F for 15 seconds rule. Why make such an exception? We don't know, but it seems to make no scientific sense.

Of course if you are serious about the safety of lightly cooked eggs, the right thing to do is use pasteurized eggs—which can be bought commercially or easily prepared.

For fish, one could argue that a pathogen other than *Salmonella* is the primary target of the time-and-temperature requirement. But the FDA does not specify the hazard, and there are no obvious candidates for a fish-specific pathogen that would be adequately reduced by 15 seconds of cooking. Many people, the authors included, consider fish overcooked at 63 °C / 145 °F. So the rule ensures that fish will be overcooked but not necessarily safe.

In many ways, the fish requirement is and example of food safety rules at their absolute worst. The regulation accomplishes little to nothing in terms of real food safety while grossly harming quality. Because fish is cooked optimally at very low temperatures (at least in our opinion), you can't pasteurize fish without overcooking it. So when you serve fish, you must accept that it isn't pasteurized. This is a small risk that most people consider acceptable. Following the FDA regulations will overcook the fish *but won't make it appreciably safer.*

The fundamental conclusion to draw here is that the time specified for fish and eggs cooked to order is likely more of a symbolic requirement than one driven by scientific verities. If the fish or

The fish and egg rule is meaningless "make-work" regulation—it achieves little but lets inspectors and cooks feel as if something has been done.

For more on pasteurizing eggs, see page 4·78.

Egg pasteurization is not covered in the FDA Food Code, in part because of a bureaucratic issue that a raw pasteurized egg might be considered a "food ready-to-eat" and thus be within the purview of the USDA rather than the FDA.

FDA-Specified Oven Temperatures for Roasting Whole-Meat Roasts

Roast weight	Oven type	Temperature (°C)	Temperature (°F)	Note
<4.5 kg / 10 lbs	still dry	177	350	minimum oven temperature for small roasts in still ovens
	convection	163	325	minimum oven temperature for small roasts in convection ovens
	high-humidity	121	250	relative humidity must be greater than 90% for at least 1 h as measured in the cooking chamber or exit of the oven, or roast must be cooked in a moisture-impermeable bag that provides 100% humidity; temperature given is a recommendation but can be less
≥4.5 kg / 10 lbs	still dry or convection	121	250	minimum oven temperature for large roasts in still or convection ovens
	high-humidity	121	250	see note above for high-humidity oven roasting

FDA Time-and-Temperature Standards for Cooking and Storage Sous Vide

Sous vide specification	Regulation
raw animal foods	cooked to temperatures and times as for other foods (see FDA-Specified Cooking Times and Temperatures, page 184)
stored at 5 °C / 41 °F	stored for no more than 72 hours
stored at 1 °C / 34 °F	stored for no more than 30 days
stored frozen (less than −20 °C / −4 °F)	no limit on length of storage
raw food stored in sous vide bag at 5 °C / 41 °F before cooking and consumption	stored for no more than 14 days

FDA Time-and-Temperature Standards for Freezing Raw Foods

Food	Temperature (°C)	Temperature (°F)	Time	Note
raw or partially cooked fish (except tuna and farmed fish)	-20	-4	7 d	raw fish must be frozen at specified temperatures and times then thawed before being served
	-35	-31	15 h	
	-35/−20	-31/−4	1 d	frozen at −35 °C /−31 °F; stored at −20 °C/−4 °F
raw or soft-cooked eggs	no minimum temperature or time requirements should not be served to highly susceptible populations must warn consumers			
raw or rare cooked meat				
molluscan shellfish (such as clams, oysters)				
raw tuna				
raw fish, commercially farmed				
raw food of plant origin	no minimum temperature or time requirements no warning requirement			

eggs are contaminated, this amount of cooking will not make them safe to eat. If they aren't contaminated, then the requirement is moot; even eating them raw would have no harmful effects.

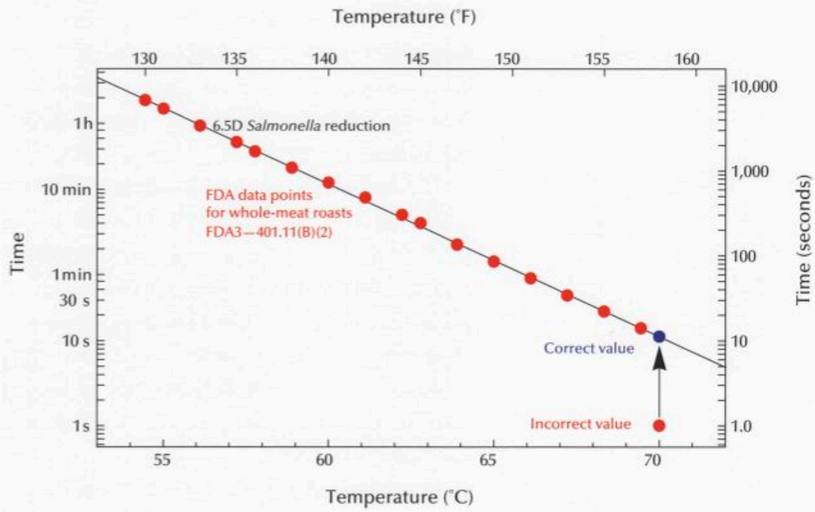
The requirement for cooking the surface of beef (see brown dot in graph at bottom right) raises a similar issue. One second at 63 °C / 145 °F has no substantial impact on typical beef pathogens such as *E. coli* or *Salmonella*. The 6.5D reduction curve for *Salmonella* shows you need to cook steak for one second at 76 °C / 169 °F; one second at 63 °C / 145 °F is far too short. As in the fish and egg cases, an arbitrary and ineffective number has been chosen to make it seem as if the regulation is effective, but there is no science to back that up.

In actual practice, searing a steak typically involves much higher temperatures. Searing meat with a hot pan, griddle, *plancha*, or blowtorch is almost always done at 75 °C / 170 °F or above; many steaks are seared until they brown at temperatures greater than 100 °C / 212 °F. As a practical matter, then, the level of pathogen reduction on the exterior of most seared steaks will approach the 6.5D level no matter what the rules are.

The FDA's requirement for cooking the surface of beef also raises the question of why the rules single out steaks but not roasts, which are also intact beef muscle. Officials in the FSIS, in fact, confirmed to us that no real difference exists between a thin rib roast and a thick rib-eye steak when it comes to pathogen reductions. More generally, repeated food safety tests have shown that animal muscles are generally sterile inside—at least with regard to the most common food pathogens. This finding is not true for parasites like *Trichinella*, of course, but most meats do not harbor the parasitic worm. So why not broaden the surface-cooking requirement from beef to lamb and other commercially farmed meats?

The Last Step Is a Big One

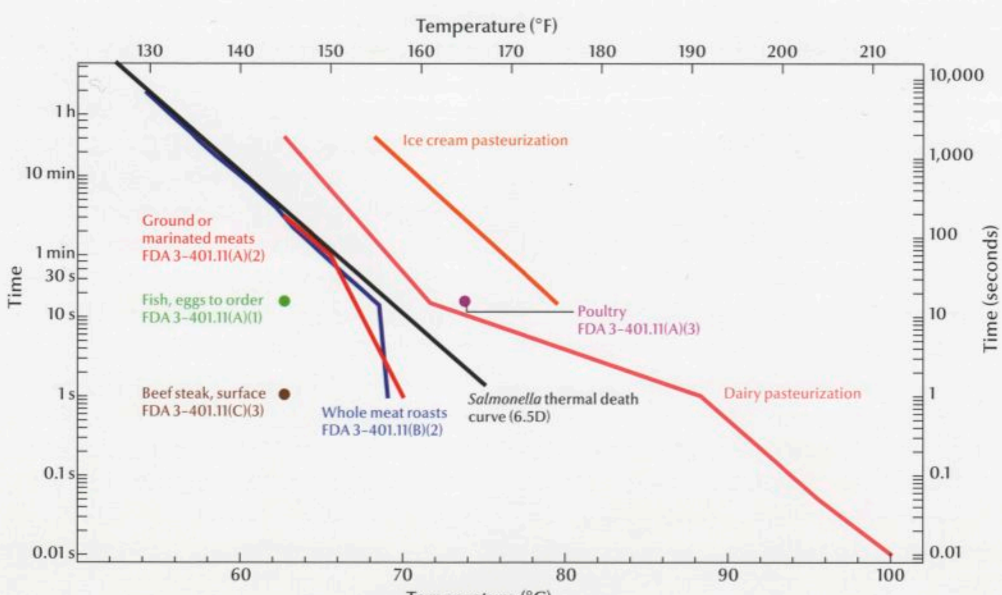
The thermal death curve for a 6.5D reduction of Salmonella in beef (black line) has been established by many scientific studies. The FDA's time-and-temperature recommendations for cooking whole-meat roasts (red dots) accord well with the scientifically determined parameters, except for one notable deviation at 70 °C / 158 °F. Here the FDA recommends cooking whole roasts for one second or less—a rule that flouts the scientific evidence and could be downright dangerous because such a brief cooking time is unlikely to reduce Salmonella populations to safe levels. The correct cooking time (blue dot) is 11 seconds.



FDA Time-and-Temperature Curves

The curve plotted from the FDA's time-and-temperature table on whole-meat roasts (blue line) follows the curve for a 6.5D thermal reduction of Salmonella in beef (black line) except for an odd deviation at 70 °C / 158 °F. The curve plotted from the FDA's time-and-temperature table for ground or minced fish and meats, injected or mechanically tenderized meats, and eggs other than those cooked to order (red line) also follows the same basic curve as the 6.5D reduction in Salmonella, except that it starts at 63 °C / 145 °F instead of at 54.4 °C / 130 °F.

The cooking recommendation for both fish and eggs cooked to order (green dot) would reduce Salmonella counts by less than three-fold instead of the more than 3-million-fold drop produced by using the 5 min cooking time suggested by the Salmonella curve. The single data point for cooking the surface of beef (brown dot) is equally unlikely to yield a substantial drop in pathogen levels. The FDA-recommended temperature for cooking poultry (purple dot), on the other hand, is needlessly high. It's even more conservative than the pasteurization curve for dairy (pink line), which is based largely on outmoded methods of analysis. The curve for ice cream (orange line) reflects concerns about the difficulty of destroying pathogens in eggs and milk fat, but its accuracy has not been demonstrated.



Food safety regulations for poultry are particularly puzzling because FDA standards contradict those of other government agencies as well as the results of state-of-the-art scientific research (see Misconceptions About Chicken, page 180 and purple dot in the lower graph on the previous page). The FDA, for instance, recommends the outrageously high cooking temperature of 74 °C / 165 °F for 15 seconds. Tables produced by the FSIS include temperatures as low as 58 °C / 136 °F. And more recent reports suggest that cooking at temperatures as low as 55 °C / 131 °F for much shorter times is sufficient.

So what should we believe? The FDA's 74 °C / 165 °F temperature point is simply too high to be credible, and the FSIS tables are relevant only if you are making poultry forcemeat or sausage for a commercial market and desire a 7D drop in *Salmonella* levels. For whole chicken breast or thigh meat, however, the temperatures and times specified in the 2007 Juneja paper—55 °C / 131 °F for 1 h 15 min and 57.5 °C / 135 °F for 34 min 8 s, respectively—seem more than adequate. After all, that study looked at ground chicken meat, which would arguably be at greater risk of contamination than whole meat. If anything, its cooking recommendations might be overly conservative for whole chicken breasts and thighs.

For dairy pasteurization, the FDA includes two time-and-temperature points that are in widespread use around the world. Low-temperature, long-time (LTLT) pasteurization, or vat pasteurization, typically means heating milk to 63 °C / 145 °F for 30 minutes. In contrast, high-temperature, short-time (HTST) pasteurization requires heating the milk to 72 °C / 162 °F for at least 15 seconds. Commercial dairy producers favor these points by convention, not by necessity; any time-and-temperature combination on the curve would produce the same amount of pathogen reduction (see pink line in the graph on page 187).

You may wonder, as we did, why pasteurization times are so lengthy for dairy products. According to the U.S. government food scientists we consulted, the main reason is that the data was gathered long ago with rather crude laboratory methods. Some believe the time requirements could be substantially revised if they repeated the studies with today's more sophisticated techniques, but the necessary lab work has yet to be done.

THE HISTORY OF

The New York Sous Vide Hysteria

Health departments have a difficult and often thankless job: to protect the public from dangerous pathogens by inspecting restaurants and food-processing facilities to make sure that they comply with the law. Most health departments perform this duty well; every now and then, one falls short of the mark. Then there's the case of New York City's strangely activist health department, which seems so determined to meet its responsibilities that it errs on the side of action (see page 237).

In August of 2005, *The New York Times Magazine* ran a story by food writer Amanda Hesser on sous vide cooking that mentioned that food prepared sous vide had found a place on the menus of some of the city's fine restaurants. Officials at the health department must have noticed because, in the first quarter of 2006, they conducted raids on many fine restaurants, confiscating and discarding any food in vacuum-packed plastic bags—even dry goods or spices. Inspectors tagged vacuum-packing machines as "illegal" and threatened to close restaurants in which chefs continued to cook sous vide. These actions made no scientific sense, but the New York City health department has a Mafia-like reputation among chefs, and they raised few objections for fear their establishments would be subject to harassment and even closure.

The great irony here is that the FDA had already formulated and published standards for sous vide at the time of the raids. Why couldn't the city just adopt those standards? Did health-department officials believe that pathogens act differently in New York City than they do in the rest of the country? After months of debate and complaints, New York City adopted a draconian set of regulations that include, among other measures, the requirement that chefs submit HACCP plans (see page 195) to get a permit to cook sous vide. The rules also imposed excessively high temperature standards, making it impossible to prepare fish sous vide without overcooking it. The reason? A fear of contaminants in undercooked fish—in a city that has thousands of sushi bars that serve fish completely raw.

Above 72 °C / 162 °F, the data points inexplicably deviate from a log-linear relationship of time and temperature. Cooks need not worry about these deviations, however, because they'd need highly specialized equipment to heat liquids to 96 °C / 205 °F for only 0.05 seconds.

The FDA's more conservative time-and-temperature curve for ice cream reflects the fact that increased butterfat and egg content can make pathogens harder to destroy. For ice cream, the FDA requires cooking times as much as 24 times longer than those for milk at the same temperature. It remains unclear whether these longer times or the higher minimum temperature of 68 °C / 154 °F are justified.

Keep in mind that FDA standards primarily apply to foods "of animal origin." Fruit- and vegetable-based foods can be served raw or cooked at any temperature—but that doesn't necessarily mean they're pathogen-free and safe to eat. Indeed, most of the high-profile outbreaks of foodborne illness in recent years have been associated with foods of plant origin.

As a practical matter, the FDA can't require people to pasteurize their salads. So the agency has basically given up on regulating plant foods. The primary recommendation for plant foods specifies that, if you hold fruit- or vegetable-based foods hot before serving them, the temperature must be at least 57 °C / 135 °F.

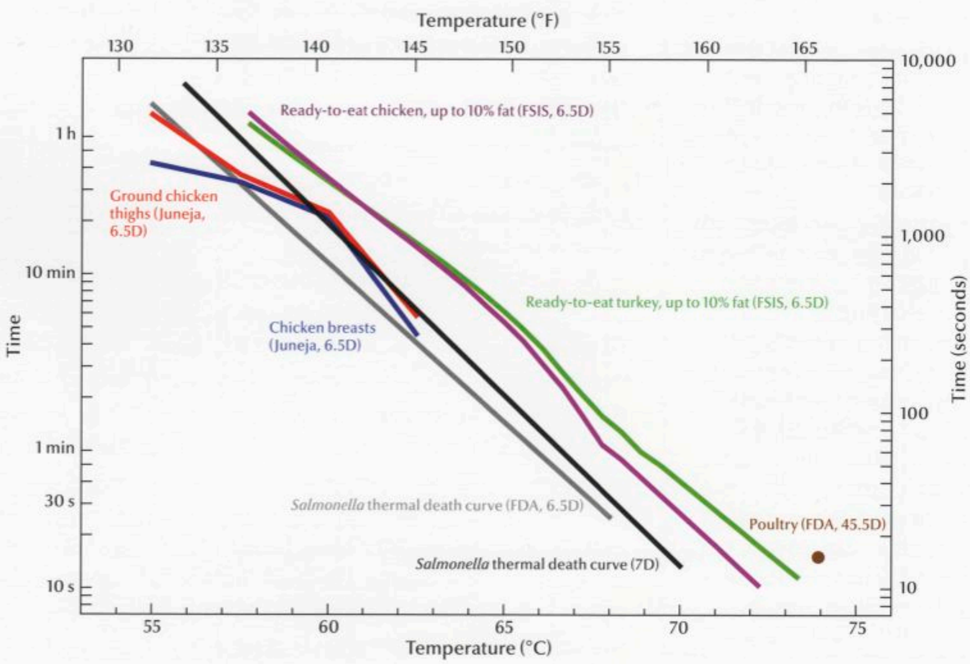
FDA regulations with regard to sous vide focus on two main requirements. First, the food must be cooked according to the same time-and-temperature specifications indicated for raw animal foods cooked using other methods. (You'll find that sous vide methods typically use temperatures on the low end of the recommended scale.) In addition, the FDA requires that food not be held in sous vide bags for prolonged periods at temperatures that encourage bacterial growth, in particular the growth of anaerobic spore-forming pathogens. Both regulations are quite reasonable and capture best practices very well.

Finally, the FDA has specific requirements for cooking in microwave ovens, ostensibly because the ovens may not heat food evenly and may therefore leave interior portions susceptible to pathogens. The FDA specifies that all raw animal food cooked in a microwave be heated to the excessively high temperature of 74 °C / 165 °F.

Once again, this rule has no basis in science. Although some microwave ovens, particularly those lacking a turntable, do cook unevenly, the same can be said of some conventional ovens and stove-top pans. A food does not suddenly become less safe when it enters a microwave oven. The job of the chef is to ensure proper cooking regardless of the vagaries of the method used.

What to Believe?

Government agencies have offered a range of contradictory recommendations for cooking poultry, as shown here. The FDA's standard 6.5D Salmonella reduction curve is shown in gray. The Food Safety and Inspection Service (FSIS) of the USDA recommends more conservative standards for ready-to-eat poultry products containing up to 10% fat (chicken standards in purple; turkey standards in green). More recent research by USDA scientists, however, has yielded less conservative recommendations for ground chicken thighs (red line) and breasts (blue line). The FDA, on the other hand, recommends cooking poultry for 15 seconds at 74 °C / 165 °F (brown dot), a ridiculously high temperature that is scientifically unsubstantiated.



SIMPLIFYING FOOD SAFETY WITH SCIENCE

The FDA's food safety rules are designed for commercial establishments in the United States, but what about home chefs or people in other jurisdictions? Our analysis of FDA requirements suggests that some simple modifications of the agency's code could yield food safety standards that are easier to follow and more scientifically sound. We formulated these simplified rules and present them in the tables on the following pages. On the opposite page, we summarize the philosophy behind the tables. It is up to you to determine whether our rules are appropriate for your own kitchen (see disclaimer at left).

Our philosophy broadly follows FDA guidelines with some exceptions. In a few cases, the simplified standards do not meet the FDA Food Code requirements, but in other cases, they are far more conservative.

The Extended and Simplified 6.5D *Salmonella* Reduction Table on page 193 shows the primary time-and-temperature listings for these simplified recommendations. For convenience, we list temperatures in small increments and in both Fahrenheit and Celsius. The highest temperatures, with their brief corresponding times, apply mostly to the blanching or searing of food exteriors.

We say that the table is "extended" as well as simplified because the first portion of the table extends the 6.5D reduction curve to temperatures lower than 54.4 °C / 130 °F. Although these parameters are below the threshold recommended by the FDA, they are supported by published scientific research.

The second portion of the table starts at 54.4 °C / 130 °F and follows the FDA table for roasts, except at 70 °C / 158 °F and above, where it follows the more logical 6.5D *Salmonella* reduction curve. You can use multipliers to obtain cooking times for different reduction levels from these figures. If you are comfortable with a lower safety margin and a reduction of 5D, for example, you can multiply the recommended cooking times by 5/6.5, or 0.77. If you want the increased safety margin of 7D, then multiply by 7/6.5, or 1.077. As discussed above, many food safety authorities think that pasteurization to the 4.5D level is sufficient. That would reduce the cooking times discussed here by about 30%. Our view is that 30% is a small enough difference that you might as well cook to the 6.5D standard. Another way to look at this is that, by cooking to 6.5D, you are adding a safety factor in case there are errors in your timing or temperature.

We provide two different sets of guidelines for cooking poultry; each ensures a reasonable level of safety. One approach is to simply cook it like any other food according to the recommendations in the Extended and Simplified 6.5D *Salmonella* Reduction Table. A second approach is to follow the thermal death curves Juneja published in 2007 for *Salmonella* in ground chicken breast and thighs (see Poultry Breast and Thigh Curves, page 193). At 55 °C / 131 °F, Juneja's results call for a cooking time of 39 min 31 s for chicken breast meat, which is substantially less than the 1 h 31 min recommended in our primary simplified table. At 60 °C / 140 °F, however, Juneja's data calls for cooking times substantially longer than those for a 6.5D reduction.

In general, you are likely better off using the recommendations in our primary table for most temperatures; those who prefer the texture and taste of poultry, particularly chicken breast, cooked at low temperatures may want to select the more accommodating range of the Simplified Poultry table on page 193.

In our Simplified Dairy table (page 194), the general dairy curve follows the standard LTLT and HTST pasteurization times; intervening points have been interpolated for your convenience. The ice cream and sweet or high-fat dairy recommendations are similar to those for general dairy but encompass higher temperatures. The table reflects standard practices for dairy pasteurization, and, in most cases, abiding by these standards is not onerous. You can extend these parameters to lower temperatures if you deem it necessary to enhance taste or texture.

Anisakid nematodes are a food safety threat that occurs with inshore saltwater fish in areas

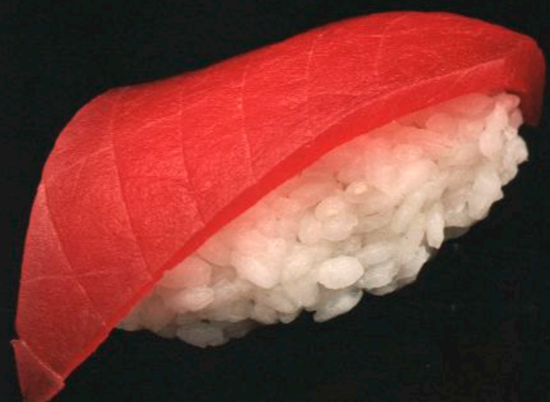
DISCLAIMER:

This book cannot and does not substitute for legal advice about food regulations in the United States as a whole or in any U.S. legal jurisdiction. Nor can we guarantee that following the information presented here will prevent foodborne illness. Unfortunately, the many variables associated with food contamination make eliminating all risk and preventing all infections virtually impossible. We cannot accept responsibility for either health or legal problems that may result from following the advice presented here. If you operate a commercial establishment and serve food to the public, consult the rules and health regulations in your area.

THE 10 PRINCIPLES OF

Our Food Safety Philosophy

1. All foods carry some risk of contamination and thus of foodborne illness. The only way to have zero risk is not to eat any food at all.
2. The goal of food safety rules is to manage risk in a sensible way that accords with your preferences. As an example, overcooking meat in the name of making it safe but serving it with a raw salad that may be more risky than raw meat is an inconsistent way to manage your risks.
3. The risks faced by susceptible people, including infants, the elderly, and people with compromised immune systems, are different from those faced by healthy people, and you should adjust the tradeoffs accordingly.
4. Almost all food can be served raw, but raw food always confers a higher risk of foodborne illness than cooked food. A good supplier and good hygiene can help you minimize that risk. Meat that you intend to serve raw must be sourced from commercially licensed farms. Heating raw fruit or vegetable salads to kill potential pathogens would reduce the risk of infection but ruin the food; either accept the risk or don't eat the salad. Likewise, eating raw filter-feeding mollusks such as oysters always poses some risk of foodborne illness.
5. Most food is safest if you heat the core to a specific temperature for an allotted length of time, as specified in the Extended and Simplified 6.5D *Salmonella* Reduction Table on page 193. This procedure is recommended for most cooked food, including meat that is mechanically tenderized without having had its surface pasteurized. Apart from a few examples discussed below, this approach produces good results in terms of food quality and provides a solid margin of safety.
6. The surface of intact muscles from commercially raised mammals (steaks or roasts) should be cooked enough to yield a 6.5D reduction in pathogens according to the standards specified in the Extended and Simplified 6.5D *Salmonella* Reduction Table. Searing or blanching will accomplish this reduction. Because most contamination originates externally, you can safely leave the interior of intact muscle raw or cook it to any temperature you desire.
7. Fish and other seafood are safer if cooked to the standards specified in the Extended and Simplified 6.5D *Salmonella* Reduction Table, but in most cases following those recommendations will leave them unacceptably overcooked. As an alternative, fish can be served raw or cooked at lower temperatures, which poses some risk. Fish that are prone to infection with anisakid nematodes can be frozen first (see Simplified Fish Freezing Recommendations, page 194) to eliminate that (very small) risk.
8. Eggs served raw or cooked less than recommended in the Extended and Simplified 6.5D *Salmonella* Reduction Table carry some risk. Using pasteurized eggs is a better approach than using raw or lightly cooked eggs (see page 4·78). Cooking with pasteurized eggs is easy, and they work well in any recipe from mayonnaise to meringue.
9. Poultry is no different from other meats. You can serve it safely if it's cooked to the core temperatures and times in the Extended and Simplified 6.5D *Salmonella* Reduction Table. You can also use the Simplified Poultry table on page 193 for time-and-temperature combinations specific to chicken breasts and thighs.
10. The Simplified Dairy table on page 194 includes an expanded set of time-and-temperature recommendations for dairy pasteurization. The general dairy listings and those for sweet or high-fat dairy products both follow FDA specifications, but we suspect that temperatures in the latter category may be unnecessarily high.



Tuna and farmed fish are exempt from the FDA rule requiring that all species of fish that are susceptible to nematodes be frozen before service.

Simplified Cooking Standards Based on Science

Food	Cooking standard		Note
intact muscles (steaks or roasts) from: commercially farmed beef, pork, lamb, or game meats; duck or squab breasts; ratites (ostrich, emu)	bring exterior to desired cooking temperature and hold there for time specified in Extended and Simplified 6.5D *Salmonella* Reduction Table (see next page); no time-and-temperature standard for interior		achieves a much higher pathogen reduction level than the FDA requires for beef steak; not appropriate for wild game or other food that may harbor parasites
wild game meat injected or marinated meats egg dishes (quiche, soufflé) ground or minced fish, shellfish, or meats, including farmed game meat pâtés, forcemeats, casseroles	cook core to the temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		core temperature is appropriate for wild game or ground or mixed meats
tuna farmed salmon wahoo, dorado, mahi-mahi, marlin, swordfish, and other blue-water fish that do not harbor anisakid nematodes freshwater fish	serve raw, or cook at any time-and-temperature combination		recommendation is valid only for fish species known not to contain parasitic nematodes
wild salmon cod, flounder, fluke, haddock, halibut, herring, mackerel, monkfish, pollack, rockfish, sole, sea bass, turbot other inshore saltwater fish	prefreeze according to Simplified Fish Freezing Recommendations, then serve raw or cook at any temperature		the best temperature at which to cook fish for optimum taste and texture is generally less than that specified in food safety guidelines
	core temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		
crab, lobster, shrimp	raw (if you started with a live crustacean)		raw crustaceans carry some contamination risk from seawater; this risk can be minimized or eliminated by hot-water blanching or by cooking the core to a temperature specified in Extended and Simplified 6.5D *Salmonella* Reduction Table
	blanch in hot water to cook exterior to Extended and Simplified 6.5D *Salmonella* Reduction Table, then cook at any temperature		
	core temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		
poultry (whole)	core temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		see text for discussion
poultry (parts)	see Simplified Poultry table		see text for discussion
clams, oysters, and other filter-feeding shellfish	raw (with some risk)		filter feeders can absorb pathogens from contaminated water
	core temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		
eggs	raw (with some risk)		pasteurized eggs are the best bet and can be served in any style
	pasteurized		
	core temperature provided in Extended and Simplified 6.5D *Salmonella* Reduction Table		
dairy pasteurization	for general dairy, heat according to left side of the Simplified Dairy table		the recommendations given in the Simplified Dairy table are likely excessive but meet current standards
	for high-fat or sweet dairy foods (including ice cream), heat according to the recommendations on the right side of the Simplified Dairy table		
sous vide holding times for cooked food	5 °C / 41 °F	72 h	cooking follows same time-and-temperature combinations as those for low-temperature cooking by other methods
	1 °C / 34 °F	30 d	
	–20 °C / –4 °F	unlimited	
sous vide holding times for raw food	5 °C / 41 °F	14 d	sealed in vacuum-packed sous vide bags
	1 °C / 34 °F	30 d	
	–20 °C / –4 °F	unlimited	

Extended and Simplified 6.5D *Salmonella* Reduction Table

The table at right incorporates FDA-recommended cooking times (bounded in red) for meat roasts for temperatures from 54.4–68.9 °C / 130–156 °F, and it extends the times to both higher and lower temperatures by using the 6.5D thermal death curve for Salmonella. Times are given in hours (h), minutes (m), and seconds (s).

°C	°F	Time
52.0	125.6	5h 14m
52.2	126.0	4h 46m
52.8	127.0	3h 48m
53.0	127.4	3h 28m
53.3	128.0	3h 1m
53.9	129.0	2h 24m
54.0	129.2	2h 17m

°C	°F	Time
54.4	130.0	1h 54m
55.0	131.0	1h 31m
55.6	132.0	1h 12m
56.0	132.8	1h
56.1	133.0	57m 31s
56.7	134.0	45m 44s
57.0	134.6	39m 51s
57.2	135.0	36m 22s
57.8	136.0	28m 55s
58.0	136.4	26m 23s
58.3	137.0	23m
58.9	138.0	18m 17s
59.0	138.2	17m 28s
59.4	139.0	14m 32s
60.0	140.0	11m 34s

°C	°F	Time
60.6	141.0	9m 12s
61.0	141.8	7m 39s
61.1	142.0	7m 19s
61.7	143.0	5m 49s
62.0	143.6	5m 4s
62.2	144.0	4m 37s
62.8	145.0	3m 41s
63.0	145.4	3m 21s
63.3	146.0	2m 55s
63.9	147.0	2m 19s
64.0	147.2	2m 13s
64.4	148.0	1m 51s
65.0	149.0	1m 28s
65.6	150.0	1m 10s
66.0	150.8	58s

°C	°F	Time
66.7	152.0	44s
67.0	152.6	39s
67.8	154.0	28s
68.0	154.4	26s
68.9	156.0	18s
70.0	158.0	11s
71.1	160.0	7.1s
72.2	162.0	4.5s
75.0	167.0	1.4s
76.7	170.0	0.7s
77.0	170.6	0.6s
79.4	175.0	0.23s
80.0	176.0	0.18s
82.2	180.0	0.07s
85.0	185.0	0.02s

Sous Vide Table

°C	°F	Time
55	131	7h
56	133	4h 37m
57	135	3h
58	136	2h
59	138	1h 20m
60	140	50m
61	142	33m
62	144	21m
63	145	15m
64	147	11m
65	149	10m

When using low cooking temperatures, remember that an accurate thermometer is critical because even small temperature changes can require sizeable differences in the corresponding cooking times.

When cooking sous vide at equilibrium, pasteurization will occur if the food takes at least as much time as shown in the table at left to reach the core temperature given. No additional holding time is required to achieve a 6.5D reduction.

If cooking for shorter than the time listed at left, or if using a hotter-than-core approach, hold the food at the target temperature for the time shown in the table at above right.

Simplified Poultry Breast and Thigh Table

Breast

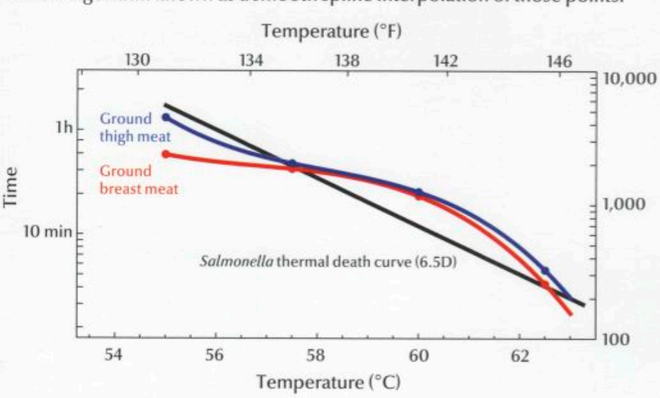
°C	°F	Time
55.0	131.0	39m 31s
55.6	132.0	36m 35s
56.0	132.8	34m 55s
56.1	133.0	34m 35s
56.7	134.0	33m 4s
57.0	134.6	32m 16s
57.2	135.0	31m 43s
57.8	136.0	30m 14s
58.0	136.4	29m 32s
58.3	137.0	28m 22s
58.9	138.0	25m 58s
59.0	138.2	25m 25s
59.4	139.0	22m 59s
60.0	140.0	19m 30s
60.6	141.0	15m 42s
61.0	141.8	12m 39s
61.1	142.0	11m 54s
61.7	143.0	8m 24s
62.0	143.6	6m 34s
62.2	144.0	5m 29s
62.8	145.0	3m 17s
63.0	145.4	2m 36s

Thigh

°C	°F	Time
55.0	131.0	1h 15m
55.6	132.0	57m 39s
56.0	132.8	48m 57s
56.1	133.0	47m 14s
56.7	134.0	40m 30s
57.0	134.6	37m 34s
57.2	135.0	35m 56s
57.8	136.0	32m 32s
58.0	136.4	31m 22s
58.3	137.0	29m 42s
58.9	138.0	27m
59.0	138.2	26m 27s
59.4	139.0	24m 8s
60.0	140.0	20m 56s
60.6	141.0	17m 24s
61.0	141.8	14m 27s
61.1	142.0	13m 42s
61.7C	143.0	10m 5s
62.0	143.6	8m 5s
62.2	144.0	6m 51s
62.8	145.0	4m 15s
63.0	145.4	3m 24s

Poultry Breast and Thigh Curves

The most recently published time-and-temperature recommendations by Juneja for cooking ground chicken breasts and thighs are presented in the table at right and in the graph below. The red curve plots time-temperature combinations for breasts, the blue curve for thighs; both curves roughly follow the FDA's standard curve for a 6.5D reduction in *Salmonella* for whole-meat roasts (black line). At temperatures below 57.5 °C / 135.5 °F, however, the recommendations by Juneja are less conservative, particularly for chicken breast meat. His recommendations between 57.5 °C and 62.5 °C / 135.5 °F and 144.5 °F, on the other hand, are more conservative than the FDA's general standard and require significantly longer cooking times. Although the original Juneja paper includes only four data points, we compiled this graph and the Simplified Poultry table at left by using a mathematical algorithm known as a smooth spline interpolation of those points.



Simplified Dairy Pasteurization Recommendations

Pasteurizing General Dairy Products			
Temperature		Time	
(°C)	(°F)	(min)	(s)
62.8	145.0	33	46
63.0	145.4	30	00
63.3	146.0	25	08
63.9	147.0	18	42
64.0	147.2	17	37
64.4	148.0	13	55
65.0	149.0	10	21
65.6	150.0	7	42
66.0	150.8	6	05
66.1	151.0	5	44
66.7	152.0	4	16
67.0	152.6	3	34
67.2	153.0	3	10
67.8	154.0	2	22
68.0	154.4	2	06
68.3	155.0	1	45
68.9	156.0	1	18
69.0	156.2	1	14
69.4	157.0		58
70.0	158.0		43
70.6	159.0		32
71.0	159.8		26
71.1	160.0		24
71.7	161.0		18
72.0	161.6		15
72.2	162.0		13
72.8	163.0		9.9
73.0	163.4		8.8
73.3	164.0		7.4
73.9	165.0		5.5
74.0	165.2		5.2
74.4	166.0		4.1
75.0	167.0		3.0
75.6	168.0		2.3
76.0	168.8		1.8
76.1	169.0		1.7
76.7	170.0		1.3
77.0	170.6		1.0
77.2	171.0		0.9
77.8	172.0		0.7
78.0	172.4		0.6
78.3	173.0		0.5
78.9	174.0		0.4
79.0	174.2		0.4
79.4	175.0		0.3
80.0	176.0		0.2

Pasteurizing Ice Cream and Sweet or High-Fat Dairy Products			
Temperature		Time	
(°C)	(°F)	(min)	(s)
68.0	154.4	34	38
68.3	155.0	30	00
68.9	156.0	23	37
69.0	156.2	22	31
69.4	157.0	18	35
70.0	158.0	14	38
70.6	159.0	11	31
71.0	159.8	9	31
71.1	160.0	9	04
71.7	161.0	7	08
72.0	161.6	6	11
72.2	162.0	5	37
72.8	163.0	4	25
73.0	163.4	4	01
73.3	164.0	3	29
73.9	165.0	2	44
74.0	165.2	2	37
74.4	166.0	2	09
75.0	167.0	1	42
75.6	168.0	1	20
76.0	168.8	1	06
76.1	169.0	1	03
76.7	170.0		50
77.0	170.6		43
77.2	171.0		39
77.8	172.0		31
78.0	172.4		28
78.3	173.0		24
78.9	174.0		19
79.0	174.2		18
79.4	175.0		15
80.0	176.0		12
80.6	177.0		9.3
81.0	177.8		7.7
81.1	178.0		7.3
81.7	179.0		5.8
82.0	179.6		5.0
82.2	180.0		4.5
82.8	181.0		3.6
83.0	181.4		3.2
83.3	182.0		2.8
83.9	183.0		2.2
84.0	183.2		2.1
84.4	184.0		1.7
85.0	185.0		1.4
85.6	186.0		1.1

where seals or other marine mammals are present. These fish include salmon, halibut, and sea bass found in most temperate parts of the world. There are two points of view on the anisakid threat. On the one hand, it is easy to find fish that have living worms in them—we have found them in fish sold by quality merchants in the Seattle area, and we have little doubt that they exist more broadly. On the other hand, experts estimate that fewer than 10 cases of anisakiasis occur each year on average in the United States, a country with more than 300 million people, so it is clearly a very rare condition. Under most circumstances, swallowing the worms does not result in any illness.

If you decide that you care about this threat, then you must freeze fish that might contain anisakid nematodes to kill the worms, as detailed in our Simplified Fish Freezing Recommendations table below. Frozen fish does not generally require any additional treatment. Freezing in liquid nitrogen at −195 °C / −320 °F or using ultralow-temperature freezers ranging from −150 °C to −40 °C / −240 °F to −40 °F is even more effective than freezing at the temperatures we list in that table and probably reduces the holding time needed. Unfortunately, no published reports have quantified just how little time in the freezer suffices to ensure that fish is safe to eat.

Simplified Fish Freezing Recommendations

Temperature			
(°C)	(°F)	Time	Note
-20	-4	7 d	core temperature should be brought to specified temperatures and held there
-35	-31	15 h	
-35 to -20	-31 to -4	1 d	initial freezing to core temperature of -35 °C / -31 °F, then holding at -20 °C / -4 °F

THE BASICS OF

Hazard Analysis and Critical Control Point Assessment

Hazard Analysis and Critical Control Point (HACCP) assessment is a method for analyzing the steps used in preparing food and for correcting any procedures that might prove hazardous. The HACCP method originated with the National Aeronautics and Space Administration (NASA), which required a hazard-assessment protocol when Pillsbury, a division of food-product corporation General Mills, began producing food for NASA astronauts. A committee of the U.S. Institute of Medicine credited USDA's broad implementation of HACCP rules, combined with pathogen-reduction standards targeting *Salmonella* in meat and poultry plants, with helping to reduce the incidence of foodborne disease in the United States between 1996 and 2002.

Although a full explanation of HACCP is beyond the scope of this book, we can provide a brief introduction to its principles for those who have heard the term and have wondered what it means. The protocol is actually part of an international standard for industrial-scale food safety and management called ISO 22000. But HACCP assessment is a useful concept for all cooks because it forces them to think systematically about how they make food and what could go wrong. It comprises the following principles:

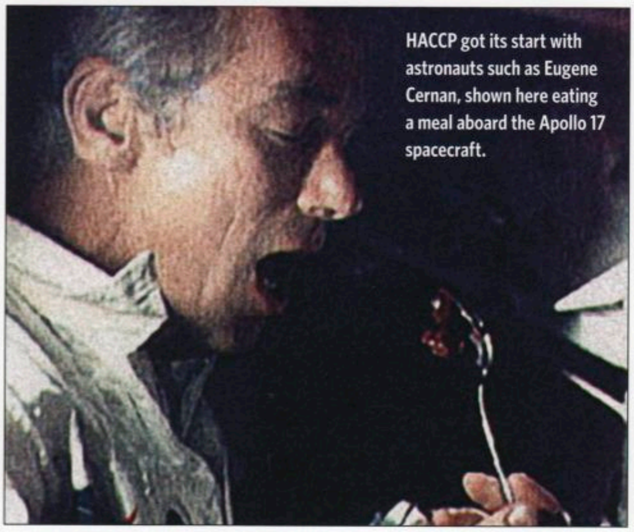
1. Conduct a hazard analysis. Review each step in food preparation and cooking processes to identify where and when food safety hazards might appear.
2. Find critical control points. These are the steps in the production process during which problems such as unsafe temperatures or contamination could occur.
3. Create critical safety limits. Establish a limit, such as a temperature or time minimum, a time-and-temperature combination, or a use-by date, for each critical control point in the production process.
4. Set critical control point monitoring procedures. Make a plan to ensure that the critical control points stay within their safety limits.
5. Define corrective actions. These rules spell out what to do when a critical control point limit is not met.
6. Keep records. Record-keeping should encompass all aspects of the HACCP plan: the control points, their limits, monitoring procedures, and corrective actions.
7. Validate. Devise a way to measure end points or results that show the HACCP system is working as planned.

As you can see, HACCP is about planning and documenting food production in a very detailed way. It's required for all commercial food factories and for New York City restaurants that use sous vide cooking (see The New York Sous Vide Hysteria, page 188), although it's not generally appropriate for restaurants.

Just as building a large structure without a full set of blueprints would be foolhardy, an incomplete HACCP plan would be hard to execute properly. But just as the blueprints don't guarantee architectural success, no food safety plan can work if it isn't followed, and a faulty plan can be problematic even if followed religiously. Food prepared under an HACCP plan is not intrinsically safer just because the plan is in place. But the discipline of creating an HACCP plan and following it can help prevent food safety problems that might otherwise occur.

HACCP, of course, is not infallible. Two major outbreaks of foodborne illness in the United States—one linked to *Escherichia coli*-contaminated spinach in 2006 (see The *E. Coli* Outbreak of 2006, page 172) and another to *Salmonella*-contaminated peanut butter in 2009—were ultimately traced to large, regularly inspected plants with HACCP plans. In fact, the spinach contamination was potentially worsened by a critical control point procedure: washing the leaves. The wash water spread contaminants from a few leaves to all the rest.

Because HACCP is about detailed planning and documentation of things that cooks do naturally, it may strike you as overly regimented and bureaucratic. Good chefs do the equivalent of critical point monitoring when they sniff milk to see if it has soured or when they check the use-by date on food stored in a freezer. Remember that HACCP was intended for large factories, not restaurants, and certainly not home chefs. Nevertheless, the protocol has been made to work in restaurants now that some local authorities require it.



HACCP got its start with astronauts such as Eugene Cernan, shown here eating a meal aboard the Apollo 17 spacecraft.

HYGIENE

Of all the miracle cures and preventive wonders medical science has wrought, none can match hygiene. Clean food and water are of vital importance to human health, and humanity is freed from a terrible burden of disease wherever good sanitation and adequate hygiene prevail.

Yet the uncomfortable fact remains that, even in the developed countries of the world, we live surrounded by contamination, much of it fecal contamination. "We're basically bathed in feces as a society," writes New York University microbiologist and immunologist Philip Tierno, Ph.D. in his 2001 book, *The Secret Life of Germs: Observations and Lessons from a Microbe Hunter.*

Contaminants in fecal matter cause the vast majority of foodborne illness. Hygiene is the first line of defense against these pathogens.

Of course, no one thinks that eating feces is a good idea. But all too often, despite knowing better, we fail to pay enough attention to hygiene, both our own and our kitchen's. Most of the roughly 80% of foodborne illness that is caused by fecal contamination of food could be eliminated with proper hygiene.

Good hygiene is critical wherever food is prepared or eaten. In a restaurant setting, maintaining excellent hygiene minimizes the risk of contaminating your customers' food, making them ill, and going out of business. For a home cook, the stakes are just as high. Tierno notes that an estimated 50%–80% of all foodborne illness is contracted in the home. Food safety hygiene isn't just the concern of professionals.

Why might otherwise conscientious cooks overlook simple hygiene measures? Perhaps these measures seem *too* simple to be of great importance. Hand washing, for example, is the single best defense against foodborne illness, yet it's often among the first tasks to be jettisoned in a busy kitchen. Most people know that dirty hands can lead to disease; they just don't appreciate the magnitude of the risk. And cooks tend to forget how much food is actually handled in a kitchen—especially in the kitchen of a high-end restaurant, where fancy meals and elaborate presentations demand that food be extensively manipulated.

What counts as good hygiene depends in part on the kind of food you're preparing. If you're making food that will be cooked through, a bit of hair or dead skin will quickly become pasteurized and won't make anyone sick. But if you're handling raw fish, ice cream bases, or other food that has a high probability of making someone ill, you must maintain the highest standards of hygiene.

We don't mean to suggest that food hygiene is easy just because it's simple. Implementing proper hygiene procedures requires unfailing discipline and keen attention to detail. It's our intention in the remainder of this chapter both to inform you and to inspire you to maintain these procedures until they become deeply ingrained habits. It's impossible to eliminate all germs on the food you prepare. But you can greatly improve the safety of food by focusing on a few critical aspects of personal hygiene, kitchen hygiene, and temperature control.

Personal Hygiene

The fact cannot be overstated: consistently maintaining good hand hygiene throughout the day is one of the most important things a chef can do to reduce the risk of foodborne illness. In a kitchen, fecal contamination is almost always abetted by dirty hands. Yet hand washing presents a disproportionate challenge.

It's not that cooks don't understand the necessity of hand washing. Most just don't realize how thorough they must be to do it right. People almost always miss their thumbs when they wash their hands, for instance, and they rarely wash long enough to achieve the desired effect. Tierno recommends washing your hands for as long as it takes to sing the song "Happy Birthday" twice through (about 30 seconds).

Washing your hands well *most* of the time won't do. Nor will washing your hands *almost* every time you go to the bathroom or start a new preparation step. You must wash your hands properly every single time they might be contaminated, even if that means dozens of times a day. If that adds a burdensome amount of time to your daily schedule, then so be it. Proper hand washing is not optional. Surgeons accept that scrubbing up is part of their job. Chefs should do the same.

Proper hand washing includes scrubbing your fingernails with the kind of plastic nailbrushes that surgeons use. The brushes are deceptively soft but ruthless to germs and great at removing dirt in otherwise hard-to-reach spots. Indeed, you can tell if a restaurant is serious about hygiene by whether its workers use fingernail brushes when washing their hands. Many places don't use brushes, because the staff washes up in the same bathrooms as the patrons and the proprietors don't want to leave the brushes lying around. But that's no

The residue of UV powder on a poorly washed hand fluoresces under ultraviolet light, showing areas where potential contaminants could remain.

excuse. Store the brushes under the sink; alternatively, chefs can carry them in their pockets.

The single most important time to wash your hands is after using the bathroom. It seems ludicrous to have to spell that out, and yet disease statistics indicate that in most cases the food isn't intrinsically contaminated; rather, it becomes contaminated with the feces of the people who handle it. Even if you're feeling perfectly fine, wash your hands very carefully after going to the bathroom. If you're not feeling well, you should probably not cook for other people.

Next in importance is to wash your hands after every preparation step that could lead to cross-contamination. The lettuce from the farmer's market could have contaminated dirt or animal feces clinging to it; so could the leeks. Whole eggs or whole chickens could be covered with bacteria. Wash your hands after you handle one food and before you handle the next. You must also make sure proper hygiene extends to everything else in the kitchen that touches the food: utensils, cutting boards, counters, and other kitchen tools and surfaces.

One myth in food safety is that meat and seafood are inherently more risky than plant foods. Remember that fecal contamination is the main culprit in foodborne illness and that produce is just as likely to carry it as meat and seafood are. Fecal contaminants can wind up on strawberries, spinach, or peanuts just as easily as on meat; indeed, each of those vegetables has in recent years caused a major outbreak of one of the dangerous strains of *E. coli*. And contaminated plant foods such as berries, green vegetables, and nuts carry an additional risk, because they are much more likely to be consumed raw than are meat and seafood. Proper hygiene is just as

To manipulate some foods, many high-end chefs are borrowing another hospital-based tool: surgical tweezers. Tweezers of this kind provide a safe alternative to handling food, as long as you sanitize them with a bleach solution between uses.

HOW TO Wash Your Hands Properly

Clean hands are the most important accompaniment to any meal, and proper hand washing is the first step to ensuring that your customers leave your establishment as healthy as when they came in. So pay close attention when you wash your hands, and learn these basic steps to get it right.

1 **Turn on the water using a knee or foot pedal.** If you must touch a faucet, use a single-use paper towel to turn the water on.

2 **Wet your hands thoroughly with warm running water.** Use a gushing stream, not a trickle.

3 **Soap for at least 20 s.** Be sure to clean your thumbs, the backs of your hands, and between your fingers.

4 **Scrub your nails with a brush.** It's the only reliable way to get at germs under your fingernails and cuticles.

5 **Clean well up your wrists.** Contaminants that have worked their way up your sleeves can just as easily work their way down again.

6 **Rinse all the soap off.** Start at your wrists and move toward your fingertips. When all the soap is gone, keep rinsing for a few seconds more. The entire washing process should last at least 30 s.

7 **Dry your hands with a paper towel or an electric blower.** If the faucet is hand operated, use a paper towel to turn it off.

Nailbrushes also work well at removing dirt from delicate foods such as mushrooms without damaging them.

This worthy admonition understates its cause. A more precise directive would be that employees must wash their hands correctly and thoroughly for 30 s or more, use a nailbrush, and avoid touching faucet handles, soap dispensers, and doorknobs.

Most of the bacteria found in a kitchen are harmless. In fact, most fecal contamination is harmless, too. That's why we can live in a society "bathed in feces" and survive. But every now and then a pathogenic contaminant shows up in the kitchen. Thorough and consistent hygiene measures prevent that infrequent visitor from becoming widespread and causing an outbreak of foodborne illness.

Sometimes crowded conditions prevent you from using separate kitchen space to carry out delicate processing and handling procedures that invite contamination. In that case, isolate the procedures in time instead. Don't separate cooked meat into portions right next to another chef who's butchering raw meat, for example; pick another time to do your portioning.

important when you are handling plant foods as it is when you are preparing meat and seafood, despite perceptions to the contrary.

Gloves can aid proper hand hygiene, but to use them effectively you need to recognize their limitations as well as their advantages. The main advantage of gloves is very simple: people generally take them off before they go to the bathroom. That alone can make them worthwhile. Gloves also keep food out of contact with bacteria in pores or fissures in the skin, under the fingernails, and in other areas that are hard to clean even with proper hand washing.

But gloves aren't a panacea. Wearing gloves over filthy hands does very little good, because pathogens on your hands can easily contaminate them when you're putting them on or taking them off. You need to maintain proper hand hygiene even when you're wearing gloves.

You also need to change your gloves after every trip to the bathroom and every task that involves food products that could host contaminants. Yes, that means the number and expense of gloves can really add up, but no restaurant should be stingy in handing them out. Issuing one or two pairs per cook for an entire day is ineffective and creates a situation that is ripe for hygiene problems. Dirty gloves will quickly cross-contaminate other kitchen surfaces, just as dirty hands would.

Be aware also of the surfaces most likely to be contaminated, such as doorknobs—particularly the knob or handle of the restroom door. It's a good bet someone who used the restroom before you didn't wash up perfectly, or at all, and that knob or handle is the first place that person's dirty hands landed. Thus, the best hand washing job can be undone if you grab the doorknob next; use a paper towel to open the door, and discard it immediately after.

The same goes for water faucet handles: people usually touch them before they wash their hands, so they're often filthy with microbes. That's one reason automatic faucets were invented. Faucets with foot or knee pedals accomplish the same end. Automatic soap dispensers are also a good idea.

Crowded kitchens with few sinks might also benefit from alcohol sanitizers installed at every workstation. This practice is becoming increasingly common, but again, it's important to understand its limitations. Alcohol, for example, isn't always effective against viruses, such as the highly infectious norovirus, one of the leading causes of outbreaks of foodborne illness.

Kitchen Hygiene

Nothing in a kitchen stays sterile for very long. Nearly everything is covered in bacteria, even if it looks clean. According to Tierno, in fact, the two dirtiest items in a typical house are both found in the kitchen: the sink and the sponge. With so many microbes in so many places, preventing cross-contamination is a cook's constant concern.

Another common hygiene offender in a kitchen is the side towel. Many kitchens keep the same towel hanging near a workstation all day. That one towel wipes down counters, hands, and equipment and soon accumulates a disgusting buildup of food, bacteria, and yes, feces. No one would reuse a dirty diaper without cleaning it, yet a side towel, at the microscopic level, is just as revolting. The difference is that we can't see the teeming masses of germs on a towel, so we imagine that it's clean.

Side towels and dish towels should be used as nothing more than potholders. Change them regularly and launder them frequently. For wiping hands and other surfaces, restaurant chefs and home cooks alike should switch to disposable paper towels. Although they're more expensive, they're also far more hygienic.

Use a hygiene strategy for everything in the kitchen, not just hands and towels. Clean all cooking implements, equipment, and surfaces thoroughly and regularly: knives, pots, pans, spoons, spatulas, blenders, cutting boards, counters, and storage containers are just a few examples. A hot, sanitizing dishwasher is good for most small kitchen tools and containers or household utensils, dishes, and pans. Be sure that the dishwasher's temperature is high enough and that it does not run out of cleaning solution or detergent.

For many kitchen surfaces and tools, a dilute chlorine solution makes a great sanitizer. Household bleaches such as Clorox are 5.25% solutions, or 52,500 parts per million (ppm). Mix one tablespoon of Clorox per gallon of water (about 4 ml of bleach per l of water) to yield a solution that is roughly 200 ppm.

Make sure the bleach solution comes into contact with every surface of every container or utensil for at least two minutes. That may mean

THE TECHNOLOGY OF

The Telltale Glow

How can you tell if you've washed your hands well enough? One of the best ways is to cover your hands with lotions or powders that fluoresce under ultraviolet (UV) light but are otherwise invisible. Apply the lotion or powder, wash your hands as you normally would, and then check them with a UV light. You may be amazed to find that your presumably thorough hand washing leaves quite a bit of the UV lotion or powder—and, therefore, many kinds of potential contaminants—on your hands. Indeed, the primary value of this exercise is to show people that their customary hand-washing routine isn't as good as they think.

UV powder is also useful for tracking cross-contamination in a kitchen. Dust some on whole eggs, for example, then handle the eggs the way you normally would. Then check around the kitchen with a UV light. Any place the powder turns up is a place that *Salmonella* from the egg shells could also be lurking.

A top biomedical researcher told us the story of a memorable study he took part in while a medic in the US Navy. During a routine on-ship physical exam, Navy doctors swabbed some UV powder around the rectums of sailors without telling them what it was. The next day the doctors scanned the ship and its inhabitants with UV light. They found traces of UV powder everywhere: on handrails and doorknobs as well as all over the sailors' faces. The results literally illuminated the perils of poor hand washing.

A hand washed meticulously (below) shows no signs of UV powder, whereas a hand lightly washed (left) clearly fluoresces where the powder remains on the fingers and around the nails.

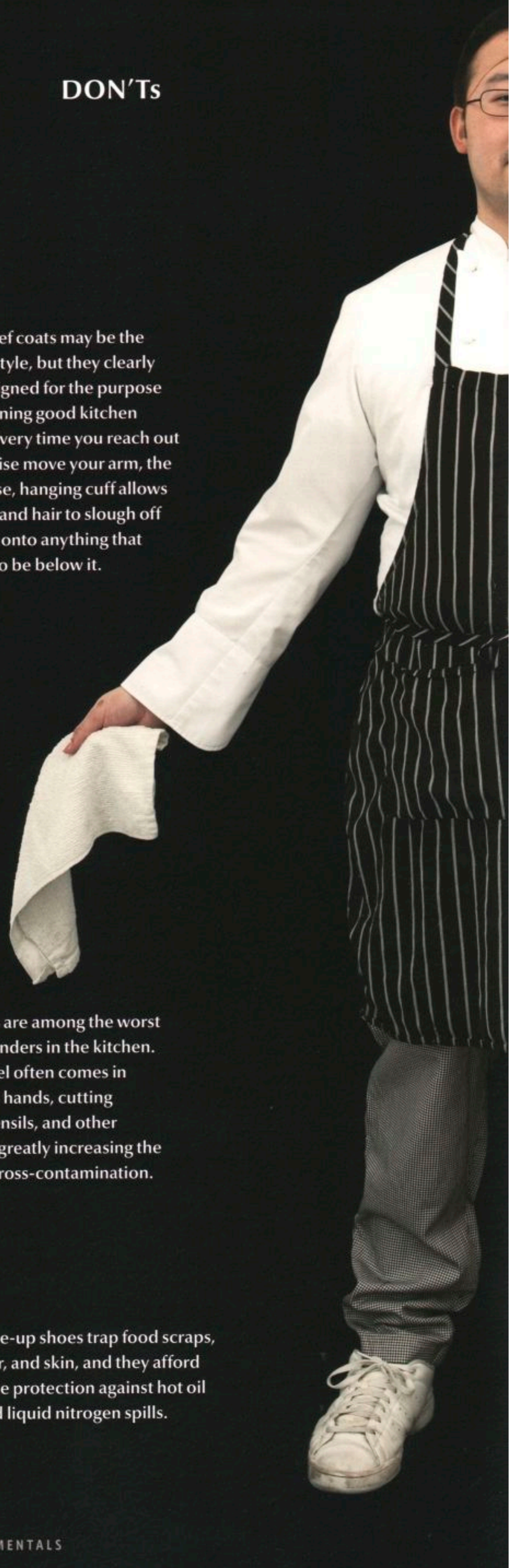
DRESSING FOR THE JOB: A CHEF'S HYGIENE ACCESSORIES

Cooks rightly worry about pots and pans, food and feces as potential sources of dangerous contaminants. But we are covered head to toe with another abundant source of contamination: the hair and skin shed so easily from our head, arms, face, and other body parts. Research by the Campden & Chorleywood Food Research Association in the United Kingdom suggests that people lose a staggering amount of skin every day, even though it's all but invisible to us. Cooks need to dress with this hazard in mind.

DON'Ts

Hairnets fail to control shedding. They do little more than keep the biggest hairs from falling into food and upsetting your customers.

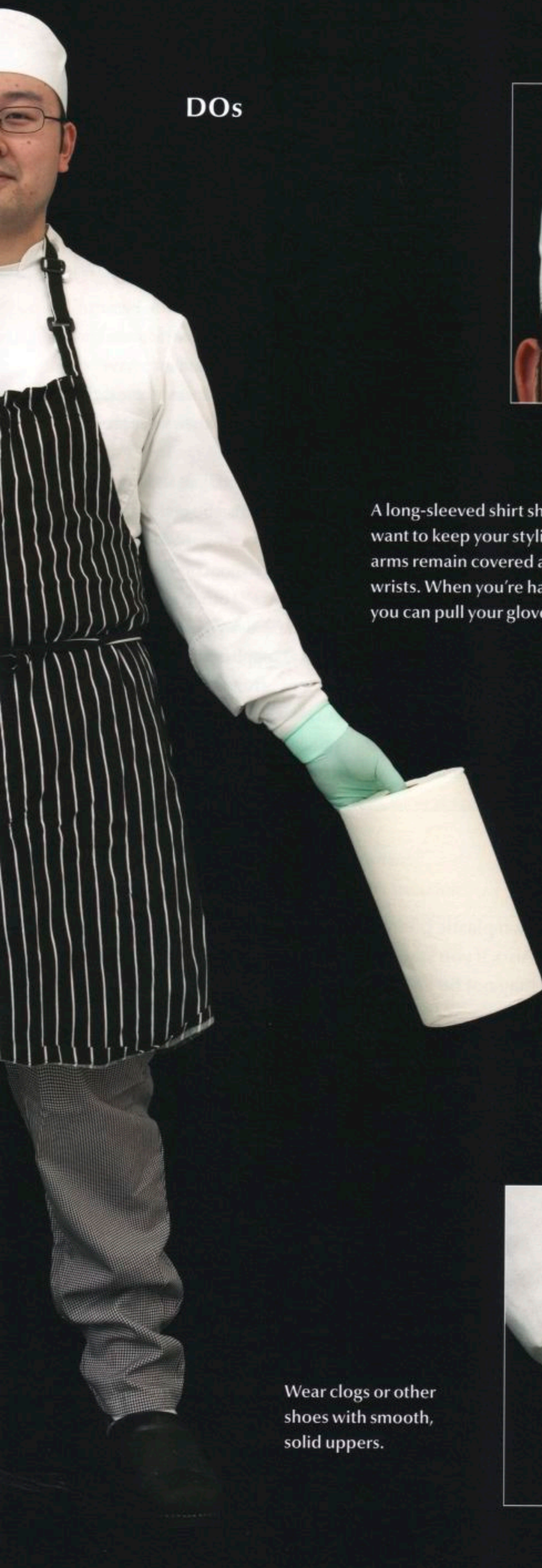
Take off rings, bracelets, and watches, which can trap contaminants and make it harder to clean your hands properly.



Typical chef coats may be the height of style, but they clearly aren't designed for the purpose of maintaining good kitchen hygiene. Every time you reach out or otherwise move your arm, the coat's loose, hanging cuff allows dead skin and hair to slough off and settle onto anything that happens to be below it.

Cloth towels are among the worst hygiene offenders in the kitchen. A single towel often comes in contact with hands, cutting surfaces, utensils, and other equipment, greatly increasing the chances of cross-contamination.

Lace-up shoes trap food scraps, hair, and skin, and they afford little protection against hot oil and liquid nitrogen spills.



DOs

Cooks who are serious about reducing sloughed-off hair and skin forgo hairnets entirely and instead wear surgical caps or the full paper hats favored by Japanese sushi chefs.

A long-sleeved shirt should be mandatory if you want to keep your stylish chef's coat, so that your arms remain covered all the way down to your wrists. When you're handling sensitive food items, you can pull your gloves up and over the sleeves.

Paper towels are more expensive but far more hygienic.

Wear clogs or other shoes with smooth, solid uppers.

A long shirt with elastic cuffs and gloves pulled over the cuffs, similar to a surgeon's outfit, is the uniform of choice in commercial food processing plants, which must maintain the strictest levels of hygiene. That may seem like overkill, but for easily contaminated foods such as sushi and ice cream, it isn't.

filling a bucket and completely submerging your tools in it or filling a lidded container halfway and then flipping it for another two minutes so that the parts of your implements that were previously exposed become submerged. It also means opening shears and other tools with mating surfaces before submerging them. After you drain the bleach solution, *do not rinse the implements or the holding container with water.* You will invariably recontaminate them if you do so. Don't use a towel to wipe off the implements, either. Let everything drip dry. Any residue of bleach that remains will be so faint that it will not affect the taste or the safety of food.

You might object that carbon-steel knives will rust if they're not thoroughly dried at the end of the night. If the knives won't be used again during a shift, you can wipe them dry with a paper towel, but it's a good idea to spray them again with the 200 ppm solution the next day and let them sit wet for two minutes before using them.

For heavy disinfection, use a 1% bleach solution, which will essentially kill bacteria on contact. This translates into a 525 ppm solution or, for typical household bleach, a 1:100 dilution with water (equivalent to 10 ml added to 1 l of water, or about three tablespoons of bleach per gallon of water). Put the solution in a spray bottle labeled for safety, and apply it directly to refrigerator shelves, counters, floors, and heavy-duty equipment like meat slicers for prompt and thorough disinfection.

Unlike the weaker version, this 1% solution requires a clean-water rinse to remove the bleach residue. The rinse requirement creates its own problem, of course. One work-around is to have a separate spray bottle of sterilized water; use it to spray down the bleached surface, then wipe the surface with a paper towel.

If you can't rinse the bleach off, you shouldn't use a 1% solution. You might also be understandably reluctant to use the heavier solution on stainless steel. Fortunately, major commercial suppliers such as Quantum sell other, equally effective chemical cocktails designed for sanitizing kitchen surfaces. A good supplier will be able to recommend bleach alternatives for stainless-steel counters and utensils. Avoid the cheaper products, as some can contaminate the flavor of meat.

Ultrasonic baths are fast, thorough, and nearly labor-free tools for cleaning small items. Jewelers use them to refresh the surface of precious metals, because the cleaning process is so gentle. In the kitchen, ultrasound provides a handy way to clean small, delicate parts, such as siphon nozzles and injection needles, that don't easily come clean with a soapy sponge.

THE CONTROVERSY OF

Cutting Boards: Wood or Plastic?

One timeless debate of food safety concerns the relative merits of wood versus plastic cutting boards. Both materials have their advantages and disadvantages, but we prefer wood. Plastic is easy to sanitize and run through a commercial dishwasher, and some versions are color-coded to help cooks segregate food and avoid cross-contamination. Because of these attributes, some jurisdictions permit only plastic boards.

Research suggests, however, that wood has natural antibacterial activity that helps to disinfect the board surface. True, water may not be able to permeate deep scratches and scars in the wood, due to surface tension. But cut wood secretes antimicrobial compounds that help keep those fissures clean. For the rest, you can scrub wood with salt as a scouring agent, then rinse it with a 200 ppm bleach solution.

Many kitchens soak their cutting boards in a bleach solution overnight. That's not appropriate for wood. But be aware that plastic floats, so to ensure proper sanitization you must weight down plastic boards until they're completely submerged. Also, if you stack the boards horizontally, the bleach solution may not be able to get between them.

A growing number of companies also sell ultraviolet light kits for sterilizing boards, knives, and other utensils. These kits use shortwave (UVC) ultraviolet light to kill up to 99.99% of most viruses, bacteria, and mold spores by damaging their DNA. Some handheld models sterilize surfaces with as little as 10 seconds of exposure. UV light can't kill germs in cracks or shadows, however, so turn food and equipment to expose all surfaces. Note that exposing food to UV light for too long can change the flavor, and you should minimize your own direct exposure to the light.

Some industrial food processors use HEPA (High Efficiency Particulate Air) ventilation hoods to maintain sterility while food is being handled. For the typical home or restaurant kitchen, these hoods may be too expensive to be practical.

Temperature Control

People do dumb things to their refrigerators and freezers. Studies show that some adjust their refrigerator temperatures based on the weather: down in hot weather and up in cold weather. Cooks who should know better store warm dishes on refrigerator shelves or linger in indecision at an open freezer door.

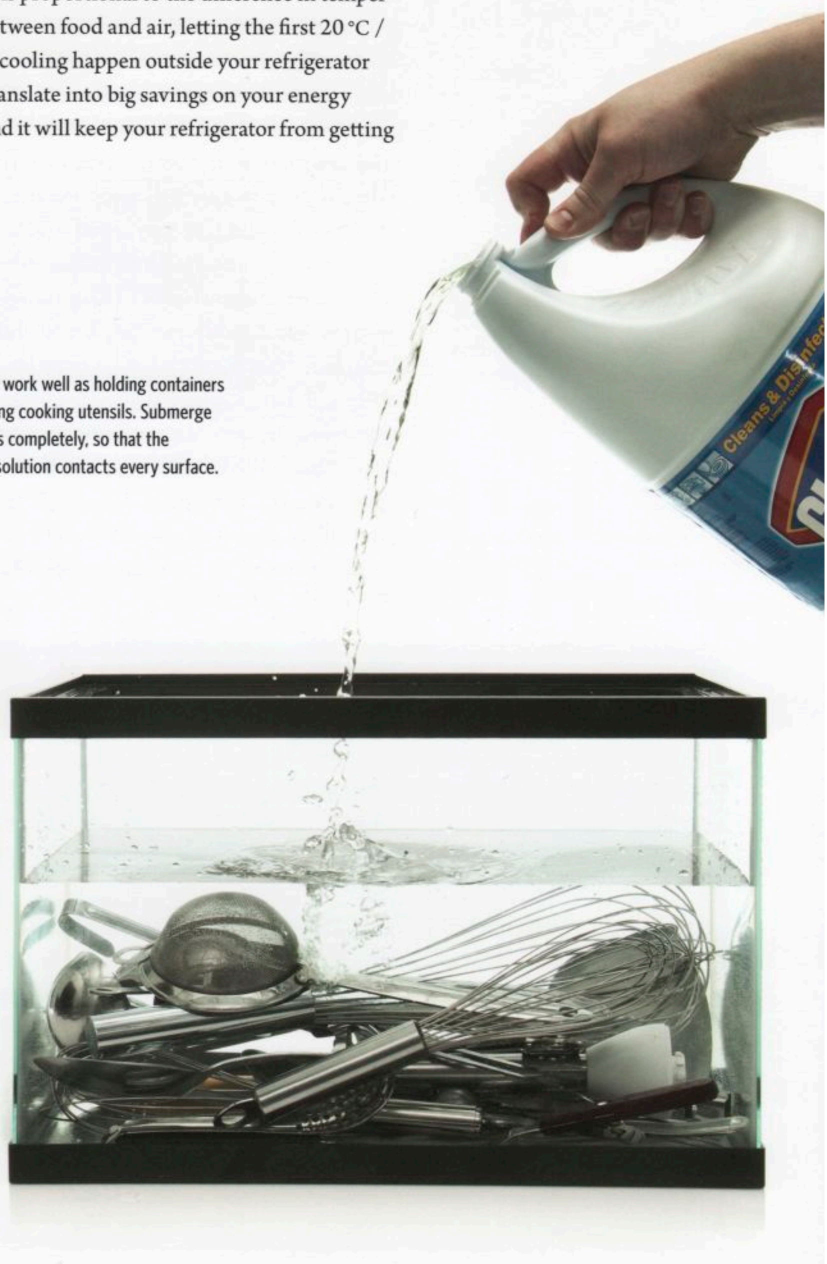
Refrigerators and freezers are somewhat delicate instruments, and keeping them functioning optimally is vital to food safety. Refrigerators in particular are prone to temperature spiking up to as much as 15 °C / 60 °F. If they lack fans to circulate air, their temperatures can vary from the top to the bottom shelves as well.

This is a special concern with some of the smaller, energy-efficient refrigerators popular in Europe. The temperature in these "passive" refrigerators can take hours to recover after a warm dish is placed on one of their shelves. Temperature swings are far less of a concern in freezers, because at the typical freezer temperatures of −20 °C / −5 °F, no microbes grow.

There are a few measures you can take to minimize temperature swings and variations in your refrigerator so that you can store your food as safely as possible. First, figure out the temperature differential in your refrigerator. No part of your refrigerator should be above 5 °C / 40 °F. Recognize that refrigerators with internal fans are better at maintaining an even temperature, so if your refrigerator lacks one, you can expect greater variation. If the only way to get your top shelf down to 3 °C / 37 °F is to have the bottom at a freezing temperature, so be it. Minimize the number of times you open the door, and close it again as quickly as possible. *And never put hot food in a refrigerator.*

Counterintuitive though it may seem, it's generally safest overall to cool hot food outside of your refrigerator. One common approach is to take advantage of the free cooling capacity of the air in your kitchen. Because the efficiency of heat transfer is proportional to the difference in temperature between food and air, letting the first 20 °C / 40 °F of cooling happen outside your refrigerator could translate into big savings on your energy bill—and it will keep your refrigerator from getting

When using low cooking temperatures, remember that an accurate thermometer is critical because even small temperature changes can require sizeable differences in the corresponding cooking times.



Aquariums work well as holding containers for sanitizing cooking utensils. Submerge the utensils completely, so that the bleaching solution contacts every surface.

Temperature spiking and internal variation are both big problems for storing sous vide foods. For more on this topic, see page 2·252.

For more on blast chillers and other freezers, see The Many Ways to Freeze, page 306.

For more on thermometer types and accuracies, see Measuring Temperature, page 269.

warm. Just cover the food to avoid contamination and don't leave it out for more than four hours.

The four-hour rule is a bit of a coarse metric, however, as we've already discussed. It is a lot safer to cool foods quickly. Use an ice bath or crushed ice in a sous vide bag. Even a dunking in cold tap water can be tremendously helpful.

Sous vide cook-chill—described in chapter 9, page 2·192 —is a great way to store critical food, because the food stays hermetically sealed after you pasteurize it. It is the best way, for example, to handle ice cream base, which otherwise is a classic contamination hazard (see Bug-Free Ice Cream below). Sous vide bags also lie flat and cool quickly.

If you're cooling lots of sauce or stock, pour it into a shallow container to increase the surface area. Generally speaking, a shallower pan equals a faster cooling time. If you cut the depth of the liquid by half, for example, you've cut the cooling time by a factor of four. You can also divide the sauce or stock among several smaller containers.

If you make a practice of chilling things often, consider getting a **blast chiller**. A blast chiller is to a refrigerator or freezer what a convection oven is to a regular oven: it speeds heat transfer by disrupting the layer of static air that insulates food. Blast chillers have large, powerful fans that move air across the food at high speed. They also have large compressors to provide sufficient cooling capacity. As the name implies, blast chillers cool food to refrigerator temperatures very quickly, and they can rapidly freeze food solid.

A challenge equal to maintaining consistently low temperatures within a refrigerator is that of trying to get a consistently accurate reading with most available thermometers. Few cooks recognize the dubious accuracy of thermometers; most believe them adequate for keeping careful tabs on temperature. Thus, they become lulled into a false sense of security about the safety of their food. We hope to dispel this complacency.

First, get rid of your analog thermometer; it cannot be trusted. Sugar thermometers are fine, and necessary for measuring high temperatures. But analog thermometers are useless at low temperatures, especially those temperatures applicable to sous vide cooking. And delicate glass is obviously not an ideal material to have around food because it can so easily break. Equally worthless are the classic meat thermometers with a metal spike and dial. Often they are accurate only to within 2.5 °C / 4.5 °F.

A digital thermometer is better, but be aware that, even if it reads out to a single decimal place, its design often limits its accuracy to no better than plus or minus 1.5 °C / 2.7 °F.

This points to the difference between **accuracy** and **precision**. You may probe a piece of meat three times in three different places and get a consistent reading on your digital thermometer

THE HYGIENE OF

Bug-Free Ice Cream

Sensitive foods require special care to ensure their safety, and ice cream is a classic example of what we mean by "sensitive." Most ice cream bases contain egg (which can carry *Salmonella* or other contaminants) plus sugar and milk (which create an ideal growth medium for bacteria). You cook the base in a pot and scrape it down with a spatula that perhaps has only been rinsed off, and then perhaps transfer the base to a container that went through the dishwasher. To do the transfer, you may pour the base through a fine-mesh sieve—a tool that is exceedingly hard to clean.

From a food safety perspective, this is a recipe not for dessert but for disaster. The problem with ice cream is that once it's pasteurized, it will never be cooked again. When we randomly screened food for the presence of fecal bacteria, ice creams were among the most notorious for testing positive.

To minimize that risk, we advocate pasteurizing ice cream in a sous vide bag. Put the bagged ice cream base into a water bath to partially coagulate the egg yolk, and then leave it in the bag to age. Keep the base refrigerated until it's time to churn it, and don't open the bag until just before churning. If you have stabilized the base (as discussed in chapter 15 on Emulsions, page 4·196), you can even freeze it, then thaw and churn it.

Properly organized freezers make it easier to manage frozen food and to turn it over on an appropriate time scale.

each time; the reading is precise and repeatable. The only problem is that it doesn't necessarily match the actual temperature of the meat. It's entirely possible to be precisely wrong every time.

Even fancy digital **thermocouples** are accurate to no more than 1 °C / 1.8 °F. For higher accuracy, your best choice is a platinum RTD (which stands for resistance thermometer diode). Most water baths now include a platinum RTD controller, with an accuracy of 0.1 °C / 0.2 °F. The downside is that these controllers are both fragile and expensive.

Domestic ovens tend to swing in temperature and can be off by as much as 5% at any given point. At 205 °C / 400 °F that 5% isn't a big deal, but for cooking something at sous vide temperatures, such as 60 °C / 140 °F, 5% can be the difference between safe and unsafe cooking. Ovens, therefore, should never be used for very-low-temperature sous vide cooking. They are simply unreliable, with temperature swings that are way too big.

Further Reading

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Juneja, V. K. "Thermal inactivation of *Salmonella* spp. in ground chicken breast or thigh meat," *International Journal of Food Science & Technology,* **42**:12, 1443–1448; December 2007.

Juneja, V. K., et al. "Modeling the effect of temperature on growth of *Salmonella* in chicken," *Food Microbiology,* **24**:4, 328–335; June 2007.

Tierno, Jr., P. M. *The Secret Life of Germs: What They Are, Why We Need Them, and How We Can Protect Ourselves Against Them.* Atria, 2004.

U.S. Food and Drug Administration (FDA). Food Code 2009. Available online at: www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodCode/FoodCode2009/

Vegetables generally keep best at 3–4 °C / 37–39 °F, whereas fish and meats do best at 0–1 °C / 32–34 °F. If you can consistently keep your refrigerator at 1 °C / 34 °F or lower, you can store most food cooked sous vide for 30 days, according to FDA standards. At a refrigerator temperature of 3 °C / 37 °F, however, the recommended length of storage drops to three days.

4 FOOD AND HEALTH

FOOD AND HEALTH

The most delicious foods are often condemned as bad for you. A chef who serves foie gras, pork belly, and butter (yum!) is likely these days to face accusations from fans of low-fat diets that those rich ingredients actually harm his guests. Others would argue that the pasta, desserts, and other carbohydrate-laden foods on the menu pose the greater concern. It seems like newspaper health columns praise coffee, alcohol, and cow's milk one week, only to pan them the next. Medical associations and food labels urge us to choose high-fiber, low-salt options. We are bombarded with claims about the health effects of eating that are inconsistent, hard to apply, and ever changing.

Our modest goal in this chapter is to present the best and latest scientific understanding of which foods are good for you and which are not. That might seem at first like a straightforward thing to do. If anything, you might expect it to be a rather dry, boring recitation of scientific facts.

Yet that is not our expectation. On the contrary, this is likely to be the most controversial chapter in the book. Beliefs that certain foods are unhealthy are both widespread and very strongly held. In some cases, people believe in their dietary choices with almost religious intensity. Vegetarians shun meat, and vegans avoid animal products altogether. Raw food devotees believe they're eating as humans were meant to, benefitting from nutrients that would otherwise be lost to cooking. Fans of the "paleo diet" believe the same thing, but with a totally different set of foods and cooking methods. Banking on an ever-growing number of people who believe they are choosing the healthiest options, stores and restaurants elevate organic food to special status.

Whether they're medical or moral, cultural or religious, such rules about what we should and shouldn't eat—let's call them **dietary systems**—are almost always well-intentioned, albeit artfully exploited by food manufacturers and advocates. Yet we found, as we explored this topic, that much of the information that we are told by the media, medical associations, and government bodies about which foods cause heart disease, cancer, and high blood pressure is unproved.

Indeed, merely unproved dietary advice seems to be the best-case scenario. In many instances, rigorous research has refuted or cast great doubt on the popular assertions. This chapter examines several cases in which beliefs—and official recommendations—have persisted even after science contradicts their central claims.

As diners and cooks, we must navigate through this barrage of conflicting information, so we need to understand how dietary systems form, how they rise to fame, and how their assertions are tested. It's devilishly difficult to apply rigorous scientific scrutiny to the many potential causal factors at the intersection of dietary intake and individual physiology. The most reliable information comes from scientific studies that are carefully designed and executed, yet such studies have generally failed to support the health claims made for popular dietary systems.

These results are surprising. It's hard to accept that much of what we have been taught for the past

Too much of a good thing is often bad for you, and that is certainly true for many kinds of food that taste good. But popular notions that certain types of food—those high in saturated fat, for example—should be avoided at all costs are beliefs that have little or no direct scientific support.

40 years about the health problems supposedly caused by saturated fat, salt, monosodium glutamate, and other vilified ingredients may be unsubstantiated. When we discuss this paucity of evidence with others, we commonly hear reactions such as "But everybody knows that isn't so!" and "That can't possibly be true!"

But science doesn't purport to reveal truth—merely the best explanation that is fully consistent with all the facts available. That is especially pertinent in nutrition and epidemiology, where hard facts are so difficult to obtain. The results we report are based on the latest rigorous scientific research available at the time of writing.

These are not our private theories; they are results of research performed by large teams of medical doctors and statisticians. The results and their interpretations had to pass muster with the researchers' peers before they were published in scientific journals. In some cases, these results are widely accepted in the scientific community, even if they are not yet incorporated into practice in restaurants and home kitchens. In other cases, controversy still rages among scientists in the field. Either way, we think it is only fair to report that these issues are far from settled.

Some may find that assertion itself controversial. Many health and dietary professionals take a paternalistic attitude toward the public out of a belief that ordinary people cannot be trusted to make informed decisions. Seeing themselves as the keepers of the public good, such experts oversimplify complex issues into dicta.

When those axioms are refuted, they are too often loath to admit that they are wrong or that there is disagreement among the experts, fearing that people will lose confidence in them (as, indeed, people should). Our approach is quite the opposite, and that is certain to ruffle some feathers.

To cover every food and every claim would take a book this size dedicated solely to the topic of food and health. Instead, we have focused on some of the most frequently discussed examples relevant to gastronomy.

The sad truth is that it is much easier to disprove old ideas than to come up with new answers. Often, the most honest assessment is that science simply doesn't know what we should eat to stay healthy. It might be more satisfying to be told "Eat this and you will be well," but that would be a fiction based on guesses, as the disappointing story of dietary fiber attests (see page 214).

Ultimately, the choice of what to put in our mouths is up to us. We need to take responsibility for our decisions. That responsibility is best exercised if we know the facts about which ideas have been proved and which haven't.

We also need to critically examine assertions that new (or new-sounding) ingredients, such as those used in Modernist cuisine, are actually harmful to diners. In certain circles, Modernist food has a reputation of being laced with chemicals or being a product of chemistry. Indeed it is, but as we explain toward the end of this chapter, that is true of all food, no matter how natural its source or preparation.

Everyone knows that you should eat your veggies to prevent cancer, right? Sorry, but it seems it doesn't work that way (see page 217).

CONTROVERSIES

Hold That MSG?

During the past 40 years, one of the most interesting popular concerns about a food ingredient has centered on the common additive monosodium glutamate (MSG)—despite the fact that scientific research has repeatedly failed to confirm the concern.

Glutamate is an amino acid that has a savory *umami* taste (see Myths About Taste and Flavor, page 4·341). It mimics flavors found naturally in tomatoes, soy sauce, and cheese, among other foods. It was isolated in 1907 from fermented wheat and patented soon after as a food additive by a Japanese company formed for the purpose: Ajinomoto. The company, whose name means "essence of taste," has been a leading producer of MSG ever since. (More recently, Ajinomoto commercialized the enzyme transglutaminase; see page 3·250).

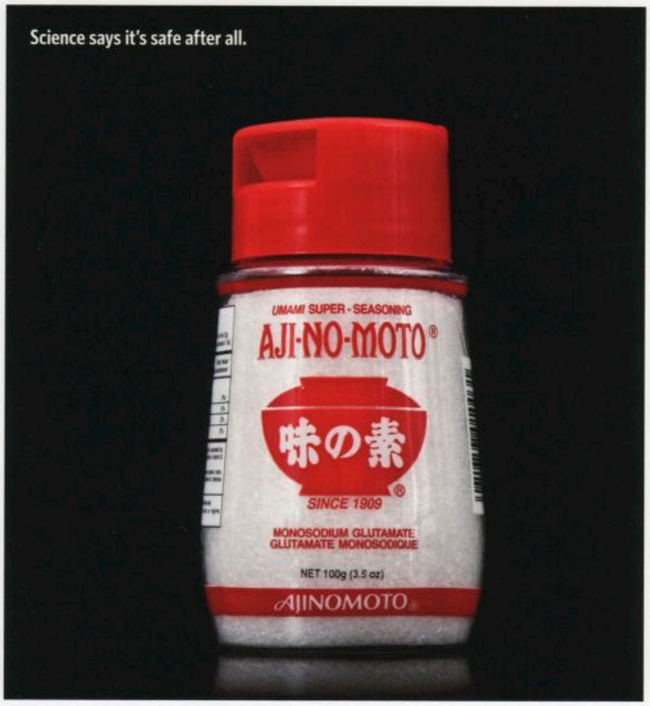
As it was invented in the 20th century, MSG is hardly a "traditional" food. It is quite tasty, however, and has found its way into most processed food formulations in both Western and Asian countries.

Chemically speaking, the safety of MSG ought to be a slam dunk. The sodium part is also found in common salt. Glutamate, a salt of glutamic acid, is an amino acid and thus is found in many foods. Like other amino acids, it is a fundamental building block of protein; it also acts as a neurotransmitter in the brain and nervous system. It is so common that Europeans and Americans get an estimated 1 g a day of glutamate from natural food sources.

All was fine with MSG until a 1968 letter to the editor of *The New England Journal of Medicine* described "Chinese restaurant syndrome," whose sufferers complained of numbness, palpitations, and other symptoms after eating Chinese meals. By then, MSG had become popular in Asian restaurants. To this day, most people strongly associate MSG with Asian food, although it is used in virtually all fast foods and in ketchup and other condiments.

In the years following the article, MSG has been investigated many times to uncover harmful health effects; these studies invariably have found the compound to be safe.

Vindication by science has done little to quell the controversy, however. It is still common to hear people claim that they are sensitive to MSG and suffer a raft of pernicious symptoms when they eat it. Self-diagnosis of MSG intolerance is so common that many Asian restaurants place notices in their windows or on their menus that pledge "No MSG."



Science says it's safe after all.

What makes the case so puzzling is that extensive research has yet to identify a test subject who can reliably distinguish food with or without MSG in a double-blind study (i.e., one in which neither the subject nor the researchers know the answer in advance). That is true even for studies that have focused exclusively on people who claim to have MSG sensitivity. Alas, the bottom line is that science has found no health effects due to MSG consumption at the levels in which it is present in food. Self-diagnosed sufferers are mistakenly blaming MSG for symptoms caused by something else. But good luck persuading them of that.

The influential food critic Jeffrey Steingarten once tackled the topic in an article titled "Why doesn't everyone in China have a headache?" Steingarten pointed out that the food with the second-highest concentration of glutamate, the natural form of MSG, is Parmesan cheese. Sun-dried tomatoes and tomato paste also have large amounts of glutamate, "and yet I have never heard of a Parmesan Headache or Tomato-Paste Syndrome," he writes.

Still, MSG remains *non grata* in the popular imagination. Ironically, because it tastes good, it also remains in our diets.

DIETARY SYSTEMS

The rise and fall of **dietary fiber** illuminates the typical trajectory of a dietary system. You may have heard that fiber-rich foods will help to reduce your risk of colorectal cancer. This powerful idea originated with Denis Burkitt, M.D., an Irish medical missionary who spent many years in Kenya and Uganda in the 1940s and thereafter. Burkitt was a competent surgeon who is credited with the discovery in African children of a new type of cancer, now known as Burkitt's lymphoma.

Burkitt also cast his keen eye upon colorectal cancer, realizing that he had observed remarkably few cases of it among the people he doctored. Upon his return to the United Kingdom in the 1960s, he wrote up an anecdotal study—a study based solely on his own experience—comparing patterns of disease in British and African hospitals. He concluded that there was less colorectal cancer in Africa.

Whether this is actually statistically true is unclear: Burkitt did not present a proper analysis. Nevertheless, the idea that rural Africans had lower rates of colorectal cancer was Burkitt's inspiration for a hypothesis. He speculated that a diet high in fiber would push fecal matter out of the gut more quickly so that residual bile acid would have less time to have a carcinogenic effect.

This led to tireless promotion of the theory, including a 1979 book for general audiences titled *Don't Forget Fibre In Your Diet*, which was an international best seller and made him a nutrition celebrity. While a few small studies seemed to confirm Burkitt's hypothesis, a few others seemed to refute it. There certainly was no scientific proof that fiber prevented colorectal cancer, however.

For more on prospective studies, randomized trials, meta-analysis, and other ways of scientifically testing ideas about how what we eat affects our health, see Testing a Dietary System, page 218.

By 1984, food companies climbed on the bandwagon. Kellogg added health claims to its All-Bran brand of breakfast cereal. Changes in U.S. federal law in 1990 allowed manufacturers greater liberty to make health claims in food advertisements and on labels. Health food stores, cookbook authors, and journalists who covered food and nutrition joined in. Soon, there were hundreds of food products, books, and articles proclaiming the benefits of high fiber content.

From a scientific perspective, however, the connection between fiber and cancer was still little more than speculation. Dietary studies are notoriously rife with bias of various kinds and plagued by confounding factors that can create an illusion of a causal link where none really exists. Durable conclusions can come only from large, **randomized intervention trials**: studies that randomly divide hundreds or thousands of people into at least two groups—one of which eats a specific diet and another that eats normally—and that then tracks the health of every subject. Even then, chance can play a role, so results cannot be considered definitive until several such studies have arrived at the same conclusion and have ruled out any possible confounders.

Did Burkitt's idea have merit? The first tests were performed using small, simple studies, which are far quicker and much less expensive than large, randomized trials. In some of these small-scale studies, people who ate lots of fiber did seem to experience lower rates of certain diseases. Burkitt and others trumpeted these preliminary findings.

They should have been more cautious. Dietary fiber comes from many kinds of food, and foods are chemically complex things. Some contain lots of potentially healthful compounds; fiber is just one—or two, actually, because fiber comes in both soluble and insoluble forms. So even if eating certain foods with fiber does reduce disease, a conscientious scientist has to ask whether the effect is due to the fiber or to some other compound that is along for the ride.

Twenty years after Burkitt published his book, the first large, long-term trial on fiber reported its results. The Nurses' Health Study had followed more than 88,000 women. After crunching the numbers, the researchers concluded that no matter how much fiber the nurses ate, their risk of colorectal cancer was essentially the same.

Although this study was imperfect in many ways, other **prospective studies** (in which people have their health and lifestyles tracked over a period of time) **and randomized trials soon** reported the same results. High dietary-fiber intake doesn't significantly reduce the likelihood of colon cancer, and a low-fat diet, a diet high in fruits, or a diet high in vegetables doesn't, either. In fact, subjects in one study who ate more vegetables actually showed a *higher* risk of colorectal cancer, although the increase was so small that it was likely just due to chance. None of the popular dietary-system theories about colon cancer proved to have any value.

Dodging Reality

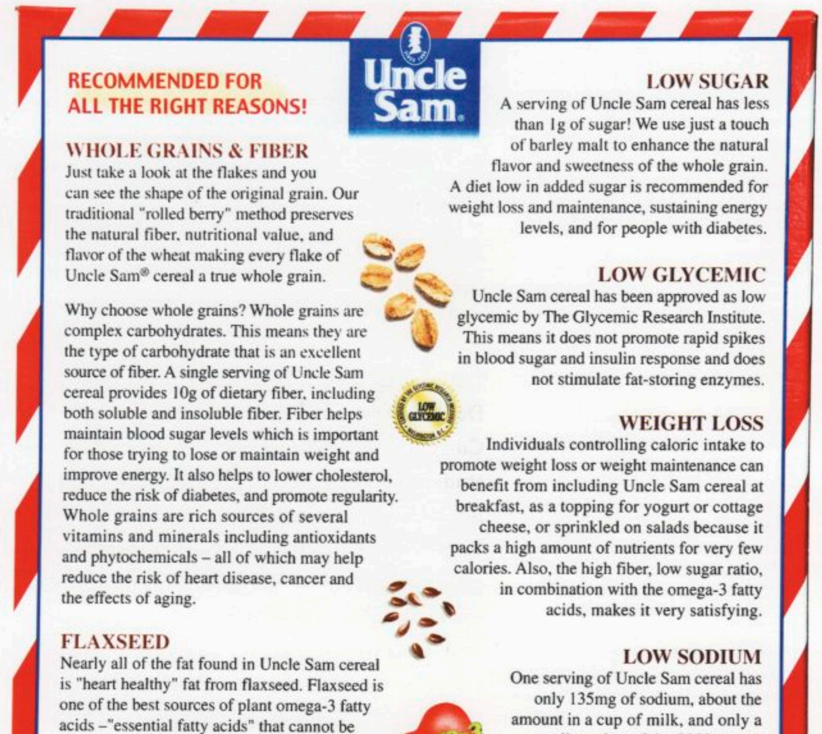
Burkitt did not live to see his theory refuted. At the time of his death in 1993, he was still being feted for his great fiber discovery. One might think that, confronted with such strong evidence that there is no practical value in eating fiber to prevent colon cancer, Burkitt's followers and fellow fiber advocates would recant. They did not. Instead, the advocates switched gears as soon as the scientific papers came out: they began arguing there were plenty of other reasons to eat a high-fiber diet.

Sources that ostensibly should be even more responsible acted likewise. When the U.S. National Institutes of Health published the results of the Polyp Prevention Trial and the Wheat Bran Fiber Study in 2000, the press release included a question-and-answer section. It gave three answers to the question, "Why didn't these trials show a protective effect?" All three are excuses seeking to explain away the results. None of them concedes that the idea was wrong. Another part of the press release tries to reassure people that there are other reasons to eat a high-fiber diet.

This is intellectually dishonest, but it is also human nature. People are reluctant to admit they were wrong. This is particularly true for health "experts" who want to maintain an aura of authority, an aura that they know what is best. If they admit the entire fiber escapade was a sham, people might be less likely to believe them the next time around.

Consumers might also be angry that they were swindled into paying billions of dollars to buy foods with useless fiber supplements that did nothing to decrease their likelihood of contracting colon cancer. Food companies have the most to lose: they want to continue promoting their high-fiber products and supplements, so they don't want to admit that the whole fiber issue was based on what was, at best, a mistake.

To this day, you'll hear statements from nutrition authorities, particularly in the mainstream press, that tout the cancer-preventing benefits of high-fiber diets. A 2008 position paper from the American Dietetic Association states, "Despite the inconsistency in the results of fiber and colon cancer studies, the scientific consensus is that there is enough evidence on the protectiveness of dietary fiber against colon cancer that health professionals should be promoting increased consumption of dietary fiber." Yet nothing of the sort is true. The data from clinical trials consistently and conclusively fail to show any benefit from fiber for colon cancer. Such a stubborn grip on dogma is irresponsible but typical of converts to dietary systems.



Health claims dominate the packaging of many kinds of foods these days. But these promises are rarely based on sound science, and government authorities do little to keep manufacturers from stretching the truth.

TIMELINE

Fiber and Colon Cancer: Advice and Evidence

POLICY

1979 Irish physician Denis Parsons Burkitt, M.D., publishes the book *Don't Forget Fibre in Your Diet*, which becomes an international best seller

1984 The Kellogg Company adds health claims to its All-Bran brand of breakfast cereal

1990 The U.S. Congress passes the Nutrition Labeling and Education Act, which requires food manufacturers to measure and publish the fiber content of most packaged foods

SCIENCE

1990 The American Cancer Society issues its first diet guidelines for reduction of cancer risk, including advice to eat more fiber

Fool Me Twice, Shame on Me

Does fiber fight diseases other than cancer? Current fiber advocates point to some small-scale studies that seem to support their arguments that fiber is helpful for heart disease or other conditions. Unfortunately, the history of medical research has shown time and again that we need to be careful with results that come from small trials because they may reflect disease rates that are actually due to chance. If I collect the five people on my block who eat oatmeal and none have diabetes, it's a lot more likely that diabetes isn't common enough in the general population to appear in my tiny sample of five people than it is that oatmeal prevents diabetes.

To be certain that an intervention—be it fiber or a drug—actually has a consistent effect, investigators have to perform a lot of detailed research. These larger and better-designed trials frequently contradict the results of small-scale studies. But as of this writing, no large-scale test of fiber and heart disease has been published. Until one is, we really don't know whether a high-fiber diet helps, hurts, or has no effect on the risks of heart disease.

The next best thing to a large trial is combining results from small studies and analyzing them together, a technique called **meta-analysis.** Meta-analysis has been applied to these small fiber studies but so far has turned up no positive effect on heart disease. Faced with this fact, and the fact that other findings from small studies on fiber have not been confirmed by more rigorous examination, a skeptic would say there is no reason to believe any of these claims for fiber's benefits until they are verified by a large, randomized, controlled clinical trial.

The lesson of fiber is that it is very difficult to learn the truth behind dietary claims. Good studies take years or even decades to complete. Until the proof is in, food companies and nutrition authorities can promote anything they want—and they can make a very good living promoting health claims about dietary systems, however shaky those claims may be. When the data finally do arrive, advocates can switch to new claims faster than science can check them out. Even after a claim is disproved, conventional wisdom tends to change slowly or not at all.

2008 The American Cancer Society states, "Links between fiber and cancer risk are weak, but eating these foods is still recommended"

2008 The American Dietetic Association states, "Despite the inconsistency in the results of fiber and cancer studies ... health professionals should be promoting increased consumption of dietary fiber"

1994 Eating fiber in general, and fruits and vegetables in particular, is found to be unrelated to colon cancer in a long-term study of nearly 50,000 men ...

1999 ... and in a different study of more than 80,000 women

2000 Two randomized, controlled trials find that fiber fails to prevent the recurrence of colorectal adenomas

2006 A randomized, controlled trial finds that colon cancer, breast cancer, heart disease, and weight loss are not significantly influenced by increasing whole grains, fruits, and vegetables in the diets of nearly 50,000 women

Trials of Dietary Fiber and Colon Cancer

These randomized, controlled clinical trials showed that increasing dietary fiber does not prevent colon cancer or precancerous colorectal adenomas. For explanations of risk, see "Testing a Dietary System," next page.

Study 1: Women's Health Initiative

Studied outcome: invasive cancer of the colon or rectum
Study duration: about eight years

Intervention group: low-fat, high-fiber diet
Participants: 19,541
Participants with disease: 201 (0.13% per year)

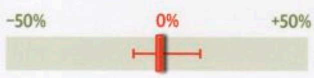
Control group: regular diet
Participants: 29,294
Participants with disease: 279 (0.12% per year)
Comparative risk: not significantly different

Study 2: Polyp Prevention Trial

Studied outcome: recurrence of colorectal adenomas
Study duration: four years

Intervention group: high-fiber diet
Participants: 958
Participants with disease: 380 (39.7%)

Control group: regular diet
Participants: 947
Participants with disease: 374 (39.5%)
Comparative risk: not significantly different



Study 3: Wheat Bran Fiber Study

Studied outcome: recurrence of colorectal adenomas
Study duration: about three years

Intervention group: fiber supplements
Participants: 719
Participants with disease: 338 (47.0%)

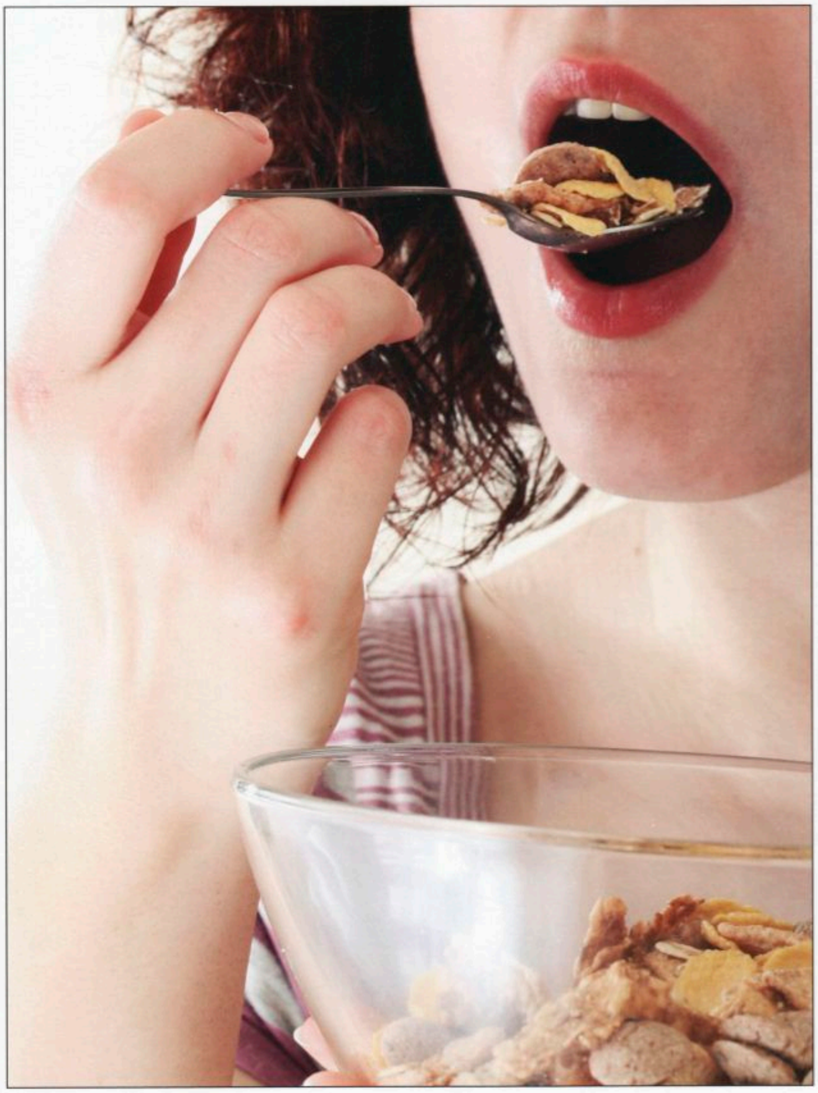
Control group: regular diet
Participants: 584
Participants with disease: 299 (51.2%)
Comparative risk: not significantly different

Testing a Dietary System

Science has developed a rigorous process that can, in principle, determine whether a food contributes to (or helps prevent) a particular disease. In practice, this scientific process sometimes breaks down, largely because this kind of science—known as **nutritional epidemiology**—is a blend of human physiology and sociology, both of which are tremendously complex and difficult to control experimentally.

The first step in scientifically testing a dietary system is to express it in the form of a **hypothesis**, which is a statement about the relationship between measurable quantities whose veracity can be supported—or, more important, contradicted—by experimental evidence. Burkitt's hypothesis, for example, was "A diet rich in fiber reduces the risk of colon cancer."

Go ahead and eat high-fiber, bran-rich cereal if you like it—just don't expect it to lower your risk of cancer.



Epidemiologists test their hypotheses in several ways (see Types of Nutritional Epidemiology Studies, page 221). The most rigorous is a prospective randomized, controlled clinical trial. Burkitt was a surgeon, however, not an epidemiologist, and he based his enthusiasm for his high-fiber dietary system on anecdotal evidence from an ecological study. Many years after his idea caught on, large, randomized, controlled trials proved his hypothesis wrong—an unfortunately common fate for hypotheses about diet and health.

The first hurdle a new nutritional hypothesis must clear is usually a small-scale study. Relatively cheap, fast, and easy to run, small-scale studies are useful for selecting dietary systems that are worth testing in a more rigorous way.

Small studies do not usually definitively settle a scientific question, however, because they suffer from various kinds of errors and bias that undermine the reliability of the results. **Sampling error** is familiar from opinion polls—it reflects the fact that whenever you choose a subset of people to represent a larger group, or humanity as a whole, sheer coincidence might give you a group that produces a misleading answer.

Bias comes in several varieties. **Recall bias** often plagues nutritional studies when researchers ask people to remember how frequently they have eaten certain foods in recent months or to keep a food diary. In either case, people may subconsciously suppress memories of eating certain foods and exaggerate their consumption of others. Prospective clinical studies that actually measure or control subjects' diets can eliminate recall bias, but these are relatively rare.

Observation bias occurs when the act of studying a person changes his or her behavior. Weight-loss intervention studies frequently overestimate the benefit of the proposed diet, for example, because participants stick to the diet only as long as the scientists track their progress. Once the study ends, the subjects tend to slip off the diet and regain their weight.

In another form of observation bias, researchers tend to treat patients receiving an intervention differently from the "control" patients, who receive only a placebo. **Double-blinded trials**—in which neither the doctor nor the patient knows who is getting the intervention—significantly reduce this bias. But they are hard to do when it comes to food.

Selection bias afflicts nearly every nutritional study because it is so hard to recruit a group of participants that mimics the composition of the population overall. Almost always, one arm of the study ends up with more men, for example, or fewer African-Americans, or more tall people than the other arm has. As a result, it is rarely possible to know whether the findings of the study will apply to groups that differ from the study cohorts. Randomizing participants into different arms of the study helps reduce selection bias. But randomization cannot overcome the limits of a study that includes only men (as some have done) or only female nurses (such as the Nurses' Health Study).

Selection bias sometimes occurs in a more insidious form, when researchers deliberately try to skew the outcome. Ancel Keys, M.D., the initial champion of a link between dietary fat and heart disease, was accused of such intentional selection bias by other scientists.

Even if a study is large enough to reduce sampling error and careful enough to avoid significant bias, **confounding effects** can produce misleading results. Confounding occurs when two unrelated characteristics, such as gray hair and colon cancer, appear strongly connected because both are affected by the actual causal factor (age, in this example).

When the studies have been done and the papers have been written, **publication bias** can come into play. A recent study shows that clinical trials with positive results are more likely to be published in scientific journals than studies that show that a treatment did not work. This means that negative results often disappear unheeded.

Imagine if your local newspaper published only good news and never informed you about murders, break-ins, and assaults. You would imagine that your local police force was 100% effective. Publication bias similarly deprives doctors and their patients of all the relevant facts about the risk of disease as they consider the relative merits of a particular treatment or dietary system.

When scientists compare the risks experienced in various arms of a study, they often use the terms **hazard ratio, odds ratio**, or **relative risk**. These numbers have a similar interpretation; namely, whether the risk of getting a disease was higher or lower in the intervention group than in the control group. A hazard ratio close to 1.0 tells us that there was little difference between the intervention and control groups, so the intervention did not work.

In the Women's Health Initiative study, for example, the women who ate a low-fat, high-fiber diet were slightly more likely to get colorectal cancer than were the women who ate their normal diets. The hazard ratio was 1.08, meaning those in the low-fat, high fruit-and-grain group were 8% more likely to get cancer (see page 217).

Very strong statistical associations—such as the observation that smokers are about 10 times as likely to get lung cancer as nonsmokers are—can persuasively link a behavior to a disease even if scientists are uncertain of the detailed causal mechanisms at work. But in nutritional epidemiology, associations between diet and health outcomes are generally far weaker—closer to 10% than to 1,000%—so the links are much less clear.

Before you get alarmed, look at the 95% **confidence interval** (the error bars on the chart). This span of numbers reflects the **statistical power** of the study, which depends on its size, length, and design. In the case of the Women's Health Initiative study, the 95% confidence interval spans the range from 0.90–1.29—that is, from a 10% reduction in cancer risk to a 29% increase in risk. The study lacked the statistical power to distinguish which number in that range represents the true change in risk. A less technical way to say this is that the trial results show that fiber might reduce the risk of cancer by 10%, might increase cancer risk by up to 29%, or might affect cancer risk by a percentage anywhere between those two values.

The 95% confidence interval means that, in principle, if you ran the study 100 times, then you'd expect that, 95 times out of 100, the result would fall within that range, and five times out of 100, the result would be outside the range. As a general rule of thumb, if the confidence interval includes 1.0, then the best interpretation is that the comparative risk of the two groups is not significantly different.

Unfortunately, this crucial point often gets lost in mass media reports on medical research. The statistics are so complicated to use and interpret that even doctors themselves often misunderstand the clinical implications (or lack thereof) of a published study. In a landmark but controversial 2005 paper titled "Why Most Published Research Findings Are False," epidemiologist John Ioannidis of Tufts University School of Medicine presented mathematical arguments that the statistical and experimental practices commonly used in epidemiological research often produce misleading results. Ioannidis concluded that, despite the use of statistical tests like the 95% confidence interval, more than half of all studies are likely to yield incorrect results because of subtle flaws in their statistical approaches. "For many current scientific fields," he wrote, "claimed research findings may often be simply accurate measures of the prevailing bias" of researchers in the field.

Even if that is too pessimistic a view, any epidemiologist would agree that gathering strong evidence in support of a dietary system is very difficult. You need a very large, long-term, randomized, controlled clinical trial, followed by a careful statistical analysis of the results that factors out all potential confounding variables. The process works best for very dramatic results, such as the link between smoking and lung cancer, that cannot plausibly be explained by confounding factors. The exact figures vary with gender and age, but smokers have roughly 10 times (1,000%) the risk of lung cancer that nonsmokers do.

Vitamin deficiencies produce similarly dramatic effects, so they were conclusively identified long ago. But science has now found most of those dramatic effects. What remains unknown are the links between diet and chronic diseases that have far more intricate webs of contributory risk factors and much subtler effects. Much larger numbers of people are needed in trials that aim to uncover any causal relationships among these factors.

How large is large enough to assure researchers that the results are not due to chance or bias? To estimate the right size, scientists must factor in the prevalence of the condition under study and the rate of new cases, the duration of the study, the compliance rate of the volunteers, the magnitude of biases and confounders, the number of variables under study, and myriad other considerations that affect the study's statistical power. There are no simple rules of thumb, except that the rarer the condition, and the smaller the effect you are looking for, the larger the trial that you need.

To achieve proper statistical power, studying dietary risk factors for even a relatively common disease like heart disease requires a large trial that costs as much as $250 million. That is why such experimental evidence is so sparse in nutritional epidemiology. To work around the cost and complexity of running a single big trial, investigators often pool data from many different studies and use meta-analysis to approximate one large study. This approach is not nearly as reliable as a single large, well-designed, randomized trial. But these are sometimes the best results that science is able to produce.

TYPES OF NUTRITIONAL EPIDEMIOLOGY STUDIES

	Ecological study	Case-control study	Cohort, or prospective, study	Randomized clinical trial
Kind	observation	observation	observation	intervention
Design	compares the nutrition and health status of groups of people at a particular time	compares people with a disease (the cases) to people without the disease (the controls)	tracks group members' lifestyle and health status over time, then looks for correlations between diet and disease	assigns volunteers randomly to an intervention group (that eats a specified diet, for example) or a control group (that carries on as usual), then tracks subjects' health
Strengths	good when data on individuals are unavailable or when differences between individuals are small	relatively quick and inexpensive	can eliminate recall bias	can reveal evidence of a causal relationship between the intervention and the outcome
Weaknesses	results may not apply to individuals; publication bias; confounding effects	sampling error; selection bias; publication bias; confounding effects; observation bias; recall bias	sampling error; selection bias; publication bias; confounding effects; observation bias	sampling error; selection bias; publication bias; confounding effects; observation bias
	Weakest →			Strongest

CONTROVERSIES

Is Grilled Meat Bad for You?

Each year, as the weather warms, newspapers roll out warnings about alleged carcinogens (cancer-causing compounds) in grilled meat and fish. Much of the concern revolves around a set of chemicals called **heterocyclic amines** (HCAs), which are produced by the **Maillard reactions** that cause seared meat to brown. People get concerned about HCAs because the U.S. National Toxicology Program says these chemicals are "reasonably anticipated" to be carcinogens in humans. The International Agency for Research on Cancer concurs. When lab rats are fed high doses of these compounds, the rats get more cancer than usual.

But does that mean the chemicals also cause cancer in humans? Not necessarily. Many reports document that what is true for rats or mice is not necessarily true for humans. And a recent, very large prospective study that followed more than 120,000 women for eight years found no association between breast cancer and red meat consumption or the way the red meat was cooked. It is thus premature to declare that HCAs are dangerous.

Several lines of evidence suggest that humans or our ancestors adapted to eat cooked food, whereas lab rats and their ancestors did not (see Origins of Cooking, page 6). It's quite possible that we tolerate Maillard reaction products better than rodents do—and even that some of the chemicals are beneficial. Animal studies show, for example, that Maillard products act as antioxidants and suppress the bacteria responsible for peptic ulcers. And people seem to tolerate breakfast cereal, crusty bread, and potato chips just fine, even though those ubiquitous foods all get their toasted, golden hue from Maillard reaction products such as acrylamide—which also is "anticipated" to act as a carcinogen.

MEDICAL DIETARY SYSTEMS

The usual rationale for a dietary system—a set of claims about which foods are good for you and which aren't—is that following the eating habits recommended by the system will improve your health, or at least will remove a potential threat to your health. Often the sellers or champions of dietary systems promise very specific results, effects that are measurable and thus testable by the scientific method. This makes it reasonable to ask, "Do they work?" and "What is the best current scientific knowledge about how well they work?"

Unfortunately, the answer is that, for the most part, they don't work.

That sad truth applies even to dietary systems in which many people—doctors and laypeople alike—believe. Everybody "knows" that eating lots of fiber protects you from colon cancer, that reducing cholesterol in your diet is good for your heart, and that salt consumption raises blood pressure. Alas, none of these "facts" have held up under scrutiny. The best scientific evidence available so far refutes the most commonly believed claims about each of these dietary systems.

Indeed, as a general rule most popular dietary systems make claims that scientific evidence just flatly contradicts. Alarmingly, this is true even of some dietary systems promoted by medical doctors and nutritional scientists.

There are some important exceptions, which we discuss below. And there is much ongoing controversy. The sad state of affairs, however, is that most of what we are told about which foods are healthy and which are not either has no strong proof or has been strongly disproved.

The saga of fiber that we recounted above is a familiar story, but it is just one of many examples in which seemingly authoritative science has yielded conflicting advice on what to eat. Two other well-known instances are the cases of dietary fat and salt.

Fat and Cholesterol

As fiber was adored, fat was vilified, resulting in a particularly long-lived, far-reaching dietary system that—as you may have guessed—was based on a very shaky foundation of scientific research. Over time, increasingly more sophisticated studies have steadily chipped away at that foundation, leaving researchers uncertain now whether consumption of most kinds of fat and cholesterol really are risk factors for serious disease.

In order to make sense of the nutritional research, we need to understand the important differences among the various kinds of fat and cholesterol that we eat, as well as how the body breaks them down into simpler molecules.

Fats and oils are types of **lipids**. They are composed of carbon, hydrogen, and oxygen. The carbon and hydrogen atoms are strung in chains called **fatty acids**. A molecule of glycerol—also made of hydrogen, oxygen, and carbon—participates in a chemical reaction that anchors to its backbone a trio of fatty acids; hence the chemical designation **triglyceride**. Fats contain more than twice as much energy (nine calories per gram) as do proteins and carbohydrates (which carry four calories of energy per gram). Fauna and flora alike use fat for energy storage precisely because it is so space-efficient. To put it in technological terms, food-based fats have an energy density quite similar to that of gasoline, diesel, or jet fuel.

Saturated fat, the stuff of most animal fats, has been particularly demonized. A saturated fat is one that is saturated with hydrogen—all the carbons in the fatty acid chains are bound either to another carbon or to a hydrogen. Saturated fats are solid at room temperature because the fatty acid chains can line up in close-fitting rows.

Most oils, including vegetable oils, consist mainly of **unsaturated fat**—"unsaturated" meaning the carbons bind fewer hydrogens than those in saturated fats because some of the carbons are double-bonded to each other instead. Rigid segments form in the carbon chains, and such fatty acids cannot snuggle together so closely, so these substances remain liquid at room temperature. If the fatty acid molecule has just one double bond it is called a **monounsaturated fat**; the presence of two or more double bonds in the molecule makes it a **polyunsaturated fat**.

You have probably been told to stay away from **trans fat**, more familiarly known as margarine and vegetable shortening. This form of fat is extremely

The Life Cycle of Medical Dietary Systems

Many hypotheses are wrong. A completely rational scientist would not get too excited about a new idea until it is proved. But scientists are people, too, and many find it impossible to resist charging ahead before then. It's only human that they focus on the potential life-enhancing benefits and want to get these to people quickly; in this view, it is a public health issue as much as a matter for dispassionate scientific inquiry. As side benefits, promising-sounding health ideas can bring fame and larger research grants. Outside of science, food companies and retailers are driven mainly by the quest for profits; they tend to see health claims as a way to promote new products. These players and motives interact with the slow-moving process of scientific investigation to produce a common life cycle for dietary systems that emerge from medicine.

1 Inspiration comes from a field observation, small study, or data mining from broad health statistics. Sometimes it's just somebody's hunch.

EXAMPLE: FIBER

While in Africa, Denis Burkitt notices that not many people suffer from colorectal cancer. He speculates that a high-fiber diet prevents cancer.

2 Initial confirmation comes from small-scale studies, at first often anecdotal. Later, studies done on just a dozen or so people for a short time offer some confirmation.

Burkitt compares his observations to colorectal cancer rates in the United Kingdom and published his "results."

3 A charismatic scientist or medical doctor champions the cause and proselytizes to other researchers and the public at large about his or her point of view. A dietary system is born.

In the early 1970s, Burkitt and his colleagues publish widely in scientific journals.

4 A long-term prospective study is launched but won't have results for many years.

In 1976, Nurses' Health Study is launched. While designed to investigate health effects of The Pill, it provides data on diet and cancer, too.

5 The dietary system is communicated to the public by various nutrition "experts" with the well-meaning goal of alerting people to something that could improve their health, even before hard statistical proof comes in.

In 1974, *The Washington Post* and *Reader's Digest* cover Burkitt and his theory. In 1979, Burkitt publishes a book for a general audience.

6 Large food companies jump on the bandwagon, offering products that are advertised as meeting the new dietary system ("low-fat," "high-fiber," "zero trans fat"). In addition, they produce "public service" advertisements promoting the dietary system —which also promote their products.

Kellogg's and other food companies add claims about the health benefits of fiber to their labels.

7 Government agencies are lobbied to include the dietary system in official recommendations and to allow food companies to advertise health benefits to the public.

8 The results of the more rigorous trials come in, showing that the dietary system has no effect on reducing disease, or that it increases the risk of disease.

In 1999, the Nurses' Health Study shows that the risk of colorectal cancer is the same no matter how much fiber a person eats. The same result is found in two large, randomized and controlled clinical trials.

9 Despite no evidence of a benefit, the dietary system "experts" and the original charismatic promoter rarely, if ever, admit it. Instead, they criticize the study or refer to the earlier small studies that seemed to show benefit.

About the findings, another researcher says, "It is possible that there really is a true relationship between fiber intake and colorectal cancer, but it is just that the epidemiologic tools that we use are too crude to see it."

10 New claims and benefits are added faster than large, randomized, controlled studies can be done to refute them. So even when the original claim is refuted, other benefits are quickly substituted.

11 Advocates of the dietary system and food companies have strong motives to continue promotion. Food product advertisements continue. Government agencies are slow to change official recommendations. The dietary system remains part of conventional "wisdom," misleading people for many years until support slowly fades away.

In 2008, the American Cancer Society and the American Dietetic Association continue to recommend fiber for its alleged cancer-fighting properties.

12 This pattern repeats again and again.

rare in nature; it occurs in foods primarily when manufacturers add hydrogen atoms to vegetable oils (making them partially hydrogenated) so that they will tend to stay solid at room temperature.

Cholesterol is not a fat but a sterol, which is a type of alcohol. That's why it ends in "-ol." Cholesterol is found in the blood and tissue of all animals. It is an essential component of cell membranes, nerves, and other crucial machinery of life—cholesterol is a crucial component of the brain, for example. Cholesterol occurs naturally in many fatty foods of animal origin. The human liver also synthesizes cholesterol directly.

The American Heart Association and other groups shout to the world that eating saturated fat increases our cholesterol, which then becomes deposited in our blood vessels and eventually contributes to the development of heart disease. This theory linking fat to cholesterol to heart disease has a curious origin and a troubled past.

The supposed connection between diet and heart disease got a big initial boost from Ancel Keys, M.D., a physician who puzzled over his observation that well-fed American businessmen were suffering from a high incidence of heart

Food companies exploit people's belief in the health benefits of certain foods and nutrients, proved or not. Any assertion you read on a food package should be taken with a grain of salt—make that sodium-free salt substitute.

disease while Europeans, malnourished in the wake of the Second World War, seemed to experience lower rates of heart trouble. Keys initiated a research program that would eventually collect data from all over the world and become known as the Seven Countries Study.

In the 1950s, early results from the study seemed to establish links among dietary saturated fat, cholesterol, and heart disease. Keys began to promote the connection to the public and to policy makers, thus setting in motion an examination that continues to this day of how dietary fat may affect heart disease.

The evidence so far strongly suggests that the amount of cholesterol you eat is pretty much irrelevant to what happens in your blood vessels. That's not to say that you shouldn't get your blood cholesterol tested every so often. It's just that diet is not a good way to control it.

Some people who eat lots of cholesterol have very little of it in their blood. Other people who eat very small amounts of cholesterol nonetheless have very high levels in the bloodstream. Because the cholesterol that accumulates as dangerous plaque on blood vessel walls originates in the blood, the notion that one should eat less cholesterol was

Large studies have shown a clear health risk associated with cholesterol—but not in the direction that you would think. Below a certain level (total cholesterol of 160 mg/dl), mortality risk appears to increase. Interestingly, a remarkable number of deaths among people with very low total cholesterol result from accidents or violence.

When this link was first illuminated, it was quite controversial, but it has since been confirmed in several large studies in humans. Even more intriguing, it has been replicated in animal studies using monkeys. At present there is no real explanation, but the theory has been floated that without a certain amount of fats and cholesterol, your body goes into a "survival mode" that includes more inclination to engage in risky behaviors.

replaced by the idea that one should reduce the amount of cholesterol circulating in one's blood, or what is known as total serum cholesterol.

Thanks to inexpensive blood tests, millions of people now know their total cholesterol count. Unfortunately, the Framingham Heart Study and other large-scale studies showed that total serum cholesterol is not much of a risk factor for heart disease. In fact, the Framingham study found, in part, an inverse correlation to mortality: for men over 50 years old, the less cholesterol they had in their blood, the more likely they were to die of heart disease!

Further study showed that the situation is far more complicated than originally thought. Cholesterol is shuttled from the liver around the body contained within large molecular assemblages made mostly of compounds called **lipoproteins**, which are carried in the bloodstream. These assemblages come in a variety of densities.

High-density lipoproteins (HDL) are the garbage trucks for cholesterol: they transport the cholesterol from bodily tissues through the blood and back to the liver, and for that reason they actually tend to keep cholesterol from building up in the blood vessels. Other forms, called **low-density lipoproteins**, or LDL, are the delivery trucks: they typically transport cholesterol to places it is needed—and perhaps contribute to heart disease.

LDL is popularly called "bad cholesterol" and HDL "good cholesterol," an oversimplification that equates the lipoprotein with its cholesterol cargo. In reality, both types of lipoprotein contain the same cholesterol, but it has different destinations depending on which lipoprotein assemblage it is carried by. This subtlety explains part of the reason why a total cholesterol test was less predictive than Keys and others expected. Total serum cholesterol is a sum of the counts of HDL and LDL, one of which is likely good for you and the other likely bad for you. If in fact one is good and the other is bad, the sum of the two isn't going to tell you who is at risk. A new generation of blood tests was thus rolled out to the public to measure LDL and HDL cholesterol levels.

Once again, however, further research revealed the simple good/bad dichotomy to be an oversimplification. LDL comes in several forms, including **very-low-density lipoprotein** (VLDL), **small dense LDL** (sdLDL), and intermediate-density lipoprotein (IDL). The sdLDL appears, at this writing, to be the really bad stuff. But these notions will probably be refined as the science continues to progress.

Technology adds a further complication. Most blood tests do not actually measure LDL levels—the particles are too variegated. Instead, they measure total cholesterol, HDL (which can be separated by **centrifuge** because of its higher density), and triglycerides; the LDL values are then calculated using a formula that is only

Five Kinds of Lipoproteins

Think of lipoproteins as cholesterol-carrying vessels. As they move around your body depositing their cargo, some act more like delivery couriers, others more like garbage trucks, and they can change shape and size. Labs used to measure total cholesterol. Today, most cholesterol tests measure your total cholesterol, triglycerides, and HDL. Your other lipoproteins are too small and light to measure except with expensive equipment usually found only at academic medical centers.

Lipoprotein	Characteristics	Diameter (angstroms)	Density (g/ml)
very-low-density lipoprotein (VLDL)	a precursor to LDL; synthesized by the liver from triglycerides	300–700	0.95–1.01
intermediate-density lipoprotein (IDL)	formed when the liver has fewer triglycerides to work with	270–300	1.01–1.02
low-density lipoprotein (LDL)	formed from VLDL when it has deposited some of its cholesterol; includes at least seven subclasses of LDL	220–285	1.02–1.06
small dense low-density lipoprotein (sdLDL)	densest of the LDLs known so far; associated with a higher risk of heart disease	220–255	1.04–1.05
high-density lipoprotein (HDL)	densest of all cholesterol-carrying lipoproteins; transports cholesterol back to the liver; high levels are associated with lower risk of heart disease	70–100	1.06–1.21

approximately correct. One study found that the formula underestimated LDL levels by 20 points, compared to a method that measures LDL directly but is too expensive for use as a routine test.

How Bad Is "Bad" Cholesterol?

Our doctors tell us LDL or sdLDL is bad for us. But do these natural compounds "cause" heart disease?

The strict answer is that the precise cause-and-effect relationship remains unknown as of this writing. High LDL or sdLDL levels might be an important cause of heart disease, or they might be a symptom of heart disease, or both heart disease and high LDL levels could be driven by a common cause.

We know at least that LDL is not the only cause of heart disease because there are well-documented cases of people who had very low cholesterol levels (including low LDL levels) but nevertheless suffered from serious heart disease. Some cardiologists suggest that the most important underlying cause of this killer condition is inflammation in the heart tissues, which ultimately leads to the buildup of plaque in artery walls. In their view, cholesterol is a building block that plays a role in the disease, but it is not the instigator.

In a city where lots of brick houses are being built, you will tend to find a large inventory of bricks. But a surplus of bricks didn't cause the houses to be built—they are a symptom of an underlying cause driving the construction. That is the cause-and-effect question being asked here.

Nevertheless, in the court of public opinion, cholesterol, particularly as carried by LDL, has been convicted as the villain. Many medical professionals have accepted this viewpoint and see it as a closed case; so do many nutritionists and diet promoters. Unfortunately, the truth cannot be quite that simple.

We've learned from a group of drugs called **statins** (best known by their brand names, including Lipitor and Crestor) that lowering cholesterol may or may not reduce the risk of suffering or dying from heart disease. While these drugs do indeed lower cholesterol in men and women, large and well-designed studies have repeatedly shown that only men seem to reap the heart-health benefits. Some meta-analyses of statin trials have found that these drugs provide no statistically significant protection from cardiovascular disease for women. Other meta-analyses do find some benefit. When they take statins, women do experience decreases in LDL levels; they just don't have less heart disease—or if they have less heart disease, then they have no reduction in mortality. Meanwhile, millions of women are prescribed statin drugs in the hope that they might gain some benefit.

The mystery of why men and women differ in the benefits they receive from statins shows that there must still be a level of complexity beyond the simple idea that LDL causes heart disease. Clearly, there is some aspect of female physiology or blood chemistry that seems to negate the quite substantial benefits that statins give men. Many researchers are working hard to solve this puzzle. Recently, a trial called JUPITER did show a statin benefit for women, but the trial only covered women who had a high level of C-reactive protein in the blood. C-reactive protein is often interpreted as a marker for inflammation and appears to be a risk factor for heart disease.

Another clue comes from the failure of a drug called Vytorin. This popular cholesterol-reducing drug includes a statin, but it also has another component that lowers LDL by a different mechanism. As a result, Vytorin is very effective at reducing LDL levels.

A four-year study of 1,873 patients, however, showed in 2008 that Vytorin did not reduce the incidence of major cardiovascular events or deaths from heart disease, despite cutting LDL levels by at least half. The failure of Vytorin strongly suggests that the link between cholesterol—particularly LDL cholesterol—and heart disease is not as simple as conventional wisdom suggests. Indeed, some critics point to this as proof that cholesterol is exonerated as a cause. As with many aspects of this problem, more research is needed to arrive at firm conclusions.

On the other hand, statins do reduce heart disease (at least in men), but they may not do so by lowering LDL levels. Statins have many effects on the body in addition to lowering cholesterol. For example, they also reduce inflammation. These other effects may be why they work and may also help to explain why statins lower cholesterol in women without preventing heart disease.

Trials of a Cholesterol-Lowering Drug and Heart Disease

Two randomized, controlled clinical trials demonstrated that the drug Vytorin does not decrease the incidence of heart disease, even though it is effective at lowering LDL cholesterol and increasing HDL cholesterol.

Study 1: ENHANCE

Studied outcome: plaque buildup in carotid artery

Study duration: two years

Intervention group: given Vytorin

Participants: 357

Results: artery wall thickened by 0.011 mm

Control group: given simvastatin

Participants: 363

Results: Artery wall thickened by 0.006 mm

Comparative results: LDL fell significantly more in Vytorin group, but arteries thickened in both groups

Study 2: SEAS

Studied outcome: major cardiovascular events in subjects with narrowed aorta

Study duration: four years

Intervention group: given Vytorin

Participants: 944

Participants with condition: 333 (35.3%)

Control group: given placebo

Participants: 929

Participants with condition: 355 (38.2%)

Comparative risk: not significantly different

CONTROVERSIES

Those Paradoxical French

Gastronomes around the world rejoiced in the early 1990s when the popular press touted the work of Serge Renaud, M.D., a scientist at Bordeaux University in France, as a new reason to hope for better health and longer life. Renaud and followers noted that the traditional French diet included lots of saturated fat from butter, foie gras, cheese, and other delectable sources, yet the French tended to die much less often from heart disease. The dogma at the time in cardiology (and still today in some circles) was that saturated fat causes heart disease, so the relatively good health of the French people seemed to pose a paradox.

Scientists cannot abide a paradox, so many focused their research on uncovering what was keeping the French healthy. Was it compounds found in red wine? Was it just the alcohol in wine? Was it the role of "good" fats like olive oil? Or was it the climate?

Theories multiplied, medical research grants were awarded, and (not waiting for an answer from science) diet activists filled books with their own ideas. Among gastronomes, a lot of red wine consumption was rationalized as being "good for you." Indeed, red wine consumption soared in North America. Life was good.

Unfortunately, subsequent research ended the party when it settled on two much simpler explanations. The first is that saturated fat isn't associated with heart disease anywhere, in any large study. So it's not just the French who can eat their fill of saturated fat without all getting heart disease—people elsewhere can (and do), too! Indeed, there also seems to be no link between total fat consumption (excluding trans fat) and heart disease.

The second part of the solution to the puzzle is equally mundane: bad statistics. When the World Health Organization investigated causes of death in France more closely, it found that the French *do* actually die of heart disease at about the same rate as people in neighboring countries.

So the paradox was a big bust—except that it did, in the end, yield some interesting research. From those studies we learned that moderate quantities of alcohol do seem to have a health benefit. Resveratrol, a compound in red wine, may also have some health benefits, but no compelling results have emerged from human trials, and animal studies found benefits only at very high doses. Neither of these findings are part of the solution to the paradox because the effects of wine and its compounds are small—and because no paradox really existed in the first place!

Fat and Heart Disease

Public opinion and the recommendations of most of the medical profession are very clear: eating food high in fats is a primary cause of high cholesterol, which is a primary cause of heart disease. Yet the latest science shows that links between cholesterol and heart disease are far more complex and nuanced. The same can be said for the links between fats and heart disease.

Speculation about the role of diet in heart disease has spawned several very different dietary systems over the years. In one common view, all fat is bad for you, so a low-fat diet is healthiest. Others single out saturated fats, trans fats, or both. Still others praise unsaturated fats such as those in extra-virgin olive oils and omega-3 oils from salmon and other cold-water fish.

Yet once again, it has been hard to get reliable, scientific answers to two basic questions: do changes in diet change cholesterol levels? And if they do, do cholesterol levels influence the development of heart disease? The answers to these two questions need not be the same.

Fat consumption can indeed have a rapid effect on HDL and LDL levels in the bloodstream. This relationship has been confirmed by many studies, which are relatively easy to do well because they don't have to follow people for many years to get an answer. It is far simpler to measure cholesterol than it is to actually record who gets sick.

Even so, the connection between cholesterol in the food and cholesterol in the blood is muddied by genetics. People in some families can consume large amounts of fat without developing high cholesterol, whereas those in other families have high cholesterol levels no matter what they eat.

Nevertheless, studies have found that for most people, the more fat they eat, the higher the total level of cholesterol (HDL plus LDL) in their blood.

But a puzzle remains: in general, a diet rich in saturated fats increases HDL more than it increases LDL. If HDL is "good" cholesterol, shouldn't a diet high in saturated fats be protective against heart disease? That, after all, is the root idea beneath the belief that unsaturated fats, such as omega-3 fats or olive oil, have protective properties. They promote HDL and help prevent the oxidation of LDL, a reaction that is one of the steps in the formation of arterial plaques.

Clearly the biology is complicated, so it makes sense to investigate directly whether fat consumption affects the incidence of heart disease. Most of the large, controlled trials of this hypothesis have concluded that eating fat has no effect, or at most a small effect (see timeline, next page).

Trials of Dietary Fat and Heart Disease

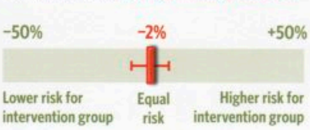
Three randomized, controlled clinical trials found that eating less total fat or saturated fat for several years does not lower the incidence of heart disease, stroke, or other cardiovascular diseases.

Study 1: Women's Health Initiative
Studied outcome: cardiovascular disease, including heart disease and stroke
Study duration: about eight years

Intervention group: low-fat diet
Participants: 19,541
Participants with disease: 1,357 (0.9% per year)

Control group: regular diet
Participants: 29,294
Participants with disease: 2,088 (0.9% per year)

Comparative risk: not significantly different



Study 2: Multiple Risk Factor Intervention Trial
Studied outcome: deaths from heart disease
Study duration: seven years

Intervention group: counseling to reduce saturated fat and dietary cholesterol
Participants: 6,428
Participants who died: 17.9 per 1,000

Control group: no change in health care
Participants: 6,438
Participants who died: 19.3 per 1,000

Comparative risk: not significantly different

Study 3: Minnesota Coronary Survey
Studied outcome: heart attack and death
Study duration: one to two years

Intervention group: diet of 18% saturated fat, high cholesterol
Participants: 4,541
Participants with disease: 131 (2.7% per year)

Control group: diet of 9% saturated fat, low cholesterol
Participants: 4,516
Participants with disease: 121 (2.6% per year)

Comparative risk: not significantly different

(no confidence interval reported)

The Minnesota Coronary Survey was particularly interesting. It included both men and women, and both groups ate diets in which fat provided about 40% of the calories. The diet of one group, however, was high in cholesterol and heavy in unsaturated fats: just 9% of the calories came from saturated fat. The diet of the other group contained much less cholesterol and twice the proportion of unsaturated fat. When the study ended, researchers found no difference among the cardiovascular events, deaths from heart disease, or mortality from any cause experienced by the two groups.

Because the intervention studies on saturated fat consumption and heart health have shown no clear association, a group of epidemiologists at Harvard School of Public Health and Children's Hospital in Oakland, California, performed a meta-analysis to summarize the overall findings to date of all the prospective studies published by 2009. Their analysis, published in early 2010, included data on almost 350,000 subjects gathered during more than 20 years of observation. The authors determined that "there is no significant evidence for concluding that dietary saturated fat is associated with an increased risk of coronary heart disease or cardiovascular disease." In another 2009 study that looked at dairy foods (including milk, cheese, and butter), the authors found that "there is no clear evidence that dairy food consumption is consistently associated with higher risk" of cardiovascular disease. In yet another meta-analysis, published in 2010, investigators looked at the relation between red meat and heart disease, diabetes, and stroke. They found no increased risk. Interestingly, they did find increased risk associated with processed-meat consumption.

Not Better than Butter

If any kind of fat truly is very dangerous to eat, it may be trans fat, the manufactured variety that includes margarine and hydrogenated shortenings and cooking oils. In the Nurses' Health Study, those women in the highest range of margarine consumption had a 35% higher risk of heart

TIMELINE

Fat and Heart Disease: Advice and Evidence

POLICY

1961 The American Heart Association issues an alert that dietary fat is a dangerous substance

1977 The U.S. government issues diet advice for the first time, recommending that fat consumption be reduced to 30% of total calories

SCIENCE

1950s Ancel Keys, M.D., publishes early results of the Seven Countries study, a post-WWII, cross-cultural evaluation of the link between consuming a rich diet and developing heart disease

1977 The Framingham Heart Study finds no link between total cholesterol levels in the blood and risk of heart disease

1981 The Framingham, Puerto Rico, and Honolulu heart studies all find that subjects having heart disease ate no more or less fat than healthy peers did

1982 The MRFIT study shows that men who eat less fat have at best a slightly reduced risk of heart disease after six to eight years

1989 The Minnesota Coronary Survey serves diets greatly reduced in cholesterol and saturated fat to hospital patients for one to two years but finds no change in risk of cardiovascular illness or death compared to subjects fed more cholesterol and twice as much saturated fat disease. And the Framingham study of men found a strong risk of heart disease associated with margarine but not with butter.

This is quite ironic because for many years, margarine was recommended as a healthier alternative to butter! The prejudice against butter's saturated animal fat was strong. Although there was no proof that margarine's polyunsaturated fats were more healthful, they seemed like a perfect substitute. Now that the studies are in, we know that the trans fat modification applied to the polyunsaturated fats made them deadly, whereas butter is probably harmless despite being rich in saturated fats and cholesterol.

The confusion over margarine illustrates how leaping to conclusions based on preliminary data is not just bad science—it can actually mislead people into an early grave. Many diet advocates, when pressed, will admit that full proof is not yet in for their favorite theory, but they argue that the answer is too important to wait for the years of testing.

"What if people die in the meantime?" they ask. "Let's go ahead with what we think is healthier for now," they reason. The case of trans fat and margarine shows that "doing good" is not so simple. Promotion of margarine likely did shorten lives; the fears of butter were overblown, and trans fat is more dangerous than first appreciated. Burkitt's fiber theory caused people to waste a lot of money on fiber-enhanced processed foods, but thankfully, it hurt only their pocketbooks. Pushing margarine over butter had far more lethal effects.

Are Some Fats Good for You?

Browse the oils or chips aisles at the supermarket, and you're bound to see products touting the supposedly healthful properties of omega-3 fats or olive oil. Researchers grew interested in these particular forms of fat when they learned rates of heart disease seem to be lower in regions where people eat a lot of these oils.

Omega-3 fats, for example, are found in cold-water fish, as well as in animals, like seals, that eat cold-water fish. People native to the Arctic and other regions with few vegetables largely eat fat

1997 The Nurses' Health Study finds no strong association tying total fat or saturated fat consumption to heart disease

2005 The U.S. updates dietary guidelines to state that "high intake of saturated fats, trans fats, and cholesterol increases the risk of unhealthy blood lipid levels, which, in turn, may increase the risk of coronary heart disease"

2006 The Women's Health Initiative trial finds no reduction of the incidence of heart disease among women who reduced the fat and increased the fruits and vegetables in their diet

2009 The American Heart Association advises limiting total fat to 24%–35% of total energy consumed, trans fat to less than 1%, and saturated fat to 7%

2010 A meta-analysis of all prospective cohort studies published before September 2009 finds no significant evidence linking saturated fat consumption to cardiovascular disease. Another meta-analysis finds no clear evidence that dairy food consumption is consistently associated with cardiovascular disease. A third meta-analysis shows no evidence of increased risk with red meat consumption (but does find increased risk with processed meat consumption)

Trials of Omega-3 Fats and Heart Disease

The three largest randomized, controlled clinical studies of omega-3 fats to date all studied people who already had suffered heart attacks, which limits the applicability of their results to the general population. A pooled analysis of 48 randomized clinical trials, however, found no reduction in mortality or major cardiovascular problems among people who increased their intake of omega-3.

Study 1: DART 1
Studied outcome: death from any cause among men who had already suffered a heart attack
Study duration: two years

Intervention group: advised to eat oily fish or given omega-3 supplements
Participants: 1,015
Deaths: 93 (9.16%)

Control group: regular diet
Participants: 1,018
Deaths: 131 (12.86%)

Comparative risk: lower

Study 2: DART 2
Studied outcome: death from any cause among men who had already suffered a heart attack
Study duration: three to nine years

Intervention group: advised to eat oily fish or given omega-3 supplements
Participants: 1,571
Deaths: 283 (18.0%)

Control group: regular diet
Participants: 1,543
Deaths: 242 (15.7%)

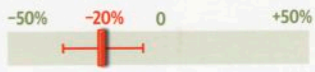
Comparative risk: not significantly different

Study 3: GISSI-Prevenzione
Studied outcome: death, stroke, or heart attack among subjects who had already suffered a heart attack
Study duration: 3.5 years

Intervention group: daily omega-3 supplements, half with vitamin E and half without
Participants: 5,665
Deaths or events: 556 (9.8%)

Control group: no daily supplements or vitamin E supplement alone
Participants: 5,658
Deaths: 621 (11.0%)

Comparative risk: lower



and fatty meat from fish or marine mammals yet seem to have lower rates of heart disease than people who eat a "Western" diet.

But, as we have seen with fiber, the "French paradox," and other cases, ecological studies alone can be very misleading. Several randomized clinical trials have examined whether adding omega-3 fats to the diet has any substantial effect on heart disease risks. So far, the answer seems to be that any benefits are small at best. One short trial, the Diet and Reinfarction Trial (DART 1), reported a significant reduction in mortality rates among heart attack victims advised to start eating more fatty fish. But when the study was repeated with more subjects for a longer period, the benefit did not appear again. So far, no trials have lasted long enough to provide a truly reliable answer that can be applied to the healthy population (see charts above).

Olive oil has been hailed in some quarters as a "miracle" fat that explains a lower incidence of heart disease among people in Spain, Italy, Greece, and other regions where a so-called Mediterranean diet is common. Ancel Keys speculated that the Mediterranean diet was low in total fat and was healthful for that reason. The latest theory, ironically enough, is that high consumption of olive oil—and of extra-virgin olive oil in particular—is responsible.

Unfortunately, as of this writing, no randomized, controlled studies have been reported that test whether eating olive oil separately—rather than as part of the Mediterranean diet as a whole—can lower the risk of disease. The best data available instead come from meta-analyses of observational studies and case–control studies in people who already had heart disease or were at high risk. These "studies of studies" suggest that a Mediterranean diet might reduce risks of heart disease and other chronic ailments. But the meta-analyses cannot attribute those effects to olive oil in particular.

One small study of 200 males who consumed olive oil with varying amounts of phenolic acids—a group of chemicals with antioxidant and anti-inflammatory effects—suggested that the higher the phenolic content, the more HDL cholesterol increased and the more markers of oxidative stress fell. What does this small study tell us about the benefits of olive oil? Not much more than this: perhaps, among the more than 230 chemical compounds in olive oil, polyphenols are beneficial

Trials of Dietary Fat and Cancer

Cancer is as much a public health priority as heart disease, so researchers have also investigated with some rigor whether eating fat is connected to cancer risks. So far, however, science has established no such link. The randomized, controlled clinical trials summarized below found that lowering fat consumption does not decrease the incidence of cancer.

Study 1: Women's Healthy Eating and Living
Studied outcome: new or recurring breast cancer
Study duration: seven years

Intervention group: repeated counseling and classes to promote low-fat (15%–20%) diet
Participants: 1,537
Participants with disease: 256 (16.7%)

Control group: cursory, one-time advice
Participants: 1,551
Participants with disease: 262 (16.9%)

Comparative risk: not significantly different

Study 2: Women's Health Initiative
Studied outcome: new breast cancer
Study duration: eight years

Intervention group: low-fat (24% fat) diet
Participants: 19,541
Participants with disease: 655 (0.42% per year)

Control group: regular (35% fat) diet
Participants: 29,294
Participants with disease: 1,072 (0.45% per year)

Comparative risk: not significantly different

Study 3: Women's Health Initiative
Studied outcome: ovarian cancer
Study duration: eight years

Intervention group: low-fat (24% fat) diet
Participants: 19,541
Participants with disease: 0.036% per year

Control group: regular (35% fat) diet
Participants: 29,294
Participants with disease: 0.043% per year

Comparative risk: not significantly different

Study 4: Polyp Prevention Trial
Studied outcome: prostate cancer
Study duration: four years

Intervention group: low-fat (24%), high-fiber (34 g/d) diet
Participants: 627
Participants with disease: 22 (3.5%)

Control group: regular diet (34% fat, 19 g/d)
Participants: 603
Participants with disease: 19 (3.2%)

Comparative risk: not significantly different

THE CHEMISTRY OF

What's in a Fat

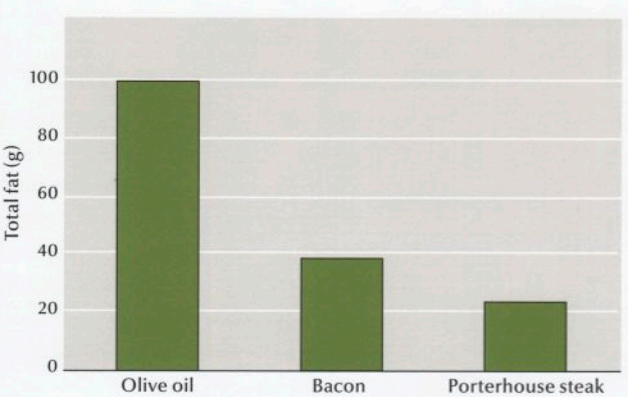
First we were told that all fat was bad, then that all saturated fat was bad. Now a closer look at the individual fatty acids of which all fats are composed reveals that "good" and "bad" fats really have similar chemical compositions.

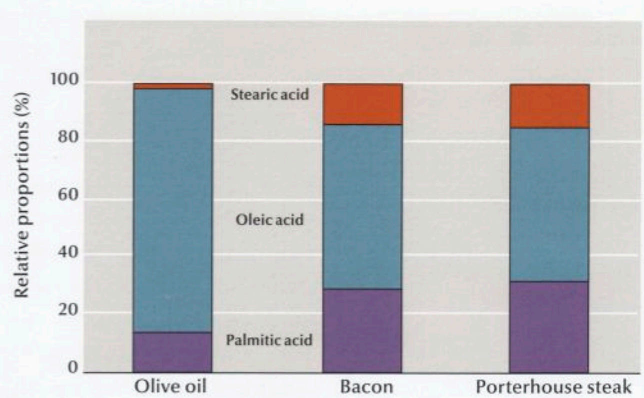
Olive oil, which has a reputation as a healthful fat, is mostly oleic acid, which does not raise LDL cholesterol. But the fat in cooked steak is also nearly half oleic acid. And the majority of bacon's fat is oleic acid, too.

The principal other fats in cooked bacon and steak are the saturated fats palmitic acid, which has been found to raise LDL cholesterol (yet is also present in olive oil), and stearic acid, which the body rapidly metabolizes into oleic acid.

Not So Different

The graphs below show the total fat (left) and palmitic, oleic, and stearic fatty acids (in purple, blue, and orange, respectively, at right) in 100 grams of olive oil, cooked bacon, and cooked steak.





Trials of Salt and Hypertension

The largest of the randomized, controlled clinical trials of salt reduction show pretty modest reductions in blood pressure.

Better results were obtained from the DASH diet, which emphasized fruits, vegetables, and low-fat dairy foods.

Study 1: Trials of Hypertension Prevention I
Studied outcome: blood pressure
Study duration: 18 months

Intervention group: reduced-sodium diet
Participants: 327
Results: pressure dropped by 4.1%/5.2% (systolic/diastolic)

Control group: regular diet
Participants: 417
Results: pressure dropped by 2.4%/3.8%

Comparative effect: lower pressure

Study 2: Trials of Hypertension Prevention II
Studied outcome: blood pressure
Study duration: three years

Intervention group: reduced-sodium diet
Participants: 594
Results: pressure dropped by 0.5%/3.5% (systolic/diastolic)

Control group: regular diet
Participants: 596
Results: pressure changed by +0.5%/−2.8%

Comparative effect: lower systolic pressure

Study 3: Dietary Approaches to Stop Hypertension (DASH) I
Studied outcome: blood pressure
Study duration: eight weeks

Intervention group 1: controlled diet rich in fruits, vegetables, and low-fat dairy foods
Participants: 151
Results: pressure dropped by 5.7%/2.3% (systolic/diastolic)

Control group: controlled regular diet
Participants: 154
Results: systolic pressure dropped by 1.5%; no change in diastolic pressure

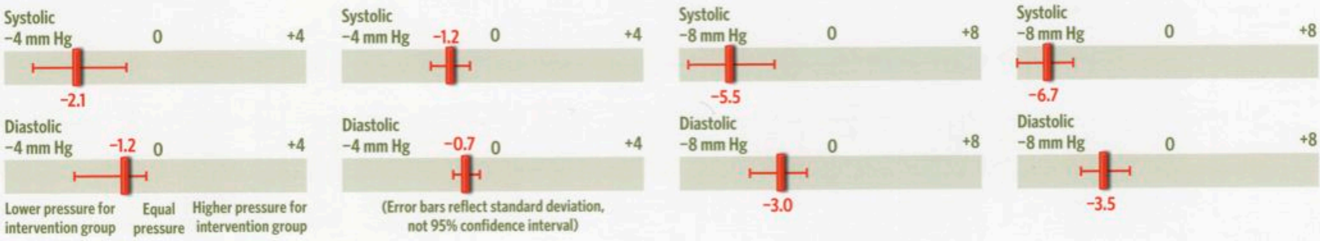
Comparative effect: lower pressure

Study 4: Dietary Approaches to Stop Hypertension (DASH) II
Studied outcome: blood pressure
Study duration: 45 days

Intervention group: controlled diet low in sodium
Participants: pressure dropped by 5.7%/2.3% (systolic/diastolic)

Control group: controlled diet high in sodium
Participants: 192
Results: pressure on low-sodium diet dropped by 5%/4% (systolic/diastolic)

Comparative effect: lower pressure



Oleic acid, palmitic acid, and stearic acid are just a few of dozens of individual fatty acids now recognized.

Number of fatty acids in
olive oil: 11
bacon fat: 14
beef fat: 10

Normal systolic/diastolic blood pressure, in mm of mercury (mm Hg):
≤ 115/≤ 75

Prehypertension:
120–139/80–89

Hypertension, stage 1:
140–159/90–99

Hypertension, stage 2:
≥ 160/≥ 100

for our hearts. There's still a lot to learn.

The science of fat has grown increasingly sophisticated since Ancel Keys first demonized all saturated fats with one broad stroke. Now laboratory investigators are illuminating the particular molecular signatures of various fatty acids, gaining a better understanding of their function in—and potential harm to—humans.

If it turns out that particular kinds of fatty acids are harmful, that will make it hard to give simple dietary advice. A given fatty acid is likely to be found in a variety of foods, both those that are high in saturated fat and those that are high in unsaturated fat. It might even be produced by the body itself during metabolism by combining parts of other fatty acids.

You can see how this could quickly become confusing. Scientists, for example, now know that stearic acid, a saturated fatty acid that is more plentiful in foods like steak and bacon than in olive oil and fish, does not raise total or LDL cholesterol, the bad stuff on which we allegedly quickly slip toward heart disease. When volunteers eat a bacon cheeseburger—a so-called "heart attack on a plate"—they ingest a lot of stearic acid, but their blood becomes as rich in oleic acid as it would if they had eaten a salad generously dressed with olive oil, which is composed primarily of oleic acid. And oleic acid has no apparent effect on HDL, LDL, or VLDL cholesterol.

The researchers who made this finding concluded that stearic acid is quickly metabolized into healthy oleic acid. Is bacon, at last, redeemed? If the oleic acid theory is correct, then we can enjoy bacon without guilt. More likely, however, the real lesson is that, once again, the situation is far more complex than simply labeling fats "good" or "bad."

Salt and Health

Low-sodium diets have been, next to low-fat regimens, perhaps the most pernicious restrictions placed on gourmands. Sodium chloride, or table salt, allegedly raises our blood pressure. Scientists have in turn drawn strong links between chronic high blood pressure, also called hypertension, and a host of health problems, including heart attacks, strokes, and kidney disease. So if salty food raises blood pressure, and hypertension harms health, then salt must harm health, it is widely believed.

CONTROVERSIES

Vitamin Supplements

Vitamins are critical nutrients that our bodies don't make, so we must get them from food. When human diets are restricted (or when we get too little sun exposure to synthesize the vitamin D we need), our health can suffer.

Fortunately, chemists can synthesize or derive large quantities of nearly any nutrient, allowing medicine to achieve heroic victories over scourges caused by vitamin deficiencies. The thiamine deficiency beriberi and the niacin deficiency pellagra are now rare. Rickets, a vitamin D deficiency, was widespread well into the 20th century before fortification of milk and other foods largely eradicated it in richer countries. More recently, an aggressive campaign to fortify foods and prenatal vitamins with folic acid dramatically decreased the incidence of the spinal-column defect spina bifida in newborns.

These public health successes led to great enthusiasm about vitamins. Tantalizing small studies suggested that people who eat a variety of fresh foods have lower incidences of cancer and heart disease. These results added to the buzz. So did laboratory test results showing that certain vitamins (especially the antioxidants, which include beta-carotene, lycopene, and vitamins A, C, and E) seem to protect human cells from wear and tear (when studied outside the body).

Healthcare practitioners understandably hoped to employ vitamins as preventatives, sort of a "good diet in pill form" that might compensate for some of our bad habits. Active marketing by supplement manufacturers and retailers pushed this view as well, with great success in the market: half of Americans now pop vitamin supplements routinely, generating more than $20 billion in annual sales.

Yet as large-scale clinical trials have tested the benefits of vitamin supplements, they have yielded results that are at best confusing. One early randomized, controlled study gave the nutrient selenium to people who had already had skin cancer. It had no effect on whether the cancer recurred—but, intriguingly, overall mortality fell by half and cancer mortality fell by one-third among the subjects taking selenium. The intervention group also benefited from lower rates of lung, prostate, colorectal, and esophageal cancer than the control group did.

The Women's Health Initiative study followed more than 160,000 women for about eight years and reported in 2009 that the 42% of participants who took multivitamins got cancers, heart attacks, and strokes at essentially the same rates as those who did not take supplements. Vitamins added no years to life. Yet another trial of vitamins C, E, beta-carotene, selenium, and zinc seemed to lower rates of cancer and death among men but not women.

A few trials have even demonstrated harm. In two separate trials, lung cancers were more common among people taking beta-carotene and other supplements. In 2008, a randomized, controlled trial including more than 30,000 men was halted early when researchers realized that selenium and vitamin E were not reducing the rate of prostate cancer, and that vitamin E might even be increasing the numbers of cancers.

These conflicting results are perhaps not so surprising when you consider that foods contain thousands of biologically active ingredients. Science has yet to discover many of the synergistic relationships among these ingredients and human physiology. Although supplements do relieve obvious deficiencies, it seems clear that providing purified vitamins and minerals in pill form is not sufficient for general good health and may actually be harmful.

Some doctors would prefer that we all take a multivitamin as "insurance," but others point out that those most likely to take vitamins—the health-conscious—are the people least likely to need them. The latest edition of the USDA's dietary guidelines states that, for most of us, essential nutrients are best obtained through food rather than as supplements.

The guidelines also note, however, that a lack of fruits and vegetables is responsible for widespread shortages of vitamins A, C, and E and magnesium in most Americans' diets. Your mother was right: you need to eat your vegetables.

While vitamin supplements can beat some diseases, they don't seem to affect others, including heart disease and cancer.

Like so many other conclusions about eating and health, however, this dietary system was erected on a shaky foundation of ecological studies. Researchers compared the incidence of hypertension and cardiovascular diseases among people in less developed areas (where only about one in 100 adults have high blood pressure) to their incidence in those living in industrialized areas (where about a third of adults have hypertension). Among the many dietary differences between the populations, salt seemed a likely suspect.

Yet intervention studies that have encouraged subjects to lower the sodium in their diets (or have fed them low-salt food directly) have turned in results that are both controversial and mixed. On the one hand, people who already have high blood pressure may benefit from reduced-salt diets. One study found that hypertensive people were more likely to be able to reduce or eliminate their high blood pressure medication after they started eating low-sodium diets. And two large studies that included more than 3,000 subjects with elevated blood pressure found a 25% reduction in the risk of heart-related medical problems among those on low-sodium diets. The benefits persisted for years after the intervention had ended.

On the other hand, some clinical trials have also found that reductions in salt intake do not seem to strongly affect blood pressure if it is already within normal limits. A handful of studies seem to show that the amount of salt one eats has no bearing on one's risk of dying of heart disease. And several analyses of health data collected from thousands of people representative of the U.S. population as a whole have shown that those with the lowest salt intakes have *higher* rates of death from cardiovascular problems and from all causes.

These varied results illustrate that there's no one-size-fits-all dose of salt that ensures good health. Yet health professionals with impressive credentials insist nonetheless that we should all reduce our intake (see Legislating Salt, next page).

The study of salt's impact on health is one of the most bitterly controversial in all of science. In an award-winning article titled "The (Political) Science of Salt" that appeared in the journal *Science* in 1998, journalist Gary Taubes described the acrimonious debates between scientists that study salt. According to Taubes, "The controversy over the benefits, if any, of salt reduction now constitutes one of the longest running, most vitriolic, and surreal disputes in all of medicine." Little has changed since this article appeared.

A 2009 meta-analysis of salt studies done from 1966 through 2008 found that risk of stroke was higher in those who ate the most salt, but the 95% confidence interval allowed that the risk might still be low (1.06–1.43). The risk of cardiovascular disease (95% confidence interval: 0.99–1.32) was lower than the risk of stroke. Many observers would interpret these confidence intervals as indicating a low risk of stroke and no significant risk of cardiovascular disease. But in the controversy-filled world of salt research, these findings are unlikely to alter many opinions.

More recently, a few scientists have been exploring the intriguing possibility that our increased rates of hypertension in the rich world are due not to an excess of salt in our diets but rather to a deficiency of potassium. Processed foods tend to be high in sodium but low in potassium. Fruits and vegetables, in contrast, are usually low in sodium and high in potassium.

The potassium hypothesis gained traction when a large study called INTERSALT reported that subjects who excreted less potassium in their urine (indicating that they had ingested less) had higher blood pressure than their peers and that those with both high sodium and low potassium were most likely to have hypertension. A clinical study provided some support for the idea: participants who ate their usual portion of sodium but less potassium saw their blood pressure rise.

Or perhaps the real answer is that what matters for maintaining normal blood pressure is eating a mix of healthful nutrients. The Dietary Approaches to Stop Hypertension (DASH) trials fed subjects either typical U.S. diets or better diets, rich in fruit, vegetables, potassium, and low-fat dairy. Within weeks, the latter group enjoyed a significant drop in blood pressure despite eating just as much salt (more than the U.S. recommended daily allowance) as their peers.

These data speak well of eating a diet rich in fresh produce. But there's little to suggest that those of us with normal blood pressure will benefit, in the long term, from hiding the salt shaker.

CONTROVERSIES

Legislating Salt

In 2009, New York City health department commissioner Thomas R. Frieden (later appointed to head the U.S. Centers for Disease Control and Prevention) asked manufacturers of packaged and mass-produced restaurant food to reduce the amount of sodium in their products by one quarter over five years. In the following five years, Frieden wanted to see another 25% reduction.

He claims that cutting by half the salt in products like these, which are allegedly responsible for 80% of the salt in the average diet, will save 150,000 lives each year. (That figure is often repeated but rarely with a citation to its source, which actually refers to a rough estimate of lives that might be saved by sodium reduction across all 300 million people in the United States.)

"If there's not progress in a few years, we'll have to consider other options, like legislation," Frieden said, according to *The New York Times*.

The sense of urgency seems misplaced when the best evidence suggests that sodium reductions are ineffective at reducing blood pressure by a significant amount in most people with normal blood pressure. Low-sodium diets may help some people with hypertension control their blood pressure. But why legislate the salt consumption of millions of people for the benefit of a few? Frieden responded to that question with a line of reasoning often used by advocates of dietary systems. Most Americans eat twice the recommended amount of sodium, he asserted, so eating less salt will result in some blood pressure reduction, which will reduce the risk of heart attack and stroke.

As the DASH studies have shown, however, eating more fruits, vegetables, and low-fat dairy lowers blood pressure more effectively than low-sodium diets do. Unfortunately, regulating several positive additions to people's diets seems much more difficult than demonizing a single ingredient.

Frieden suggests that consumers won't notice a gradual, 50% reduction in sodium over a decade, the sort of change that he likes to call "stealth health." Perhaps, but this sort of activist health legislation done in advance of firm scientific knowledge seems unjustified—and possibly dangerous if it encourages food manufacturers to search for new flavor enhancers that might be less benign.

TIMELINE

Salt and Heart Disease: Advice and Evidence

POLICY

1979 The Surgeon General's report asserts that salt clearly causes high blood pressure

1980 The U.S. Department of Agriculture issues dietary guidelines that caution against eating too much salt

2005 The U.S. government dietary guidelines state that "on average, the higher an individual's salt intake, the higher an individual's blood pressure. Nearly all Americans consume substantially more salt than they need. Decreasing salt intake is advisable to reduce the risk of elevated blood pressure"

SCIENCE

1988 The INTERSALT study of more than 10,000 people finds that salt consumption is not strongly related to blood pressure

1997 The DASH trial observes that adherents to a diet high in fruit, vegetables, and low-fat dairy experience significant drops in blood pressure, even without changing salt intake

2001 A second DASH trial shows that those who both adhere to the diet and reduce salt have the largest drops in blood pressure

2004 A meta-analysis of 57 randomized, controlled trials finds that healthy subjects without hypertension experience only modest decreases in blood pressure when they reduce salt consumption

2009 A meta-analysis of salt consumption studies from 1966 to 2008 finds that those who ate the most salt had little or no increased risk of heart disease compared to those who ate the least salt

All of us live with, know, or have heard of somebody who has had a harrowing allergic reaction to food. There they are, enjoying a meal at the kitchen table, a restaurant, or a wedding banquet. Then suddenly, within minutes or a few hours, they are fighting off a severe, potentially life-threatening allergic reaction (called **anaphylaxis**) by jabbing themselves with an adrenaline injector or being rushed to the emergency ward.

Anaphylactic reactions are the most severe manifestations of food allergies. Few countries have any estimates of deaths due to food-triggered anaphylaxis, but the U.S. is one of them. According to government estimates, 100–200 people die annually from anaphylaxis in the United States, where 6%–8% of children and about 4% of adults are allergic to at least one food. Globally, a larger proportion of people, when asked whether they think they have an allergy, will say that they do, but medical tests generally confirm that only 1%–5% of a given population indeed has a food allergy.

In the vast majority of cases, allergic reactions to food come and go within minutes or hours. They usually involve distressing but easily manageable symptoms, such as hives or rashes, tingling in the mouth and throat, or coughing and wheezing. But then there are those 30,000 emergency-room visits each year from people with serious allergies. For such a person, ingesting even a trace of an allergenic food foments riot within the immune system.

The French physiologist Charles Richot, who won a Nobel Prize in 1913 for his work leading to the recognition of this over-the-top type of immune system response, explained in his Nobel speech how he came up with the word "anaphylaxis." His basis for the word says something about how the normally life-preserving immune system can go so wrong: "*Phylaxis*, a word seldom used, stands in the Greek for protection. "Anaphylaxis" will thus stand for the opposite ... that state of an organism in which it is rendered hypersensitive instead of being protected."

Such a rapid, feather-trigger, shock-and-awe response is just what the body needs to fight off viruses and bacteria because just a few of these microscopic pathogens can quickly replicate to legion and lethal numbers if left unchecked. In response to that threat, the human immune system evolved the ability to detect truly minuscule amounts of the chemicals that signal an infection and to then marshal an overwhelming systemic response, ramping it up faster than the pathogen can reproduce. Amazingly, less than *one-trillionth* of a gram of viral material is enough to induce an immune response.

You can think of a food allergy as a malfunction of the immune system. Food should not trigger self-destruction. But in people with food allergies, the immune system reacts to certain food proteins as if they were signs of a dangerous microbe. This is why the smallest hint of peanut protein, left on an imperfectly cleaned assembly line and picked up on the wrapper of a peanut-free product, can trigger anaphylaxis. To the immune cells of a highly allergic person, those few molecules of protein look for all the world like a life-threatening germ.

Some 90% of all people with food allergies respond to one of a notorious octet of allergens: shellfish, fish, peanuts, cow's milk, eggs, tree nuts (such as walnuts and pecans), soybeans, and wheat. Tree nuts are thought to be the most potent food allergens: vanishingly small amounts of the troublesome proteins, perhaps as little as 10 millionths of a gram, have triggered serious allergic reactions. According to the U.S. Centers for Disease Control and Prevention, 6.9 million Americans are allergic to seafood of some variety and 3.3 million are allergic to peanuts or tree nuts.

Only a small minority of people who have food allergies are at risk of anaphylaxis. What sets the stage for an anaphylactic response to food is the ingestion of a particular food **protein** and the presence in the body of an errant antibody that latches onto that protein. Antibodies are proteins made in an enormous variety of subtle variations by the immune system. They have a bloodhoundlike ability to find and bind with exquisite selectivity to specific molecules of concern, such as proteins in a virus's shell.

For reasons that are not entirely clear, some people develop antibodies that bind to a food protein. For these people, when that food protein is present, perhaps even from a shiny clean spoon that might previously have been used to scoop some peanut butter from a jar, it interacts with these first-response antibodies.

The antibodies, in turn, set off a cascade of events in immune system cells, including basophils in the blood and mast cells in body tissues. When stimulated by the allergen, these cells release histamine, tryptase, and other biochemical mediators that produce the wide range of symptoms we call an allergic response. The symptoms vary because different tissues react to histamine and other allergic mediators in different ways.

About 80% of people who think they have a food allergy actually have a so-called food intolerance, meaning a reaction that occurs by some biological mechanism other than an antibody response. Intolerances are even more mysterious than food allergies; in many cases, the mechanism is unknown.

Some reactions seem to be set off by irritating chemicals, such as histamine, or by toxins from troublesome bacteria. Others occur because a person lacks a particular enzyme needed to digest a component of the food. Probably the best known and most common example is lactose intolerance. Lactose is a common sugar found in milk and milk products. Lactose-intolerant people are deficient in lactase, an enzyme that breaks down lactose into simpler carbohydrates. To the normally beneficial bacteria that usually make a quiet living in the gut, the undigested lactose becomes an abundant source of food, leading to the generation of gas, pain, and other characteristic symptoms.

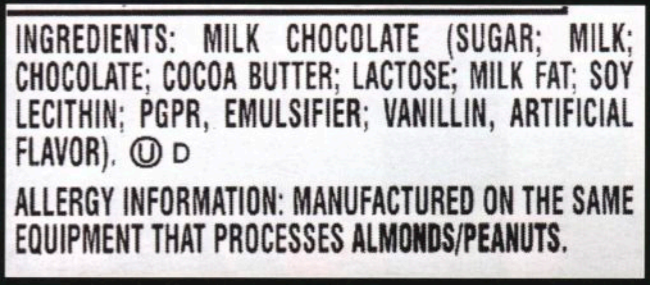
Gluten intolerance is also widespread. It takes at least two distinct forms. Some people's bodies simply react to the protein gluten as a toxin. In many others, the protein, which is a component in all varieties of wheat, barley, rye, and many other grains, triggers an inflammatory immune response that damages the small intestine. The latter condition is common enough—recent studies estimate it affects one in 133 people of European descent—that it has a name: celiac disease, from the Greek word for abdomen.

Gluten can be hard to avoid: many restaurants and food products label products that contain wheat but not other sources of gluten, including many other grains. Cross-contamination is a frequent problem. Even some medicines, vitamin formulations, and lip balms contain the protein.

Those who suffer the most acute form of celiac disease remain malnourished no matter how much they eat, as long as gluten is part of their diet. Fortunately, there is a simple and complete cure: avoid eating gluten. Even so, it can take months for the gut to heal after the offending protein is removed from the diet. As with other intolerances, the range of symptoms can vary widely, with some people suffering major discomfort if they eat tiny amounts of gluten and others able to occasionally down a slice of pizza with no ill effects.

Other common food intolerances include difficulty processing histamines (present in certain cheeses, wine, and fishes including tuna and mackerel), nitrates (ubiquitous in preserved meats), and sulfites (added as a preservative to wine and beer but also a naturally occurring constituent of onions, garlic, and fermented liquids such as vinegars, wines, and soy sauce and a frequent contaminant of citric acid and cornstarch).

Food labels in the U.S. and some other countries must alert consumers to ingredients or possible cross-contaminants that may trigger one of the more common allergic reactions, such as that to peanuts. But such warnings are not comprehensive. They don't always cover substances, such as nitrates or sulfites, to which people may be intolerant or food components that are used during intermediate processing of the product.



NONMEDICAL DIETARY SYSTEMS

Body mass index (BMI) is a measure of weight (in kg or lb) relative to height (in m or in) that roughly approximates body fat. The formulae are
$BMI = kg \div m^2$
$BMI = lb \times 703 \div in^2$
The World Health Organization classifies BMI into four categories.

BMI	Classification
<18.5	underweight
18.5–24.99	normal weight
≥25	overweight
≥30	obese

Some dietary systems are adopted more often for ethical or aesthetic reasons than for medical ones. Low-fat and low-carbohydrate diets are among the most popular of myriad approaches for losing weight. Vegetarian and organic foods are increasingly popular as well, both separately and in combination.

Like medical dietary systems, nonmedical dietary systems are promoted by marketers and advocates. Adherents to these diets often believe fervently in the health and lifestyle benefits of their choices, despite a lack of reliable scientific evidence to back those beliefs.

The largest controlled clinical trial of weight loss plans conducted to date, for example, concluded that any dietary system will help you lose weight—as long as it provides fewer calories than your usual fare. The trick to weight loss, however, isn't in shedding the pounds but in keeping them off. This same study found that participants began to gain weight back after just one year.

But science offers some good news as well: carrying a modest amount of extra weight may not be as bad for you as we've been counseled to believe. A 12-year prospective study of more than 11,000 adults found that those who are technically classified as overweight according to their body mass index were slightly *less* likely to die of any cause than their peers of so-called "normal" weight. Underweight people were 73% more likely to die than those of normal weight. A bit of padding may give people, especially the elderly, the reserves they need to cope with the metabolic demands of fighting disease.

Weight Loss Diets

The promise of weight loss drives a major industry that takes in billions of dollars in revenue each year in the United States alone. Over the years, in a pattern that is similar to the rise and promotion of medical dietary systems, scores of weight loss plans have been published and marketed.

No one has taken credit for authoring the archetypal plan: the grapefruit diet, which has been in circulation since the 1930s. It was touted as a quick, short-term way to lose weight. Although the premise is that drinking grapefruit

juice or eating the fruit combined with protein promotes weight loss, the diet—which restricts carbohydrates to vegetables and grapefruit—averages so few calories per day that most people will inevitably lose weight in the short term.

One small study has shown that the addition of grapefruit to one's diet might be more than old-time lore: 91 obese patients with metabolic syndrome were randomized to take either placebo or grapefruit in various forms—capsule, juice, or fresh—for 12 weeks. Everyone who consumed grapefruit lost weight and had improved insulin responses after eating (meaning their bodies more appropriately drew glucose from their blood into their cells), but those who ate half a fresh grapefruit before each meal lost the most weight (1.6 kg / 3.6 lb over three months) and had the best postmeal insulin profile. The authors note that half a fresh grapefruit has fewer calories than the quantity of grapefruit juice that the subjects drank and more fiber, which promotes a feeling of fullness. The acidity of grapefruit may also keep food in the stomach longer, delaying the return of hunger.

The Shangri-La diet, developed by a psychologist, supposes that foods that are familiar and rich will prompt the brain to crave more of them, leading to weight gain. Foods that are unfamiliar and bland will trick the brain into thinking food is scarce, thus lowering the body's "set point," or weight that it naturally maintains.

The trick (according to the story) is to consume a few tablespoons of fructose water or extra-light olive oil between meals. The diet's author alleges that this step, which provides calories but little taste, retrains the mind so that it no longer associates calories with taste and thus craves food less often. So far, however, the only evidence supporting the idea comes from experiments with rats.

Weight Watchers

A much more robust set of studies has looked at Weight Watchers, one of the most enduring diet programs. Initially just an informal support group, Weight Watchers has developed into a multifaceted, multitrack weight loss plan. Many nutrition experts approve of Weight Watchers because it stresses that weight loss and maintenance require long-term lifestyle changes, including more physical activity, and it teaches the skills and provides ongoing support for those changes—addressing the psychosocial as well as the physiologic facets of weight loss.

Unlike many other weight loss systems, Weight Watchers does not eliminate or overly restrict any food or food group, so adherents claim to feel less deprived. Users can count calories with the help of several tools that assign proxy values (Weight Watchers' trademarked Points system), including an online portal, or they can use a new program that permits unlimited consumption of "filling foods" from all the food groups.

A 2008 study tracked down a random sample of successful Weight Watchers participants who had met their weight loss goals and achieved lifetime membership status. Upon weighing these participants, the investigators found that half had maintained at least 5% of their weight loss after five years, and one-sixth (16.2%) remained below their goal weight at the five-year mark. The authors of the study note that these results far exceed those found in most randomized, controlled trials of lifestyle changes for obesity treatment. But that may be due largely to the fact that study subjects were recruited from only the most successful subgroup of Weight Watchers members.

Rich with vegetables, beans, nuts, olive oil, and whole grains, the Mediterranean diet has been linked in observational studies with a high quality of life and low rates of chronic disease. A recent meta-analysis of observational studies of the Mediterranean diet concludes that those who adhere to it enjoy significant reductions in overall mortality, death from heart disease, incidence of and death from cancer, and incidence of Parkinson's and Alzheimer's disease.

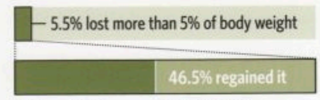
The diet is less clearly responsible for weight loss: a review of studies revealed just one that associated the Mediterranean diet (35% fat, calorie-restricted) with weight loss, compared with a low-fat (20%), calorie-restricted diet with the same calories (1,200–1,500 per day). After 18 months, the Mediterranean diet group had lost an average of 4.8 kg / 10.5 lb, while those in the low-fat group had begun to gain back their initial impressive weight loss (an average of 5.1 kg / 11.2 lb) to average a 2.9 kg / 6.4 lb loss.

Investigators in the Nurses' Health Study II, a long-term prospective study, assessed the weight loss success of young and middle-aged women. More than half of the women who lost more than 10% of their body weight gained it all back.

NURSES' HEALTH STUDY II

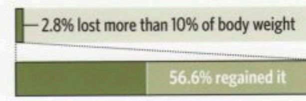
Studied outcome: long-term weight loss
Study duration: six years
Participants: 47,515

Results: 2,590 lost >5% of body weight



Of those 2,590 women, 1,204 (46.5%) regained, within 5 years, all weight lost

Results: 1,326 (2.8%) lost >10% of body weight



Of those 1,326 women, 751 (56.6%) regained, within five years, all weight lost

The Nurses' Health Study II also suggested the more weight women lost, the more they regained compared with their peers. Weight-stable women were more likely to use exercise for weight control than nonweight-stable women; cyclers were more likely to diet than noncyclers.

NURSES' HEALTH STUDY II

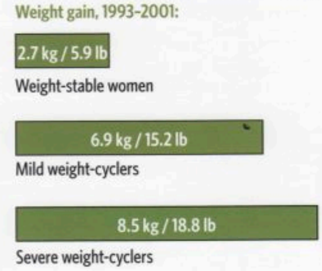
Studied outcome: long-term weight change after multiple cycles of weight loss and regain
Study Duration: eight years
Participants: 544 women who remained weight-stable from 1989-1993

741 mild cyclers who lost ≥4.5 kg / 10 lb three times from 1989-1993

224 severe cyclers who lost ≥9 kg / 20 lb three times from 1989-1993

Results: women who were weight-stable from 1989 to 1993 had gained the least weight by 2001; women who were severe cyclers gained the most weight

Weight gain, 1993-2001:



One way to determine the number of calories in a food is to place a sample of it in a pressure vessel (or "bomb"), flood the chamber with pure oxygen to a pressure of 20 bar / 290 psi, then use a red-hot, electrified platinum wire to set the food on fire. As it burns, the food heats water around the bomb, and a thermometer measures the temperature increase, which is then converted into calories. Although this method is fast and convenient, it is not especially accurate because the energy obtained by combusting the food is not the same as the net energy obtained by digesting it in a human body. Some foods, such as those very high in insoluble fiber, burn well but pass through the body largely undigested.

Atkins, Zone, and Spectrum

The Atkins diet coerces the body into **ketosis,** a condition in which it burns its fat reserves for fuel, by restricting carbohydrates to about 20 grams per day in the first two weeks (increased later on). Whether one is in the beginning weeks or in the maintenance phase, the plan prohibits refined sugar, milk, white rice, and white flour. Eating meat, eggs, cheese, and other forms of protein is encouraged. Carbohydrate consumption can be gradually increased as long as weight loss is maintained. The diet is highly controversial because of its high fat content and because it is one of the most restrictive diet plans.

The South Beach Diet is similar to Atkins but restricts saturated fats more and considers the glycemic index of a food (the degree to which a food causes you to release insulin) rather than grams of carbohydrates.

The Zone diet recommends 30% protein, 30% fat, and 40% carbohydrate to regulate the amount of insulin the body releases in response to blood sugar. It does not restrict calories but does prescribe portion sizes: protein portions should be about the size of your palm, and the amount of "good" carbohydrate (lentils, beans, whole grains, most fruits and vegetables) should be about twice the amount of protein consumed. If the carbohydrates are processed, they should be eaten in smaller amounts. The Zone limits saturated fats but not olive oil, canola oil, nuts, and avocado. It gets mixed reviews from nutrition experts, who like that it is easy to follow but criticize the scientific rationale.

Developed as part of Dr. Dean Ornish's program to reverse heart artery blockages without surgery, the Spectrum diet is high in fiber and low in fat. Rather than counting calories, Spectrum groups foods into how often they can be eaten.

Fruits, vegetables, grains, beans, and legumes can be eaten until satiety. Nonfat dairy can be eaten in moderation. All meats, oils, nuts, seeds, regular dairy, and sugar, along with most processed foods, should be avoided.

According to Ornish, this eating plan should result in a diet in which less than 10% of the calories come from fat. Ornish argues that by eating whatever quantity we like of low-calorie foods, we convince our Neolithic, feast-or-famine metabolisms to continue to work even though we are consuming few calories. In addition, the high fiber content slows intestinal absorption and prevents blood sugar levels from spiking. Although most medicos endorse the Spectrum plan, dieters find it hard to stick with because it is so restrictive.

What works? Many nutrition experts conclude that all reduced-calorie diets produce short-term weight loss regardless of their composition. In a 12-month randomized trial of the Atkins, Zone, Spectrum, and (low-fat) LEARN diets in overweight, premenopausal women, those on the Atkins diet had lost an average of 4.7 kg / 10.4 lb. Weight losses on the LEARN, Spectrum, and Zone diets were 2.6 kg / 5.7 lb, 2.2 kg / 4.9 lb, and 1.6 kg / 3.5 lb, respectively.

An earlier, one-year-long randomized trial of Atkins, Spectrum, Weight Watchers, and Zone found no statistical difference in the amount of weight that women lost on each diet. Women on the more restrictive diets, Atkins and Spectrum, were more likely to stop following the diet plans than their peers on Weight Watchers and Zone. Studies also show that, despite initial weight loss success, most dieters eventually regain weight.

Which diet is healthiest? As low-carbohydrate diets soared in popularity, many studies were done to compare their effects on cholesterol and other measures with those of conventional low-fat diets. The studies were relatively small, but nearly all showed that low-carbohydrate diets reduced total triglycerides and raised HDL ("good") cholesterol. The effect of low-carbohydrate diets on LDL ("bad") cholesterol varied from study to study, representing every possibility—perhaps reflecting the genetic variability in LDL cholesterol response to dietary fat.

A few studies included additional blood tests whose results indicated that C-reactive protein, which is thought to predict inflammation related to heart disease, was reduced and vitamin B_{12} was significantly increased. When the Mediterranean diet was included in comparisons, it generated the best insulin responses from volunteers. A study that compared the Atkins, Spectrum, Weight Watchers, and Zone diets found that risk factors for heart disease were reduced as people lost weight. Risk reduction was not associated with a particular diet.

CONTROVERSIES

Is Low Fat the Problem?

When it comes to national dietary guidelines, there is a running theme: the solution becomes the problem. Nowhere has that theme been more apparent than in the ongoing war on fat.

For 30 years, the government, food companies, the public health community, the exercise industry, and plenty of others have vilified dietary fat as a substance in food that can, among other things, wreck your heart and make you obese. This effort has changed the way many millions of people eat. Store shelves are stocked with literally thousands of often unappealing low-fat and nonfat foods.

The war has worked, in one sense: fat consumption is down in the United States for both men and women. Official health statistics suggest that in the U.S., the percentage of fat calories in adult diets (top chart at right) has been edging downward, from about 45% in the 1950s to something closer to 33% by the early 2000s. That's pretty good progress.

But here's the thing: obesity is way up (bottom chart). In 1990, no state in the U.S. had a prevalence of obesity higher than about 15%; in 2008, only one state had an obesity rate less than 20%, and 32 states had obesity rates of at least 25%.

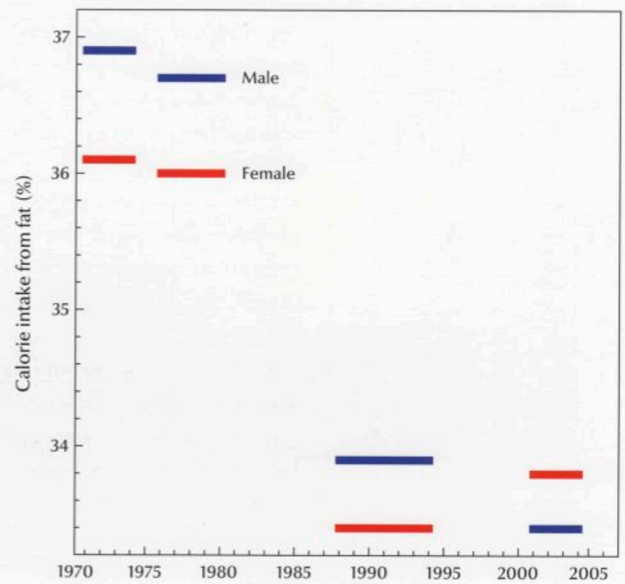
These findings lead to a paradox. The low-fat message is trying to prevent obesity. The data tell us that the low-fat message worked; we did cut at least some of the fat from our diet. But obesity has increased, and nobody is sure why.

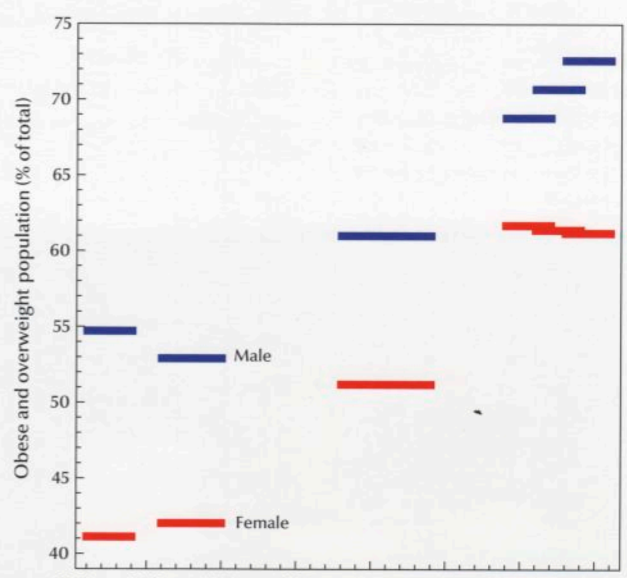
To explain society's widening collective girth, observers have pointed to sedentary lifestyles, the supersizing of food portions and calorie-packed drinks, and the affordability of consuming larger quantities of food. Cutting back on fat may not be enough if we overeat everything else.

A few scientists have advanced a bold suggestion: perhaps some obesity is actually *caused* by the low-fat approach. They argue that demonizing fat only encourages people to switch to a carbohydrate-heavy diet.

The biological effects of this switch are complex and poorly understood. Some evidence suggests that consuming excess carbs throws the body's insulin metabolism out of whack in ways that increase hunger, overeating, and ultimately the accumulation of fat in the body. Another possibility is that commercially processed low-fat foods simply encourage people to eat more.

Unfortunately, science just is not yet up to the task of answering many crucial nutritional questions, such as how much dietary fat is good for you or whether a low-fat diet will reduce your weight. Almost every national recommendation that the public drastically increase or diminish consumption of a particular dietary component thus effectively encourages hundreds of millions of people to take a leap of ignorance. When it comes to the public health problem of obesity, the leap to low-fat diets has not stopped the epidemic—and it may even have made the problem worse.





Vegetarianism

All vegetarians avoid eating the flesh of animals, but some restrict their diets further. Vegans do not consume any animal products at all. They obtain protein primarily from legumes. Lacto-ovo vegetarians eat dairy products and eggs. Ovo vegetarians eat eggs but not dairy products. Lacto vegetarians eat dairy products but not eggs. Then there are semivegetarians, who eat only certain kinds of animal flesh and avoid all other kinds. Some people, for example, eat poultry and fish, but not red meat.

It is difficult to determine scientifically whether excluding animal products from one's diet conveys health benefits because the people who choose vegetarianism generally are more health-conscious than their meat-eating peers, as illustrated by their choice to restrict what they eat. For a study to demonstrate convincingly that vegetarianism is a healthier choice, it must also account for the lower rates of smoking and drinking and higher rates of exercise among vegetarians than among their peers.

As of this writing, no randomized, controlled clinical trials have investigated the effects of vegetarianism on healthy people in the long term. But some small trials have tried to gauge such a diet's effect on heart disease and diabetes. Dean Ornish, M.D., developed an extremely low-fat, vegetarian diet and lifestyle intervention to treat heart artery blockages. Patients who followed his plan enjoyed less-clogged arteries and fewer heart attacks than patients in the control group, who suffered more than twice as many heart-related ailments.

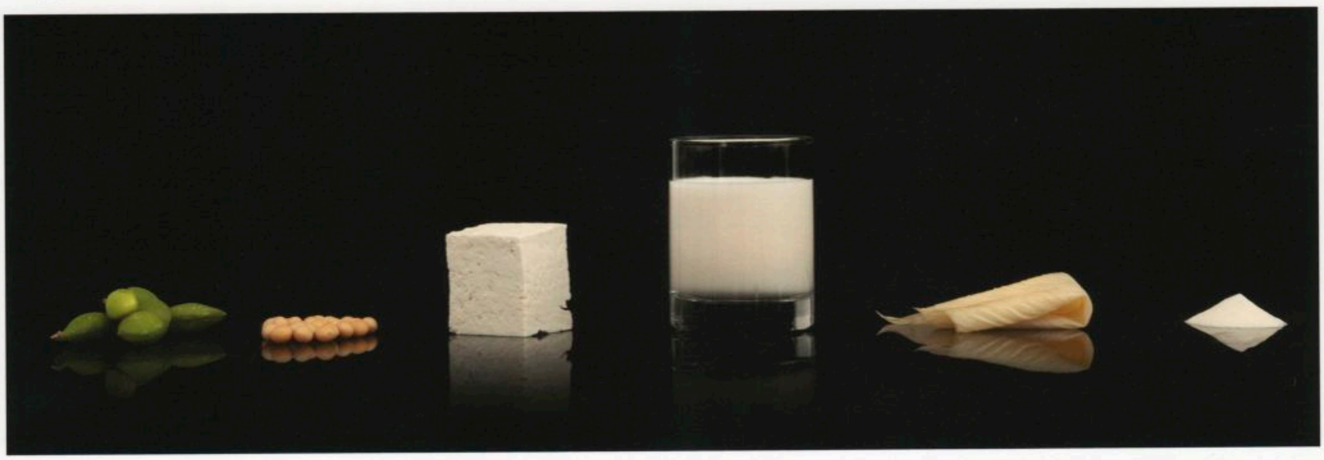
In another study, people with diabetes who ate a vegan diet experienced fewer peaks and dips in blood sugar concentrations than did those who ate the traditional diet recommended for diabetics. Unfortunately, as we have seen, it can be problematic to generalize from small-scale studies. Whether these results would hold up in large prospective randomized studies is anybody's guess.

One thing that is certain about vegetarian diets is that they are high in fiber and low in saturated fats, two characteristics that studies have associated with a lower body mass index (BMI). Moderate BMIs are, in turn, associated with lower rates of heart disease and diabetes. But as we have also seen, saturated fat seems uncorrelated with cardiovascular disease.

On the other hand, vegetarians sometimes suffer from a lack of protein in their diets, which one study has associated with a higher incidence of wrist fractures in menopausal women. Another study of more than 9,000 vegetarian women found that semivegetarian and vegetarian women reported more menstrual problems, anemia, iron deficiency, depression, and anxiety than their nonvegetarian counterparts.

That correlation does not necessarily indicate that a vegetarian diet is to blame for these troubles. It may be that people with physical and mental health issues turn to restrictive dietary systems like vegetarianism as part of their search for relief from their ailments. Until a carefully designed, large-scale, long-term intervention study is completed, there is no sure way to know whether health issues lead to vegetarianism or vice versa.

The soybean is one of the cornerstones of vegetarianism and comes in many forms, including edamame (fresh soybean), mature dried soybean, tofu (see page 4·102), soy milk (see page 4·56), yuba (see page 4·115), and soy protein flour. Soy can be an important source of protein, which is often scarce in vegetarian diets. Soy also contains lecithin, an important emulsifier (see page 4·214).



Organic Food

Many devotees of organic foods have the perception that these foods are healthier because they are all-natural, grown without chemical fertilizers, pesticides, or herbicides. And yet we are aware of no scientific study that has proven that man-made agricultural chemicals result in harm to people who buy and consume nonorganic fruits, vegetables, meats, or prepared foods.

Exposure to large amounts of agricultural chemicals can be dangerous, to be sure (and environmental consequences are outside the scope of this discussion), but there is a notable lack of scientific evidence that consumers are suffering deleterious health effects from any exposure they might get to agricultural chemicals from the usual methods of food preparation and ingestion.

In fact, sometimes it is the plants themselves that cause harm because they have evolved a series of toxic responses to being eaten by pests—pests that agricultural chemicals would have eliminated. If organically grown plants are stressed by insect infestation, for example, they may produce higher amounts of toxins (see Natural Toxins on page 249). These toxins repel pests naturally, but they are not necessarily safe for ingestion by humans.

Organic farmers have made ingenious use of such "natural" pesticides—for example, using tobacco to make a sort of nicotine-laced infusion that is sprayed on plants to kill aphids. The irony here is that nicotine has been well studied and shown to be poisonous to humans. Yet it is allowed for treating organic foods because it is "natural," whereas pesticides that are actually much safer and less toxic to humans are not allowed. This doesn't make much sense.

There are other examples. Legal loopholes in the definition of "organic" mean that organic farmers are allowed to use other powerfully toxic pesticides such as pyrethrum and rotenone, which has been linked to Parkinson's disease in humans. These compounds meet the criterion for organic labeling because they are extracted from plants—but that doesn't make them any less potentially harmful to humans than other pesticides are.

Billions of dollars in revenue ride on the ability of manufacturers to claim their food is "organic." One of the fastest-growing sectors in the food business in recent years has been the manufacture of organic versions of most food ingredients. A so-called organic muffin is leavened with baking soda, which is, scientifically speaking, an inorganic substance (not a product of a living thing). Baking soda is purified by a process that surely is chemical in nature, and frankly you don't want to forgo that step because it eliminates potentially hazardous contaminants.

The definition of organic also affords loopholes for table salt, nigari (magnesium salts used in making tofu), and other ingredients that have manifestly chemical origins or purification steps.

Even novel-sounding ingredients used in Modernist cuisine, many of which have been used in industrial-scale food production for decades, are available in certified organic form (see Modernist Ingredients, page 250). Most organic proponents would consider some of these ingredients—hydrocolloid gums, modified starches,

For more on natural toxins produced by edible plants themselves, see Plants as Food, page 3·262.

Organic food has moved from the farmer's market to big business. Processing plants such as this one in Arizona are a symbol of the organic food movement's explosive growth in recent years.

Organic foods, with labels promoting organic status, have become a multibillion dollar business. What was once a synonym for high-quality, artisanally grown produce is now a marketing slogan.

"artificial" sweeteners, and so on—the antithesis of organic. But they bear the label.

These ingredients are not necessarily more costly to produce in order to achieve the organic label, but the assurance still comes at a price. Consumers have shown they will pay more for a largely meaningless organic certification, so the food companies respond accordingly.

One reason for the price premium seems to be widespread belief that organics are held to a higher standard of safety and that organic foods retain more of their nutrients than nonorganic foods do. The few scientific studies on these matters are complicated by inconsistencies in the locations where the tested foods—all purchased at stores—were grown, how mature they were when harvested, how fresh they were, and what variety they were.

A study was published in 2009 that systematically reviewed all the scientific studies comparing the nutritional value of organic and nonorganic foods. Of the 162 studies the investigators found in the scientific literature, just 55 were of satisfactory quality; the rest were fatally flawed by uncontrolled variables, biases, or other methodological problems. The reviewers concluded that the high-quality studies showed "no evidence of a difference in nutrient quality between organically and conventionally produced foodstuffs."

At the beginning of the organic food movement, the organic label usually meant a small producer was using traditional methods of growing. Growers would often use heirloom varieties, and their product was distributed only within their locality. Food grown like this by small, artisanal producers often tastes much better. They pick in small quantities only at the peak of freshness. They take care in packaging and ship quickly to the restaurant or farmer's market.

Food like this is a joy to cook with—it has taste and texture that you just can't find in mass-produced food—but very little of that extraordinary quality is directly due to the food's being organic. Mostly it flows from the care and skill of the small producer, who must survive on quality rather than quantity. Many chefs develop direct relationships with farmers like these to get the very best and freshest produce for their restaurants. Networking with these artisans is more important than relying on a legalistic definition like "organic."

In recent years, that bucolic version of organic food has shrunk to become a small part of the giant organic food market. As more of the public asked for organic food and paid a premium, big agribusiness responded. In most rich countries, the majority of "organic" food is now grown in huge volumes for supermarkets, not farmer's markets. It is picked early and shipped far. This food may technically be organic, but it often lacks the wonderful taste and texture of small-volume, artisanally produced food.

Raw Food

One of the more recent dietary fads is the raw food diet. Proponents argue that the best way to eat is to consume food only in its raw state, which they usually define as having reached a maximum

The latest buzzwords in the food industry are "local" and "sustainable." These terms have come to describe many of the same qualities that once characterized organic foods: hiqh in quality and sold soon after harvest for optimal taste. This pursuit of excellence is a wonderful goal, but the open question is whether this focus on quality will last. In the case of organic food, industrial-scale food producers quickly caught on and ultimately undermined the meaning of the term. It remains to be seen whether "local" and "sustainable" will experience that semantic degradation.

temperature of 46–47 °C / 115–118 °F, which supposedly prevents the breakdown of beneficial enzymes in food.

Is raw food better for you? As of this writing, no large randomized and controlled clinical studies of a raw food diet have been published. Several teams of investigators have evaluated the health status of participants in the raw food movement, however, and what they have found is disturbing: people who stick to raw food diets for several years show many signs of malnutrition.

For example, when researchers examined more than 500 subjects who had been eating a raw food diet for an average of nearly four years, they found that 15% of the men and 25% of the women studied were underweight. Nearly one-third of the women in the study had stopped menstruating.

The more raw food the subjects ate and the longer they had been on a raw food diet, the lower their body mass index. The investigators concluded that, over the long term, a strict raw food diet cannot guarantee an adequate energy supply.

Another study found that the mean body mass index of raw foodists was 25% lower than that of people who ate a typical American diet. Raw foodists had lower bone density in their backs and hips than those eating conventionally. And because of the large amounts of fruit acid that raw foodists regularly consumed, they had more dental erosions than those who ate a normal diet.

Although a raw food diet seemed to confer cardiovascular and cancer-preventing benefits, it also led to dietary deficiencies. As a group, strict

THE CHEMISTRY OF

Those Dreaded "Toxins"

"Toxin" is a perfectly appropriate word for a substance that is toxic or poisonous. Unfortunately, the word has been widely used inappropriately by people who promote various dietary systems. Vegans, raw foodists, organic food fans, and proponents of faddish dietary systems all tend to claim that their approach either excludes toxins or, better yet, "flushes toxins from the body."

One of the more successful detox diet divas is Ann Louise Gittleman, author of the 2001 *New York Times* bestseller *The Fat Flush Plan.* Gittleman explains her diet this way: "excess fat, sugar, alcohol, and caffeine—along with antidepressants and birth control pills—work to sabotage your weight loss efforts by creating a tired and toxic liver that can't efficiently burn body fat. The Fat Flush Plan is designed to clean out the liver and help you drop a dress size or two."

The liver does need numerous vitamins, minerals, and amino acids to do its job of processing and removing drug metabolites, pesticide residues, and hormone-disrupting chemicals. It is doubtful that detox "diets" like the popular Master Cleanse—which requires consuming nothing for 10 days but lemonade sweetened with maple syrup and spiked with cayenne pepper—can provide enough of these nutrients to keep the liver functioning properly for very long.

Moreover, the misuse of the words "toxic" and "toxin" by food faddists is so pervasive that the safest bet is to assume that any claim that a diet removes toxins from the body is almost certainly false.

Your body does not produce toxins that need to be exorcised. Although waste products of metabolism, including carbon dioxide and urea, must be expelled, they are not toxic in the sense that they cause poisoning in a healthy person. Indeed, waste products from metabolism are *always* found at some level in your body. True toxins, on the other hand, kill or harm you even at low concentrations.

Statements to the effect that meat or cooked food is "full of toxins" are plainly false (see Is Grilled Meat Bad for You? on page 221). Many foods do contain small quantities of naturally occurring substances that can, in high concentrations, be harmful (see Natural Toxins, next page). But there is no general need to "flush" these toxins, and claims that particular dietary systems or food items exert a beneficial effect by removing these so-called toxins are not backed by scientific evidence.

The theme of purification is common to virtually all food superstitions and shamanistic practices throughout history, so it's not surprising that advocates of fad dietary systems promote the removal of "toxins." It is the dietary equivalent of exorcising demons or evil spirits. To sell people on a scheme you need to tell a story, and a purification story makes intrinsic sense to people, even if the details turn out to be false.

raw foodists had low serum cholesterol and triglyceride concentrations, which are considered heart-healthy. Nevertheless, because raw food diets are typically low in vitamin B_{12}, subjects who ate a strict raw food diet were deficient in this key nutrient. As a result, they had low serum HDL cholesterol levels and high homocysteine levels, which are both considered risk factors for heart disease.

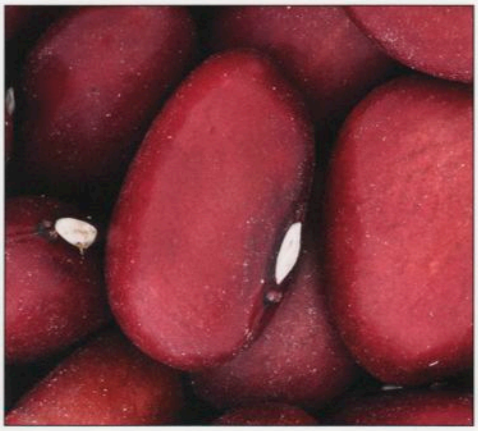
Most raw food dieters in yet another study had lycopene levels in the blood that were just a quarter of those present in people who ate cooked food. Lycopene is an antioxidant found primarily in tomatoes, and lycopene levels in cooked tomatoes are much higher than those in raw tomatoes.

Raw foodists believe their diet provides a way to achieve vibrant health, but the evidence suggests that eating food raw is a poor alternative to eating it cooked. After all, women who do not menstruate probably cannot conceive. Any diet that renders many women unable to propagate their genes puts the species at an evolutionary disadvantage—and that may be the strongest evidence yet that humans were not meant to eat all their food raw.

Moreover, raw foodists do not eat as our primate forebears did because they rely on high-quality fats from vegetables and seeds, machine-processed grains for ease of digestion, and juicers and blenders—modern creations, all of them. Cooking has been practiced by every known human society for good reason. It reliably increases the digestibility of food, and in so doing, makes it more nutritious.

Natural Toxins

Many of these chemicals are present in a variety of foods, but poisonings involving these particular vegetables have made them the poster children for natural toxins.



Potato

Toxin: glycoalkaloids
Effect: causes severe stomachache, nausea, vomiting, difficulty breathing, even death

Red kidney bean

Toxin: phytohemagglutinin
Effect: eating undercooked beans can cause severe nausea and vomiting with diarrhea

Rhubarb

Toxin: oxalic acid
Effect: at highest amounts in leaves; causes stomach irritation and kidney damage

Parsnip

Toxin: furocoumarins
Effect: causes stomachache; skin contact increases sun sensitivity and can cause blisters

MODERNIST INGREDIENTS

Modernist cooking is in many ways defined by its use of ingredients—as well as techniques and equipment—that are still new or unfamiliar to most chefs. And just as Modernist techniques such as slow, low-temperature sous vide cooking in water baths and fast freezing in liquid nitrogen have raised some new kitchen safety issues, Modernist ingredients like gellan, xanthan gum, and other exotic-sounding compounds have led some to voice concerns that Modernist food might pose health risks. We are frequently asked, "Aren't your dishes chock full of chemicals?"

We respond to that question with the honest answer, "Of course they are—just like all food." After all, everything in food is a chemical compound. Just 90 elements occur naturally on Earth. All matter on Earth is made from those elements, linked in various ways into compounds—that is, chemicals. All food, even the most natural or organic, thus also consists entirely of chemical compounds.

This book uses the same alphabet and the same vocabulary of words as other books do. Yet this book is clearly different from a spy novel, a mathematics textbook, or even other cookbooks. What makes it unique is not the letters or words in it, but rather how those basic building blocks are composed into sentences, paragraphs, and chapters.

In the same way, all matter on Earth is composed of the same "alphabet"—the elements—which are further composed into new "words": chemical compounds. The manner in which these compounds are combined in a particular food gives it a unique taste and texture in the same way that the words in sentences and paragraphs make a particular text unique.

When people ask about "chemicals" in food, what they really mean is: "Are there bad chemicals in this food that could harm me?" The short answer is "No," but the full answer is complex and interesting enough that it warrants further examination.

Many people are suspicious of food additives that they perceive as "chemicals," which have become associated in the popular imagination with low quality or health hazards. The reputation for low quality is a result largely of the heavy use of such additives by the packaged food industry, which is driven primarily by a search for cheaper ready-to-eat food products with longer shelf lives. Ideally, everyone would like to maintain high quality along with lengthy shelf life and low prices, but the reality is that in most cases something has to give, and quality is usually what suffers.

Preservatives—additives that counteract the normal processes by which food goes stale—slow spoilage, but they don't prevent food products from degrading on the shelf. So stored food is almost never as good as it was when fresh—but it's usually the aging, not the preservatives, that lowers the quality. Nevertheless, these products tend to give all synthetic food ingredients a bad reputation.

Artificial flavors pose another quality issue. A synthetic flavoring product usually captures only a few limited aspects of a natural flavor. Natural flavor usually emerges from a complex mixture of dozens or even hundreds of different flavor compounds. A synthetic flavoring typically matches only a small number of these, so it lacks the rich complexity of the original taste.

For example, vanillin, the synthetic version of vanilla, creates a sensory experience that is nowhere near as compelling as that produced by natural vanilla beans. Although synthetic vanilla is an inferior substitute for the original, it exists because it is cheap to produce.

Firmenich, Symrise, Takasago, and other dedicated companies produce product flavorings and essences that are high in quality (and often

Pectin is one of the hydrocolloid gums that have revolutionized Modernist cooking. Yet it has been used by jam and jelly makers for a very long time. It is purified from orange peels.


4

correspondingly high in cost). It is unfortunate that their products tend to get lumped in the public's mind with cheaper and less satisfying flavor compounds.

Under a Watchful Eye

Worries about the safety of food additives are largely hangover effects from public scandals in which ingredients were discovered to be tainted or unsafe. Cyclamate, an artificial sweetener widely used in diet soft drinks, was banned in the United States in 1969 because of concerns that it could cause cancer. In 1976, the FDA banned Red Dye #2, a widely used artificial food coloring, again because of suspicions that the compound is carcinogenic. These high-profile actions undermined public confidence in artificial food ingredients.

But a closer examination reveals that these bans, if anything, demonstrate the vigilance of food authorities. Cyclamate was banned in the U.S. after a study showed it increased bladder cancer in rats. The rats were fed a dosage that, in human terms, is equivalent to drinking 350 cans of diet soda a day. Because even the heaviest soda addict could never consume diet drinks at that rate, the studies were controversial. Cyclamate remains approved in 55 countries, including Canada and most of Europe. A later review by the FDA of all available evidence concluded that cyclamate is not linked to cancer. Yet it remains banned in the United States because the FDA has been unwilling to accept proposals to relist it.

Red Dye #2 has a similar history. The original suspicion was raised by a Soviet study, eventually replicated by the FDA, in which rats ate the dye at a dosage equivalent to 7,500 cans of diet soda per day. Despite the impossibility that a human could ingest this dose, consumer advocate groups and lobbyists called for a ban. The FDA responded by banning Red Dye #2 even as it insisted that the link was too tenuous to issue a finding that the dye causes cancer. Noting that the link between the compound and cancer was unproven, Canada and most European countries have allowed Red Dye #2 to remain in use.

These examples suggest that the FDA is quick to ban suspect ingredients, even before credible evidence shows that they are harmful. Canadian and European food safety agencies have required far more compelling evidence than the FDA has before they ban a substance. It comes down to a simple issue: are food regulations about politics and suspicion, or are they about science?

Many people, however, have drawn the opposite conclusion from these examples. Because a handful of food additives have been banned, they believe all food additives should be suspected to be harmful until proved innocent.

Another common myth arises when pesticides and other nonfood contaminants are confused with legitimate food additives. The two are quite different; additives are *deliberately* added, but pesticide residues are accidental contaminants that aren't supposed to be in the food at all. Complicating the issue, the organic food movement conflates

Alginate gels became famous when Ferran Adrià used them to create "spherified" foods. But alginates have been used for decades to make the pimento strips stuffed into olives. Alginate may seem exotic, but everybody who has ever had a martini has had some.

THE NATURAL HISTORY OF

The Gum Eater

At weights up to 20 kg / 44 lb, the kori bustard (*Ardeotis kori*) is the heaviest flying bird in the world. It lives in Africa, where it mostly walks on the ground, flies only sporadically, and thus enjoys a lifestyle much like that of a turkey. Like humans, the bird is an omnivore; it eats seeds, fallen fruit, lizards, insects. It also eats one other food that is rather unusual and that earned it the Afrikaans name *gompou,* meaning gum eater.

One of the kori bustard's favored foods is the gum of the acacia tree (right), the same gum that we know as gum arabic. It's unclear why the birds eat the gum. One theory is that they digest the gum and derive nutrition from it, as do vervet monkeys and many other African animals. But another possibility is that the animal is really dining on a protein-filled gel: the gum along with the array of protein-rich insects that get trapped in the sticky substance.

food additives with pesticides and other non-organic farming practices. It is common to hear members of the public, including chefs, say in a single breath that they don't want "chemical additives, preservatives, or pesticides" in their food—as if they are three of a kind.

Conversely, fans of organic food too often view anything labeled "organic" as also "natural" and "pure"—and therefore better to eat. Some of the ingredients in Modernist food sound like some-thing to be wary of because their exotic names don't sound "natural." Yet, as we reported above, large-scale studies have not shown any health benefits for people who consume only organic food. Moreover, being natural is a relative thing. Many food products are highly processed and bear no resemblance to their original state—see Good Old-Fashioned Chemistry, page 256. Sugar, flour, butter, heavy cream, and gelatin are kitchen staples refined by the processing of natural ingredients. So are wine, vinegar, and hard liquors like brandy and whiskey.

The resulting products are unrecognizable as the starting form. White sugar is utterly unlike molasses. Gelatin sheets used in desserts don't resemble the pig or fish skin that they are refined from—thank goodness!

The same is true of many Modernist ingredients—see The Newfangled Naturals, page 257. Gum arabic is made from the sap of a tree, and locust bean gum comes from, yes, the locust bean. Most hydrocolloids, in fact, have their origins in either plants or bacteria. Agar, alginate, and carrageenan come from seaweed. Pectin is made from fruit skin (mainly that of oranges squeezed for orange juice). Xanthan gum and gellan—just like yogurt and vinegar—are derived through fermentation by bacteria.

Modernist cooking includes the use of many ingredients that are unfamiliar and that have names that sound scary and unnatural. But there is no objective reason to treat them any differently than refined sugar, salt, vinegar, baking soda, or many other ingredients we take for granted.

It is hard see any rational reasons to use sugar refined from sugar cane or beets but to rule pectin refined from orange peel out of bounds. Both products result from a series of processing steps that refine and purify a natural product. In both cases, you can specify (and pay more for) "organic" versions, if you wish.

If anything, Modernist ingredients are subjected to higher safety standards than traditional foods because they are highly purified and so must meet strict FDA approval requirements to be allowed in food. The manufacturers that make these ingredients follow very stringent specifications for purity because their industrial customers are very demanding. Companies like Nestlé and Coca-Cola that use these ingredients in their packaged foods have billions of dollars at stake. They perform thorough chemical analyses with teams of chemists to ensure exact batch-to-batch consistency. As a result, these products are far purer and more consistent than anything else in a chef's kitchen.

Indeed, most Modernist ingredients have received much more testing than the familiar-seeming food in our home pantries. Traditional ingredients have been ushered past regulatory review by a grandfather clause that goes by the term "GRAS," which stands for "generally recognized as safe." These foods have *not* been subjected to carefully controlled tests and protocols.

It is often argued that sucrose—common table sugar—would face an uphill battle if it came up for approval as a new food additive. After all, it is refined in an industrial process, and it clearly can cause harm by promoting obesity, diabetes, and tooth decay. Because sucrose, which was originally sold in small quantities in apothecary shops as an exotic additive, met GRAS criteria, it has largely avoided the intense regulatory scrutiny that newer additives face.

In truth, the most important difference between so-called "artificial" additives and traditional additives like sucrose, baking soda, and baking powder is that the newer additives were completely tested for safety, whereas their older GRAS cousins entered the market in more lax times and thus escaped such testing.

Natural, Perhaps, but Not Better

Some Modernist ingredients are indeed artificial in the sense that they are produced via chemical synthesis. One example is ascorbic acid, better known as vitamin C. Besides its use as a vitamin essential for human nutrition, ascorbic acid is also very good at preventing the oxidative reactions that brown cut fruits or vegetables like apples, avocadoes, and endives.

Vitamin C can be refined from natural sources, such as rose hips (the fruit produced by rose flowers). But ascorbic acid made in this way will generally not be very pure because the source material also contains extraneous substances. Moreover, the amount of ascorbic acid present in a particular rose hip depends on the plant's nutrition, the amount of sun it got, and other variables. So the concentration of naturally derived vitamin C tends to be highly variable.

Inconsistency of this kind is a common problem with natural foods. Compare a peach at the peak of ripeness taken directly from the tree with a hard, unripe, out-of-season peach picked green and then shipped thousands of miles. The two are hard to recognize as the same fruit. That variability can pose real problems when cooking and developing new recipes.

But ascorbic acid can be synthesized easily, and the synthetic compound is identical to the natural product. It is much easier to purify, however, so its strength and concentration can be guaranteed. There is no scientific reason to prefer the natural product, with its impurities and variable concentration, to the pure synthetic. Indeed, just the opposite is true.

The same can be said for baking soda and baking powder, both caustic salts that are best created synthetically. The Solvay process, a series of chemical reactions, produces sodium bicarbonate from salt brine and limestone. These ingredients are also sometimes purified from mineral deposits such as natron, a naturally occurring caustic salt found in dry desert lake beds.

Neither approach is "natural" by most definitions, yet most chefs don't think of baking soda and powder as unnatural because of their long history and their ubiquity in our mothers' and grandmothers' cupboards. The reality, however, is that baking soda and powder are best used in pure form, and that purity comes from either chemical synthesis or chemical purification methods.

Modernist ingredients—from calcium salts used in gelling hydrocolloids to myriad pure versions of other nonflavor compounds—are no different from baking soda in this regard. Here, too, there is no scientific basis for labeling the newer compounds as unnatural while embracing baking soda, distilled vinegar, or other common kitchen chemicals. Nor is there any reason to be concerned about chemical engineering processes that extract, synthesize, or purify food ingredients.

Indeed, we can be reassured by the fact that the nontraditional ingredients used in Modernist cuisine have been used in high volume by the packaged food industry, usually for decades. If these products really caused harm, consumers would be dropping like flies—but of course they are not. The only thing truly novel and modern about these ingredients is their increasing use in fine dining and avante-garde gastronomy.

Yet some—in particular, certain traditionalist chefs—have persisted in claiming that Modernist cuisine is associated with health or safety risks. Some of them have even publicly attacked the use of these ingredients (see Santi Santamaria Versus elBulli, page 258). Scaremongering of this kind is irresponsible. If there were actual evidence of a health concern, complaints should have been brought to the appropriate food authorities so they could launch any investigations that are warranted.

Decide for Yourself

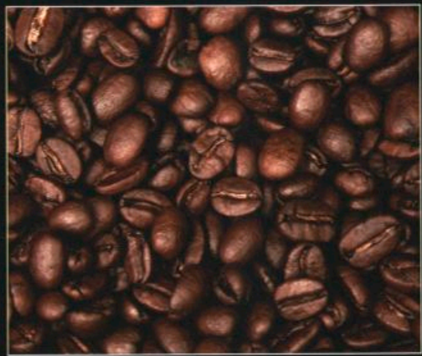
The sagas of fiber, fat, and salt teach us that it is very difficult to get the truth about the health implications of dietary choices. Three main factors cloud the issues. First, it takes a long time and a lot of money to rigorously test the benefits of a dietary system. Second, industrial food companies and advocates can make a very good living promoting claims, substantiated or not, about dietary systems. Third, even when ideas are proven to be false, they tend to linger as part of the conventional wisdom or popular viewpoint. Advocates want to keep selling diet books, nutrition experts hate to admit that they are wrong, doctors and health organizations want to maintain an aura of authority, and food companies want to keep selling products for which they can claim health benefits.

Today we know that butter seems to be okay, but trans fat-laden margarine could kill you: just the opposite of the conventional wisdom a generation ago. As medical science gains more understanding of the underlying causes of heart disease, cancer, stroke, and other common diseases, we may learn that there are some other real villains in what we eat. But it is also possible that we will find that some of these diseases are, by and large, unrelated to diet.

GOOD OLD-FASHIONED CHEMISTRY

Although we rarely think about it, many of the foods considered most natural, familiar, and safe are actually produced by chemical processing under the care and control of food scientists.

Baking soda
Made with calcium carbonate, salt, ammonia, water, carbon dioxide
Process: chemical purification from organic and inorganic sources



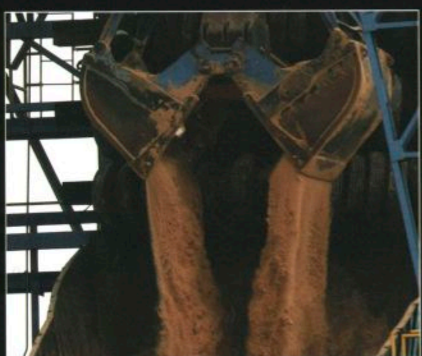
Decaffeinated coffee
Made with coffee beans and carbon dioxide
Process: critical point extraction (see page 4·363)

Gelatin
Made with pig or fish skin
Process: chemical purification from natural organic sources

Hard liquor
Made with fruits, sugars, grains, and other plant products
Process: fermentation then distillation

Maple syrup
Made with tree sap
Process: chemical purification from natural organic sources

Salt
Made with seawater, mineral salt
Process: chemical purification from inorganic sources



Sugar
Made with cane or beet juice
Process: chemical purification from natural organic sources

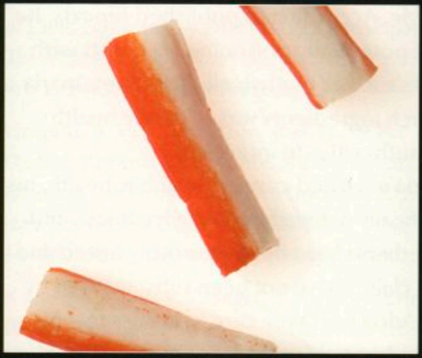
Vinegar
Made with sugars, yeast, bacteria
Process: microbial fermentation and sometimes distillation

Wine
Made with grapes, sugars, yeast
Process: microbial fermentation

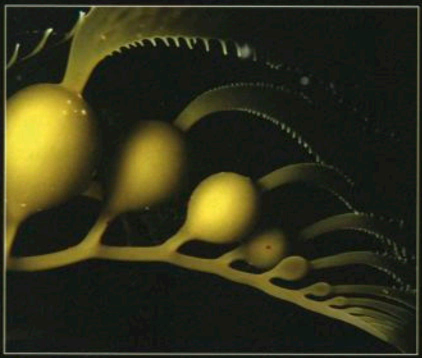
THE NEWFANGLED NATURALS

The methods used to make the Modernist ingredients below are the same as those used to produce the traditional ingredients listed on the previous page.

With the exception of xanthan gum, which is fermented, all the compounds below are made by chemical purification from natural organic sources.



Activa (transglutaminase)
Made with milk
Uses: binding, firming, improving creaminess



Alginate
Made with seaweed
Uses: thickening, spherification

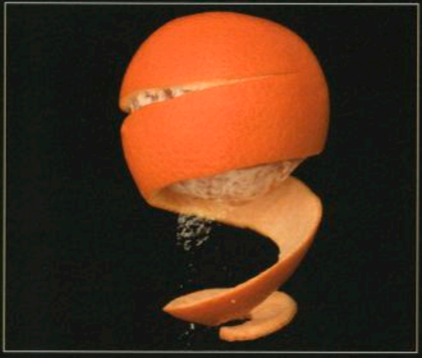
Carrageenan
Made with seaweed
Uses: thickening, clarifying, binding moisture

Guar gum
Made with guar seeds
Uses: thickening, homogenizing, binding

Gum arabic
Made with tree sap
Uses: binding

Locust bean gum
Made with locust beans
Uses: thickening, gelling

Modified starch
Made with tapioca starch from cassava root, other natural sources
Uses: thickening, stabilizing, emulsifying



Pectin
Made with orange rinds
Uses: thickening, gelling, stabilizing

Xanthan gum
Made with sugar, bacteria
Uses: stabilizing

THE HISTORY OF

Santi Santamaria Versus elBulli

Santi Santamaria is a successful and celebrated chef. His restaurant Can Fabes, situated just north of Barcelona, Spain, has held three Michelin stars for many years. It is by any standard one of the best restaurants in the world.

Santamaria is part of the great Catalan/Spanish revolution in food, to which several other Michelin three-star chefs, including Joan Roca of Can Roca, Carme Ruscalleda of Sant Pau, and Ferran Adrià of elBulli, have contributed. Together, these chefs have made Catalan Spain one of the great food destinations in the world.

So the food world was shocked when Santamaria made angry and provocative denouncements of Modernist food during a talk at the Madrid Fusion cooking conference in January 2007. Then, in 2008, he criticized Adrià and elBulli in particular. Some of Santamaria's complaints were about the aesthetic approach elBulli was taking in its dishes, and such differences among chefs about style are understandable and not uncommon. But Santamaria's criticisms went well beyond matters of style. According to published reports, he also accused Adrià of potentially poisoning his guests with Modernist ingredients such as methylcellulose. Santamaria said that the use of such ingredients was a "public health issue" and called on authorities to intervene.

Although Santamaria's avowed concern is public health, his position is not scientifically defensible. Methylcellulose and other Modernist ingredients have been rigorously tested and are safe. Santamaria's claims have not been substantiated by any food authorities. Adrià has taken care to ensure that his ingredients, though perhaps unfamiliar to some traditionalists, meet the relevant European Community standards.

Some chefs in Spain have been quoted as saying that Santamaria's real motivation is simple jealousy. Certainly his concerns about the public health hazards of Modernist ingredients are unfounded.

Eventually science will figure all this out, but until it does, the safest thing to say is that proof requires large, randomized clinical trials that take many years. Until the results of those are in, one can entertain lots of opinions but reach no genuine scientific closure on the issues.

Of course, science isn't the only measure by which people make dietary decisions. Food choices are intensely personal. Beyond palate and health concerns, these matters involve cultural and religious traditions. Often, discussing food preferences makes people emotional; they see themselves as protectors of the health of their families or patrons.

We strongly believe that people should eat what they want to eat; it is a fundamental aspect of personal freedom. If you want to eat a certain way, then by all means go ahead. Our goal in this chapter is to relate the most current research results so that you can make an informed decision.

Chefs and consumers thus must make judgments based on the numerous parameters served up by their personal experiences and the available facts—which we hope you are now better able to distinguish from hyperbole. Modernist ingredients are frequently the subject of such hyperbole, even though they've been used in mass food production for decades and have withstood intense regulatory scrutiny.

Perhaps the most modern thing about these ingredients is that they are now "open source." Whereas once they were available only to industrial chefs, now restaurant chefs and cooking enthusiasts can experiment with them as well.

As food enthusiasts and practitioners of Modernist cuisine, we hope you feel more confident in making choices about the food you eat and serve while not begrudging yourself the pleasure of new food experiences.

Further Reading

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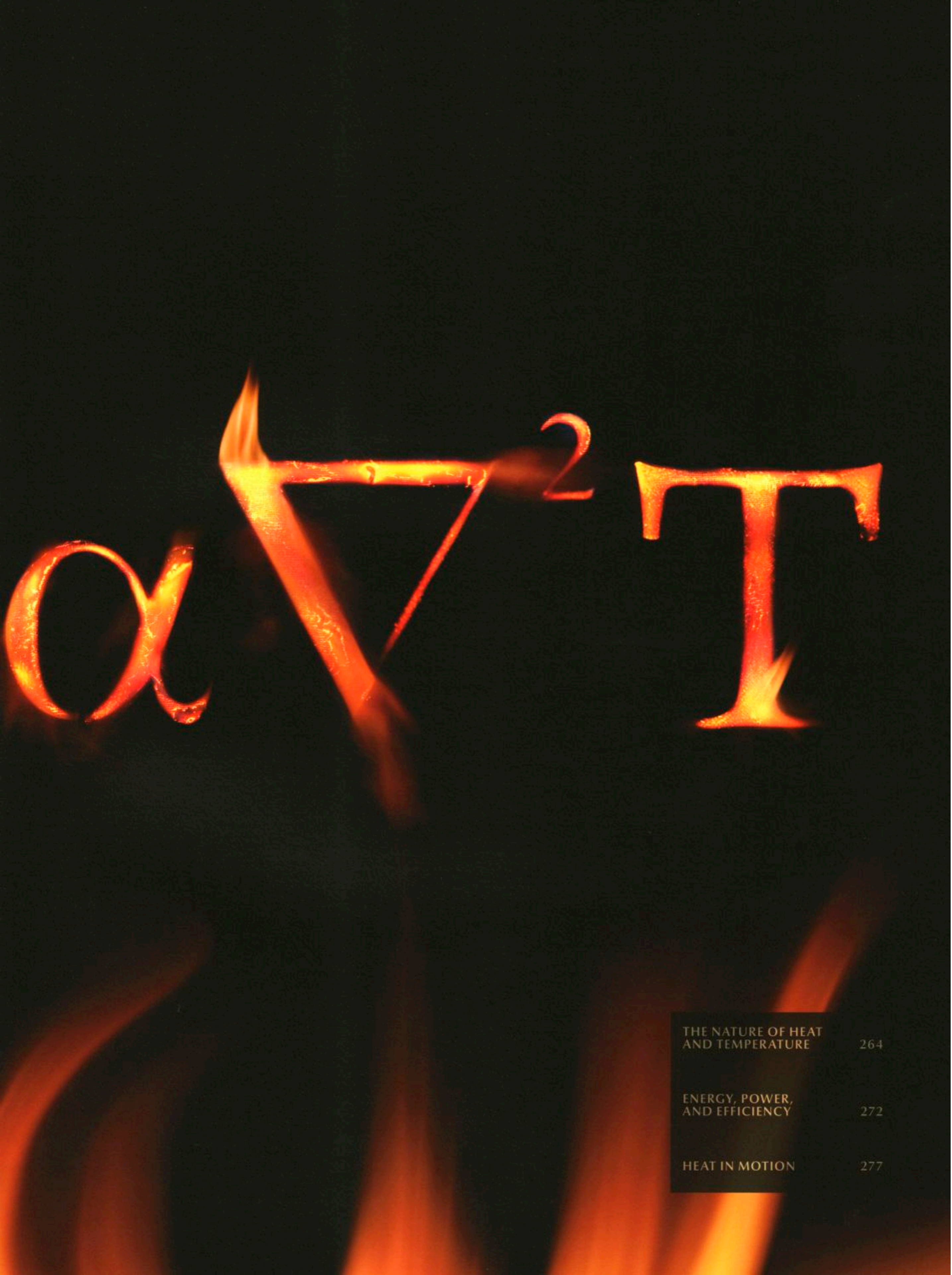
5 HEAT AND ENERGY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HEAT AND ENERGY

In the process of learning to cook, we build an intuition about the underlying science as well. We know that a copper pan heats more evenly than one made of iron, although we may not be able to explain why. We know that a thick cut of meat cooks more slowly than a thin cut does, even if we've never seen the mathematical equation that governs the difference in cooking time. We recognize that blending food too vigorously or for too long can actually cook it, yet we may be uncertain where the heat comes from.

In other words, we understand instinctively that, in addition to being an art form, cooking is also a physical process governed by scientific laws. Most of those laws describe how energy moves into, within, and from food—and what happens to the food as a result. Energy transferred by way of heat, for example, causes irreversible physical and chemical changes that transform food from raw to cooked. When chefs debate the finer points of food flavor, texture, color, nutritional value, and safety, they are often in effect talking about how energy in its various forms alters food.

Because the interaction of food and energy is so fundamental to cooking, a working knowledge of some basic physics and the fundamentals of heat transfer can greatly reduce failure and frustration. That knowledge is especially important for Modernist cooks, who are constantly pushing the envelope of the conventional. A better understanding of the underlying science opens new avenues for culinary innovation because it expands our vision of the almost unlimited ways in which food can be transformed. That's why the most inventive chefs get excited when the physics of cooking runs counter to their intuition: this remarkably common occurrence often teaches them something of real use.

Just as every great recipe builds on a foundation of great ingredients, a working knowledge of the science of cooking must begin with the two ingredients that are universal to all styles and techniques of cooking: heat and energy.

Skin of a rockfish transforms when plunged in hot oil.

Sautéed carrots (left) are the final recipient in a relay of thermal energy that passes from the gas flame to the pan, from the pan to the butter, and from the butter to the vegetables. The most fundamental formula (previous spread) that governs cooking is the heat-flow equation, discovered by Joseph Fourier in 1807. For more on this equation, see page 278.

THE NATURE OF HEAT AND TEMPERATURE

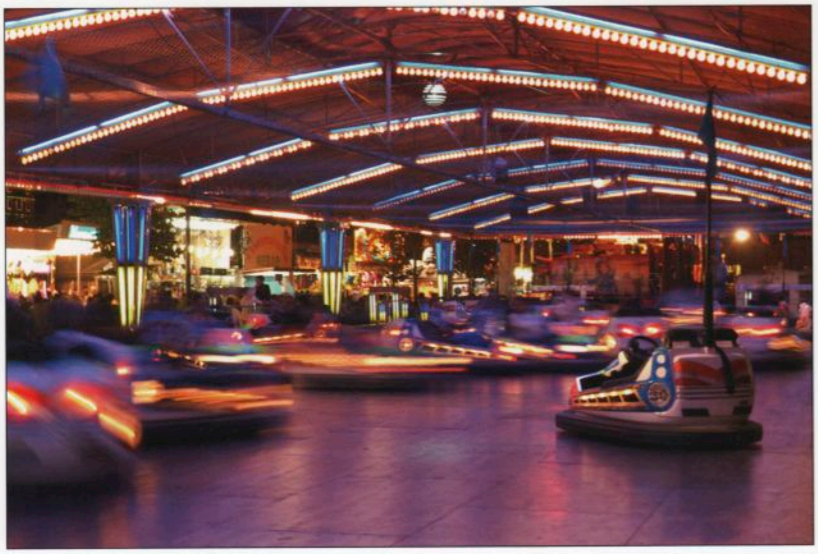
Energy is a fundamental attribute of every physical system in the universe—so fundamental that it practically eludes our capacity to define it. Standard physics textbooks define energy as "the capacity of a system to do work." But the concept of work is also maddeningly abstract. An informal approach might define **energy** as "the ability to make things happen." That definition is more useful for our purposes because it is easier to recognize what energy *does* than what energy *is*.

The actions of energy are central to a cook's concerns. Energy heats food, and energy cools it; energy transforms flavors, textures, and colors. To cook is to transform food by putting energy into it, and to eat is to get energy out of food by transforming it in a different way.

Energy takes many different forms, and it moves in a variety of ways. In cooking, the most common movement of energy is **heat.** Although technical dictionaries define heat as a transfer of energy (see note at left), from a cook's point of view it is much more useful to think of heat as a form of internal energy, one that always flows from a substance at a higher temperature to another at a lower temperature. To understand heat, we thus need a sense of what internal energy and temperature are.

Like engineers and the public at large, we use "heat" throughout the book to refer to thermal energy—that is, a form of internal energy that affects the temperature of an object or substance. The strict scientific definition of heat, however, is different: heat is energy in transit from bits of matter at a higher temperature to other bits of matter at a lower temperature. In the language of thermodynamics, heat is actually a process, not a property.

Just as bumper cars jostle one another at varying angles and speeds, molecules collide and transfer some of the energy of their motion.



Internal energy is the sum of lots of different kinds of energy stored in a chunk of matter (which can be as small as a single atom or as big as you care to define it). In a hot baked potato, for example, there is internal energy in the chemical bonds of the starch molecules, in the steam trapped under the skin, and even in the nuclear forces that hold the atoms together. But a lot of the internal energy—and much of what we think of as heat—is stored in the continuous, random movements and fleeting collisions of the potato's countless molecules.

Even though the potato may look solid, those molecules are indeed always moving; the motion is simply too small to see without special instruments. The discovery that the microscopic particles of all substances—solid, liquid, and gas—jostle constantly was one of the notable achievements of 19th-century physics. That insight led directly to some of the theoretical breakthroughs made by Albert Einstein in the 20th century.

Think of molecules in a solid as behaving like bumper cars in a carnival ride. When two lurching cars collide, they transfer momentum and energy to one another. The faster car slows down, and the slower car speeds up.

In a gas such as air, the molecules zip around and bump their neighbors in all directions. In solids, the particles are typically bound to one another, so their movements are more constrained. Still, they rattle back and forth, bouncing off one another like bumper cars connected with rubber bands.

If you were to measure the speed of each bumper car at a single moment, you would find that some are completely still (or nearly so), some are moving quite fast, and the speeds of the rest are distributed between those two extremes. The same is true of molecular motion. The faster the particles within a substance are moving, the greater the internal energy of the substance. But even in superhot plasma like the surface of the sun, some particles remain stationary at any given moment. Amazing, but true.

We cannot perceive the different speeds of all these particles without sophisticated tools. What we actually experience—and what matters when cooking—is the *average* speed of all the molecules. There is a simple and familiar measure related to that average speed: **temperature.**

When Thermal Worlds Collide

Take a steak out of the refrigerator. Throw it on a hot pan. As every cook knows, the cold steak will cool the pan, and the steamy skillet will heat the steak. At the surface where the two meet, the molecules in the pan bang into the molecules in the steak, with predictable consequences. On average, the particles in the pan are moving faster than those in the steak. Just as a fast-moving bumper car donates some of its momentum to a slower-moving car when the two bang together, each fast-moving molecule in the pan decelerates when it hits a slower molecule in the steak—and the slower molecule speeds up.

Thus we arrive at one of the fundamental laws of heat transfer: thermal energy flows in only one direction, from hotter (faster-motion, higher-temperature) matter to colder (slower-motion, lower-temperature) matter.

Think about where the heat flowing from metal to meat comes from in the first place. Are chefs somehow defying the laws of physics, creating heat where none existed? No. The heat comes

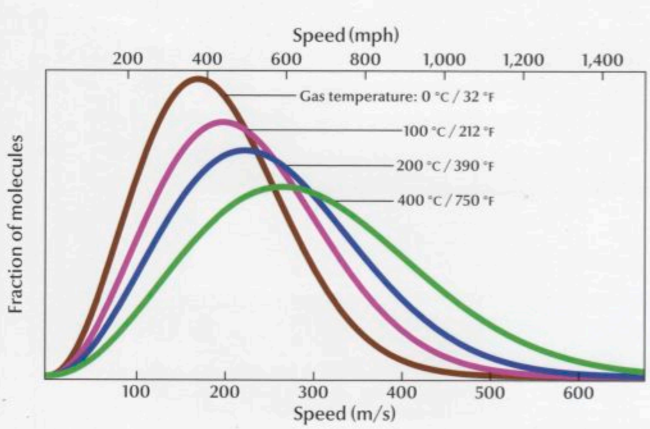
The random movement of atoms and molecules in a solid, liquid, or gas is called **Brownian motion.** It is named after the British botanist Robert Brown, who was one of the first scientists to describe it.

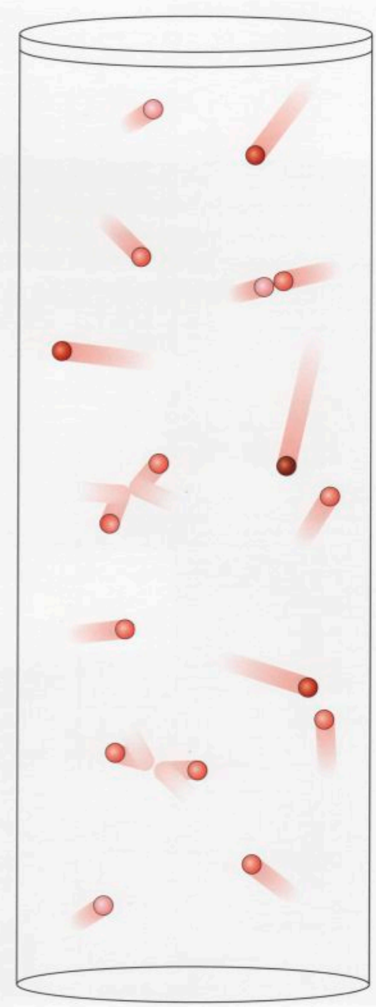
THE HISTORY OF

Defining Temperature

We don't normally think of temperature as a measure of speed. But that is essentially what temperature is. To be precise, it is a quantity proportional to the square of the average speed of molecules in a given substance as they wiggle in random directions.

Working independently, the 19th-century physicists James Clerk Maxwell and Ludwig Boltzmann worked out the math that connects the speed of particles in a gas to the temperature of the gas. Maxwell and Boltzmann were early believers in the existence of atoms and molecules, and their work on energy distributions still serves as a foundation of statistical mechanics. But their ideas were controversial in their time, and the controversy drove Boltzmann to despair. He committed suicide in 1906.





Molecules inside a bottle of oxygen gas that is at equilibrium at 0 °C / 32 °F jostle at a wide range of speeds (diagram at right and brown curve in chart above); 400 m/s (1,440 kph / 900 mph) is the most common. At higher temperatures, such as 100 °C / 212 °F (violet curve), 200 °C / 390 °F (blue curve), and 400 °C / 750 °F (green curve), the average speed of the molecules is greater, but the distribution of speeds is broader.

Celsius and Fahrenheit are the most familiar temperature scales, but many others exist. The Kelvin scale uses the same size degrees as Celsius but has a different starting point: its 0 refers to absolute zero (the lowest possible temperature) rather than to the freezing point of water. Kelvin is commonly used in science to designate very low temperatures.

Rankine is the Kelvin of the Fahrenheit scale, although it has never achieved the same popularity. The Newton, Reaumur, and Rømer scales are nearly obsolete, although the Reaumur scale lives on in relative obscurity in Italy, where it is still used for making Parmigiano-Reggiano cheese.

The rare Delisle scale has the curious feature of assigning lower numbers to hotter temperatures—which is how the Celsius scale worked until the 1740s, when Anders Celsius died and Carl Linnaeus flipped the scale around.

from the conversion of energy in some other form, such as electricity (in the case of a coil burner or induction element) or chemical bonds (in the case of a gas burner or wood-fired oven).

Without a burner or some other source of external energy to maintain the pan temperature, heat will move from the pan to the steak until the two have the same temperature. At that point they are in **equilibrium** at some temperature between the two starting points. A hot cup of coffee will cool to room temperature (and not below it) only because it doesn't hold enough internal energy to appreciably heat the room.

The rate at which heat flows from a hot pan to a cold steak is proportional to the difference in temperature between the two—the greater the difference, the faster the flow of heat. Chefs exploit this universal property of heat transfer whenever they sear a steak on a really hot griddle (see page 2·37).

Temperature difference is not the only factor that can speed or slow heating, however. No doubt you have noticed that some foods and cooking utensils heat faster than others under similar cooking conditions. Water's apparent resistance to heating, for example, spawned the aphorism "a watched pot never boils." To understand why, it helps to know more about how different materials respond to a change in internal energy.

A Capacity for Change

Materials vary in their reaction to heat. The variations are caused by several factors. The size, mass, complexity, and chemistry of the atoms and molecules in the substance all play a role. Temperature and pressure also can affect the amount of energy required to raise the temperature of a material by a certain amount—a parameter that scientists refer to as the **specific heat capacity** of the substance. From the table on the next page you can see that the specific heat of liquid water, steam, and ice are all quite different. The form the compound assumes matters, too.

Specific heat is expressed as the amount of energy required to warm a given amount of mass by

Want to eliminate hot spots in your skillet? Have a metal shop cut a thick plate of solid aluminum for you, and place it between the pan and the burner. A plate 1-3 cm / ½-1½ in thick will spread the heat more evenly than the most expensive copper pans do.

a degree of temperature. For liquid water, this is 4,190 joules per kilogram-degree Celsius (abbreviated 4,190 J/kg · °C) or 1 BTU per pound-degree Fahrenheit (1 BTU/lb · °F). So if you want to increase the temperature of a kilogram of water (that is, one liter) by a degree Celsius, just add 4,190 J of heat. Want to warm a kilo of ice by a 1 °C? You'll need only about half as much energy: 2,090 J.

Whereas a 1 °C / 1.8 °F rise in air temperature under typical room conditions comes at a price of just 1,012 J, the energetic cost for the same temperature increase in copper is just 390 J. Tungsten, the metal found in light bulb filaments, has one of the lowest specific heat capacities— it doesn't take much heat at all to change the temperature of tungsten.

At the other end of the range, hydrogen gas has a specific heat more than 100 times as high as that of tungsten. For as much energy as you'd need to warm a gram of recalcitrant hydrogen gas by 1 °C / 1.8 °F, you could instead change the temperature of a gram of tungsten by 108 °C / 194 °F.

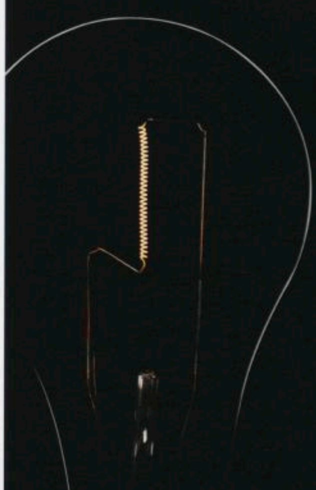
For more on the properties of food and cookware that affect heat transfer, see Conduction in Cookware, page 277.

THE PROPERTIES OF

Resistance to Change

Some of the common materials in the kitchen change temperature much more readily than others. The specific heat capacity of a material describes how much heat we have to move into a given amount of a material to raise its temperature by one degree. For the specific heat values of other kitchen materials, see From Pan Bottom to Handle, page 280.

	Specific heat capacity	
Material	(J/kg · °C)	(BTU/lb · °F)
aluminum	910	0.22
copper	390	0.09
carbon steel	490	0.12
tungsten	132	0.03
glass plate	500	0.12
wood	1,700	0.41
corkboard	1,900	0.45
Styrofoam insulation	1,300	0.31
water (liquid)	4,190	1.00
water (vapor)	1,930	0.46
water (ice)	2,090	0.49
beef loin	2,760	0.66
apples	3,640	0.87
eggs	3,180	0.76
milk	3,770	0.90
air	1,012	0.24
hydrogen	14,320	3.40
nitrogen (gas)	1,040	0.25
nitrogen (liquid)	2,042	0.49



Point of No Return

During cooking, subtle **irreversible changes,** both physical and chemical, occur in foods. These changes can alter the specific heat capacity of the food. As the name suggests, irreversible changes are the sort that cannot be undone.

Freeze some warm water, melt it again, boil it to steam, and recondense it; at the end, you'll have the same substance you started with, and its specific heat will be just as it was at the beginning. In other words, those changes are completely reversible. If you take a steak from the refrigerator at 5 °C / 41 °F and warm it to 20 °C / 68 °F, that is also a reversible change. You've made the meat 15 °C / 27 °F hotter. But not long after you return the steak to the refrigerator, it will be essentially the same as before, aside from some subtle changes due to enzymatic activity and aging.

For more on units of energy and power, see Converting Among Units of Power, page 273.

If you instead heat a steak from 40 °C to 55 °C / 104 °F to 131 °F, however, the appearance, texture, and taste of the meat all change profoundly. As in the previous example, the temperature of the meat rises just 15 °C / 27 °F. But in this case the heating elicits chemical changes that transform the meat from raw to medium-rare. You can cool the steak back to 40 °C / 104 °F, but it will never again be raw. This transformation is what we mean when we refer to an irreversible change.

Most cooking is about achieving such irreversible changes in a controlled way. Changes of this kind typically occur within narrow bands of temperature, and very little heat energy is needed to make them. Much of the difficulty in cooking is getting and keeping food within those narrow bands of temperature where miniscule amounts of

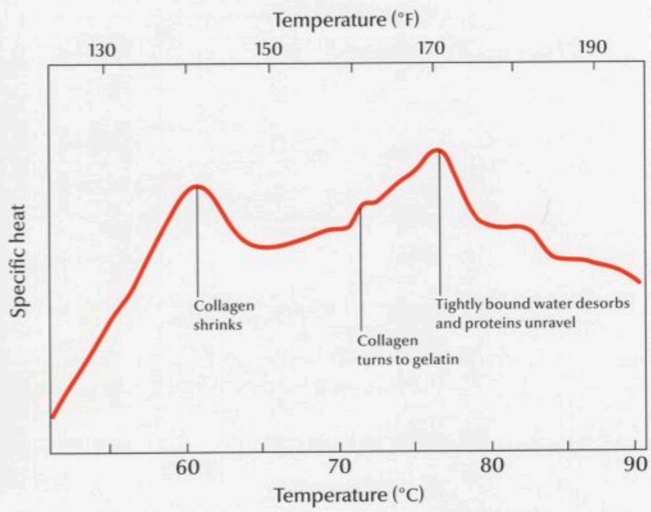
THE TECHNOLOGY OF

Measuring Specific Heat

To measure the specific heat capacity of a food, which affects how long it takes to cook, researchers use a tool called a **differential scanning calorimeter** (DSC).

Because the DSC can measure specific heat at a wide range of temperatures, it can help to identify the irreversible chemical changes that occur as cooking alters the structure and properties of the food. In the right hands, a DSC can reveal the precise temperatures at which crystals break down, proteins unravel, fats melt, or juices evaporate.

In a DSC, a small sample of the food rests on a metal platform inside the device's chamber. The machine slowly heats the sample, degree by degree, while keeping careful track of exactly how much electrical energy it has expended. The more energy that goes in before the sample temperature rises one degree, the higher the specific heat at that temperature.



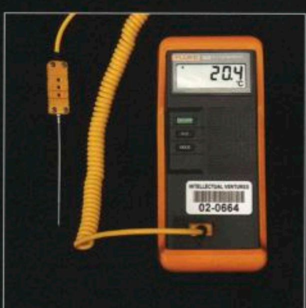
We placed a piece of Kobe beef cheek into a differential scanning calorimeter (left) and gradually heated it to typical cooking temperatures. Energy input per degree of heating (right) rose near 63 °C / 145 °F and again near 78 °C / 170 °F, signaling the irreversible changes in protein chemistry that transform meat from raw to cooked.

THE TECHNOLOGY OF

Measuring Temperature

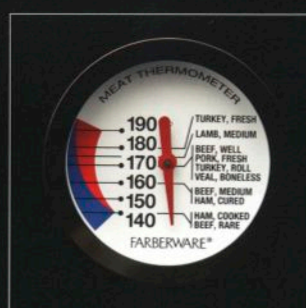
Small changes in temperature can make all the difference in cooking. Cooks should thus measure temperature as accurately as they can. One famous chef argues that by touching a skewer to his lip he can judge temperature better than any digital thermometer. We beg to differ—although few of these devices are accurate to better than 1 °C / 1.8 °F, they all outperform the human lip.

Thermometers always trade accuracy for expediency; the truest thermometers tend to be the slowest. The probes below are ranked roughly in order of their accuracy from least to most. Bear in mind that accuracy depends on how skillfully thermometers are used as well as on their inherent capabilities.



Thermocouple K

A temperature difference between two metals in the probe produces a voltage that is translated into temperature.
Accuracy: ±2.8 °C / ±5.0 °F



Analog dial

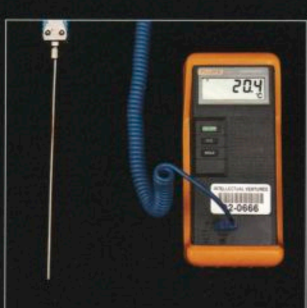
A probe connects to a metal strip that expands when heated, rotating a needle over a scale.
Accuracy: ±2.5 °C / ±4.5 °F

Infrared

A sensor measures the spectrum of long-wavelength light emitted by an object, which varies with temperature.
Accuracy: ±2.0 °C / ±3.6 °F

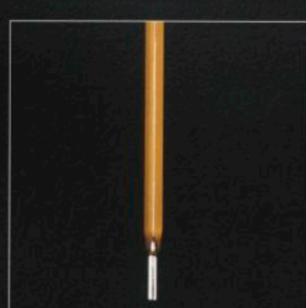
Thermistor

A metal bead encased in glass measures electrical resistance, which changes in proportion to temperature.
Accuracy: ±1.5 °C / ±2.7 °F



Thermocouple T

This device works like a thermocouple K, but uses different metals as sensors.
Accuracy: ±1.6 °C / ±2.9 °F



Analog liquid

A compound such as mercury or ethanol expands readily with heat inside a graduated glass capillary.
Accuracy: ±1.0 °C / ±1.8 °F

Platinum resistance temperature detector

Electrical resistance in a coil of platinum wire changes in proportion to temperature.
Accuracy: ±0.1 °C / ±0.2 °F

Don't be fooled by all the decimal places on your thermal probe's readout. A thermometer can be precise (as implied by all those digits) without being accurate. Precision means that the instrument will give the same value each time you repeat the same measurement. Accuracy means it gives a number that accords with the actual temperature—something no amount of digits can ensure.

energy can cause dramatic shifts in chemical composition.

Researchers identify the exact temperatures at which these shifts occur by monitoring changes in the specific heat of a substance as they slowly warm it. For more on the properties of food and cookware that affect heat transfer, see How Heat Conducts Itself, page 277.

Temperature-logging software can display and record data from multiple sources simultaneously. The software is used with an interface box that connects to as many as twelve thermal probes. The various probes—typically thermocouples or thermistors, but also platinum resistance temperature detectors on more expensive units—can be placed in different cookers or in different parts of a single food item. The software can then compare temperature differences among the probes and track temperature changes over time. Although not a strict necessity for cooks, logging systems have many uses: as an aid in developing a Hazard Analysis and Critical Control Points plan for cooking sous vide, for example, or as a tool for mapping the evenness of heating in an oven both in space and in time.

THE TECHNOLOGY OF

Controlling Temperature

Not so long ago, the mark of an expert chef lay in his ability to control the fire and to judge how long and how close to hold the food to it. But in this area at least, technology has bested human expertise, and electronic instruments are now vastly better at controlling temperature than chefs are.

A device called a **proportional-integral-derivative (PID) controller** can determine not just the current temperature but also the rate of warming or cooling of its probes and the cumulative amount of overshoot or undershoot. It then adjusts the rate of heat input accordingly (see Controlling the Temperature, page 2·230). These devices combine high-end temperature sensors with software programs and relays that regulate a heating element. The name PID refers to the way this software makes its calculations.

Because PID controllers prevent overshooting or undershooting the target temperature during initial heating, they excel at reaching and holding a stable set point.

THE TECHNOLOGY OF

PIDding Your Gear

A PID device offers so much better control over temperature than other devices that you may be tempted to attach one of them to every cooker in your kitchen. Be warned: PIDding standard kitchen gear is not for the faint of heart. PID controllers work best on "dumb" appliances that do not have their own microprocessor controllers, such as espresso machines and simple ovens. PIDding a refrigerator, or any appliance with a compressor, is a bad idea because compressors aren't designed to be turned on and off frequently.

In addition to the PID, you'll need to choose a thermal probe and a solid-state relay sized for your equipment. Attaching the wrong relay to your appliance could have dangerous consequences for which we cannot be held responsible.

As for the PID itself, various brands are more or less interchangeable. Older PID controllers had to be "tuned" to each cooker, temperature sensor, and heating element they encountered. But fuzzy logic and other improvements have since produced automatic "push-to-tune" devices and instruments with continuous, adaptive tuning that demand much less maintenance.

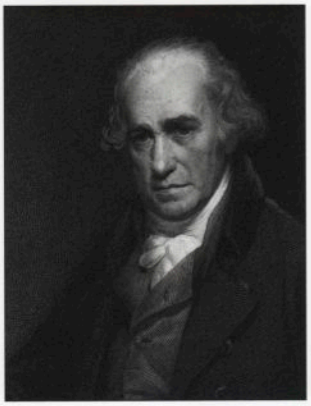
The SousVideMagic PID controller is an inexpensive device that allows an ordinary, and inexpensive, metal rice cooker to be turned into an unstirred sous vide water bath.

The CyberQ II is a controller system for barbecues that changes the temperature of smoke by regulating airflow to smoldering wood.

The PID controller on an Accu-Steam electric griddle replaces the simple control dial for greater accuracy.


PIDding espresso machines was a landmark innovation that enabled baristas to deliver coffee drinks of consistently high quality.

ENERGY, POWER, AND EFFICIENCY



James Watt was a Scottish inventor with an insatiable curiosity. He advanced the design of the Newcomen steam engine, a vital element of the industrial revolution of the 18th and 19th centuries. The watt was first named for him in 1889. In 1948 it became the standard international unit of power in recognition of his numerous contributions to the efficiency of the modern world.

Grill and oven manufacturers commonly misuse BTU, a unit of energy, to describe the *power* rating of their wares. For more on the difference—and on the proper use of BTU—see Lies, Damn Lies, and BTUs, page 2·10.

The joule is the basic unit of energy in the system of metric units most commonly used in science, which are known as SI units (abbreviated from the French *Système International d'Unités*). Because SI units are based on the fundamental quantities of a meter, a kilogram, and a second, they are also sometimes known as MKS units. A second metric system is called CGS, for the centimeter, gram, and second. The CGS unit of energy is the erg. Because it takes 10 million ergs to make just one joule, chefs are unlikely to encounter the tiny erg.

Watts, British thermal units (BTUs), calories, and horsepower—these are familiar terms that most people, including chefs, rarely pause to consider. All of us know they relate to energy or power, but we may be a bit unclear about the difference between the two or about which units refer to energy and which to power. That's not surprising given that some conventions for using these units seem to have been established purposefully to mislead.

So to clear up confusion at the outset, on one hand we have energy, a pure quantity untouched by time. Power, on the other hand, is a rate of change in energy: an amount of energy per unit of time. All units of energy and power are ultimately related to one another. And in many cases their numerical values are defined in relation to the specific heat capacity of liquid water.

The **BTU,** for example, is defined as the amount of energy that heats a pound of water from 60 °F to 61 °F. Despite having "British" in its name, the unit today is used mainly in the United States—often incorrectly as a measure of power.

A more common unit is the **joule,** which is the fundamental unit of energy in the metric system. Named for the physicist James Prescott Joule, the joule is defined as the amount of energy required to accelerate a one-kilogram mass from zero to one meter per second (3.6 kph / 2.2 mph) in one second, over a distance of one meter. Compared with a BTU, a joule is a pretty small amount of energy; it takes 4,190 J (but only 4 BTU) to raise the temperature of one kilogram (1 l / 1 qt) of water by 1 °C / 1.8 °F.

In the world of food, the most commonly used unit of energy is the **calorie,** which has been the source of endless confusion because two different definitions have been in simultaneous use. For years chemists and other scientists used calorie to mean the amount of energy that will warm one *gram* of water by 1 °C / 1.8 °F—a bit more than 4 J, in other words. But then food scientists, nutritionists, and others took to using calorie to mean the amount of thermal energy necessary to raise the temperature of one *kilogram* of water by 1 °C—1,000 times as much energy as in the older definition. Sometimes people capitalize Calorie to make clear that they mean the larger unit, but often they do not. This nonsensical custom has become so widespread that it is impossible to fight. To avoid misunderstanding, some people distinguish between a "gram-calorie" and a "kilogram-calorie." A kilocalorie, meaning 1,000 calories, always refers 1,000 of the smaller unit.

Power in the Balance

In the kitchen, cooks usually don't concern themselves with energy as much as they do with power: the rate at which energy flows from one thing to another. The basic unit of power is the watt, named for James Watt, a 17th-century scientist and inventor. One watt equals one joule of energy per second. A 500 W induction burner thus sucks 500 J through its electrical cord every second.

In the metric system, the prefix kilo- means 1,000, so a **kilowatt** is simply 1,000 watts. People often mistake kilowatts as a measure of energy because household electricity meters usually record energy consumption in kilowatt-hours. A kilowatt-hour (kWh) is the amount of energy expended at a rate of 1,000 W for one hour (3,600 seconds) so 1 kWh equals 3.6 million J. The kilowatt-hour is indeed a unit of energy, but the kilowatt alone is a unit of power. Why not simply use joules on the meters? These practices seem designed to confuse the casual observer.

One of the stranger units of power that still persists is **horsepower,** which was created as a marketing slogan for steam engines in the 19th century. To sell a steam engine, you had to tell people how many horses it could replace. So an average horse workload was computed for each engine. To this day, car engines, lawnmowers, chain saws, shop tools, and even occasionally vacuum cleaners are rated in horsepower. As you might assume from the name, a horsepower is a big unit, equivalent to about 746 watts.

It's usually pretty straightforward to apply measures of energy and power when cooking—as long as you use metric units. Suppose you have a liter of cold water at 5 °C, and you want to heat it to 55 °F. You need to raise the temperature by 50 °C. Use the specific heat of water (about 4.2 J/g · °C) to figure how much energy you need. You'll need to put 4.2 J of energy into each gram of water for each 1 °C increase in temperature. A liter of water weighs 1,000 g. Multiply 4.2 by 1,000 g then by 50 °C, and you find that about 210,000 J of energy must enter the water to heat it to 55 °C.

If you know the power your heat source can deliver (which is less than its electrical rating, as explained on the next page), you can divide that wattage into 210,000 J to estimate how long the water will take to heat. A typical 1,800 W water bath, for example, can actually deliver about 1,200 W to the water. At that rate of 1,200 J/s, the liter of water will reach 55 °C in about three minutes. Of course, your water bath probably holds something closer to 20 liters, in which case it could take an hour to heat.

James Prescott Joule, a 19th-century physicist and brewery manager from England, helped to clarify the relationship between mechanical and thermal energy. In a brilliantly simple experiment, he measured the heat produced by paddles churning a vat of water and compared it with the mechanical energy produced by a falling weight that turned the paddle wheel. His work led to the first law of thermodynamics, one of the cornerstones of classical physics.

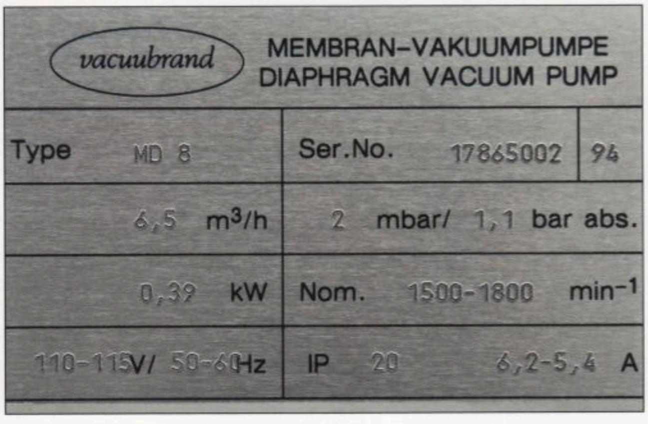
Converting Among Units of Energy and Power

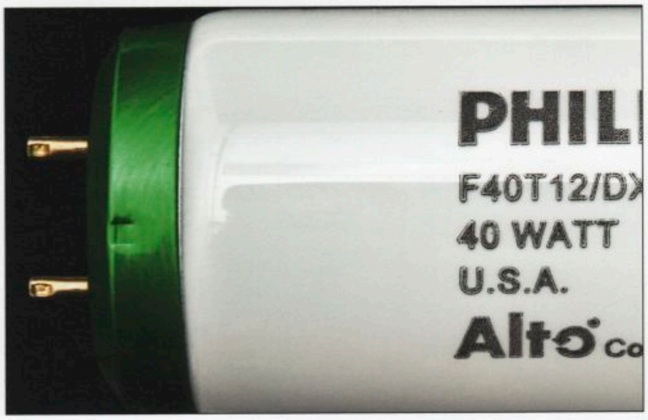
To convert from	into	multiply by
erg	joule	0.0000001
calorie	joule	4.1868
kilocalorie	joule	4,186.8
BTU	joule	1,055.06
kilowatt-hour	joule	3,600,000
joule	erg	10,000,000
joule	calorie	0.238846
joule	kilocalorie	0.000238846
joule	BTU	0.000947817
joule	kilowatt-hour	27,777,800

To convert from	into	multiply by
horsepower	watt	745.7
BTU/hour	watt	0.293071
kilocalorie/second	watt	4,186.8
watt	horsepower	0.00134102

Energy is a pure quantity unrelated to time. The fundamental unit of energy in scientific units is the joule; in the U.S. and in older British literature, BTU is common. You can use the multiplication factors in the table at left to convert almost any quantity of energy into joules then into other units.

Power is energy per unit of time. The watt is the most common unit of power. Use the multiplication factors in the table above to convert quantities of power into watts.





Power ratings on appliances and light bulbs are commonly given in watts, the fundamental unit of power in scientific terms. A kilowatt (kW) is 1,000 watts.

The concept of efficiency also applies to the power output of motors. Some unscrupulous manufacturers call a motor that draws 746 watts a "one-horsepower motor." But because no motor is 100% efficient, about 1,250 watts of electrical power are needed to generate 1 hp of usable mechanical energy at the shaft—a value sometimes specified as "shaft horsepower."

Efficiency

Like the water bath in the preceding example, most electrical appliances are rated in watts. The ratings refer to the maximum amount of electricity they draw when operating, not the amount of power they deliver during use. It's important to distinguish between those two quantities because no appliance is 100% efficient. Not all of the electrical power drawn by a water bath, for example, actually gets converted into heat, and not all of the heat that is created ends up in the food being cooked. Some of the power may be diverted to create mechanical action, such as driving a pump. And some of the heat is lost to the walls of the bath and the surrounding air.

The fraction of the input power that a device converts to useful heat and mechanical work is known as its **efficiency.** Automobile engines are typically just 25% efficient, but small electric motors such as the pump in a water bath or the motor in a blender can have efficiencies as high as 60%. A pot sitting above the gas burner of a stove is not nearly so efficient at transferring power into the food it contains (see next page). The heat you feel when standing next to the stove comes from thermal energy that has escaped without doing its job.

Other types of burners, such as electric coils or glass-ceramic stoves heated by halogen lamps, may expend fewer watts to heat the pan. Just how efficiently a burner operates depends on the shape of the burner, the materials of which it is made, and other factors.

Induction burners are far more efficient than gas burners or all other electric heating elements because they heat only the pots and pans placed on them, not the surrounding air or intervening surfaces. For all kinds of burners, the size, shape, and material of the pan being heated counts as well. Shiny pans, for example, heat more efficiently than black ones (see Why Good Griddles are Shiny, page 284).

Facts on Friction

When your hands are cold, you can warm them by simply rubbing them together quickly. The force known as **friction** opposes the movement, and the energy you expend overcoming the friction turns to heat. Any time two surfaces move against one another, friction puts up resistance. And if motion then happens anyway, heat follows.

Friction creates heat in the kitchen, too, although the amount of heat is often too small to notice. When you cut food with a knife, for example, friction is generated as the knife slides past the cut sides of the food, and this movement heats the food a tiny bit. You can't perceive this effect; it's too slight, and it happens too fast.

In a blender or a rotor-stator homogenizer (see page 2·412), however, the "knife" spins at such a high speed that the food inside can get quite hot as a result of the mechanical work against friction. Indeed, you can overheat and accidentally cook some foods in this fashion if you are not careful.

What counts as efficient or inefficient in the kitchen thus depends on our objectives. We want our blenders to be efficient at the mechanical work of turning blades; heat is an inefficiency. But we want our water baths and ovens to heat food, not move it around. In that case, the mechanical work required to run a pump or a fan is part of the cooker's inefficiency.

THE TECHNOLOGY OF

Heating Food Efficiently

There's a difference between the amount of energy a kitchen heater draws from an outlet and the amount that actually gets delivered to the food you're heating. The less efficient the heating device, the larger the difference. The energy efficiencies of burners, ovens, and water baths vary considerably depending on the design of the heater and the size, shape, and composition of the container holding the food, as well as on other factors, such as how quickly the energy is applied. If some of those differences in variables are minimized, how do the cookers compare?

We ran tests in our laboratory to check the efficiency of several heating or cooling appliances. In each case, we needed to know both the amount of electrical power the device consumed and the heat it delivered to (or removed from) a given amount of water. We monitored the power consumption of each device with an instrument designed for that purpose. To determine the heating or chilling power, we placed a measured amount of water in the device and timed how long the device took to raise or lower the water temperature by a predetermined number of degrees. With that information, we could use the specific heat of water—that is, the amount of energy required to raise a kilogram of it by 1 °C—to calculate the heating or cooling power and the efficiency precisely.

Our figures did not always match the claims of manufacturers. That discovery is perhaps not surprising because appliance-makers sometimes define efficiency a little differently: as the fraction of power that generates heat (anywhere) rather than the fraction that actually heats the contents of the cooker.

Our experiments did not account for the fact that electricity is generated by power stations that have rather low efficiencies. Gas burners have woeful efficiencies—as low as 30%. But natural gas is a cheaper source of power than electricity, and it's delivered without substantial losses en route, so cooking with gas is still a bargain.

Electric coil
42% efficient

Induction burner
56% efficient

Chilling water bath, stirred and covered
64% efficient

Water bath, unstirred and covered
85% efficient

Water bath, stirred and covered
87% efficient

Our experimental setup for measuring thermal efficiency used a pot of water over the heating source under study, a thermal probe, and a data acquisition device connected to a computer.

HOW HEAT IS LOST

The road to hot food is full of wrong turns, and heat takes them all. The sources of heat loss on any given stove top are legion. Heat streams from below, beside, and above the food being heated. It leaks from the burner to the frame. It wafts from the sides of the pot. It radiates from the lid. The exact sources of heat loss vary from one kind of burner and cookware to another, but the leaks noted here are ubiquitous.

HEAT IN MOTION

The most important ways that frying, boiling, steaming, baking, grilling, and other methods of cooking differ from one another are the medium and mode through which each transfers heat to food. In any given cooking method, four modes of heat transfer operate independently and often simultaneously. But one mode is almost always dominant.

The most common mode is conduction, which is how most heat flows within solids and between solid materials in contact. Conduction carries heat from an electric burner coil through a skillet and into a strip of bacon, for example. A second mode, called convection, dominates in fluids such as boiling water, deep-frying oil, and the hot air of a baking oven. A third form of heat transfer, radiation, consists of waves of pure energy, like sunlight. Microwave ovens, broilers, and charcoal grills all work mainly by using radiant heat. Finally, the condensation of water vapor onto a cooler surface, such as a snow pea, injects heat into the food. That process of phase change comes into play strongly during steaming.

Each of these four modes of heat transfer works in some ways that are intuitive and other ways that are surprising. The better you understand how they convey energy through your cookware and into your food, the better you will be able to wield them effectively in cooking—and to comprehend, if not entirely eliminate, those vexing circumstances in which even science cannot fully predict the outcome of your cooking efforts.

How Heat Conducts Itself

Conduction is heat transfer by direct contact; particles bumping into and vibrating against one another exchange energy and allow it to spread through a solid or from one object to another it is touching. (Conduction can also occur in liquids and gases but usually as a minor effect.)

Conduction doesn't happen at a distance. You can hold your hand just above a hot electric burner for a second or more and pull it away without getting burned. Touch the burner, however, and you'll feel conduction at work right away!

Heating the center of a solid food relies almost exclusively on conduction to ferry energy from the food surface to its interior. Stove-top methods such as panfrying and sautéing also use conduction to transfer heat from the pan to the food.

Some materials conduct heat more readily than others, of course; that is why oven mitts work. **Thermal conductivity** is a measure of the ease with which heat moves within a material. An oven mitt has a very low conductivity, so it is an **insulator.**

Metals, in contrast, respond quickly to contact with a source of heat or cold. A steel counter top feels cool to the touch because heat readily flows from your warm fingertips into the cooler counter. A plastic spatula with the same temperature as the counter but a lower conductivity doesn't feel as cool. Diamonds are called "ice" for a reason; at room temperature, they conduct heat away from your fingers about four times as fast as copper does.

Conduction in Cookware

Diamond-coated pans are not yet an option, but copper pots are quite popular because of a widespread perception that they cook more efficiently. In our opinion, the burner you use is much more important than the cookware. But cooks tend to obsess about the quality of their pots and pans, and we don't expect that to change any time soon. In particular, some cooks express a keen interest in the conductivity of cookware. Whether they know it or not, however, conductivity isn't the only quality they're looking for.

The perfect pan would be made of a material that not only allows heat to move freely but also transmits heat very evenly, without developing hot spots or cool zones. A highly conductive pan will not achieve both goals if it is too thin because heat will flow directly from the burner through the pan and into the food without spreading out sideways first. In other words, the pan will transmit the unevenness of the heat source—typically a coiled electric element or a ring of gas flames. Even heating over an uneven burner thus demands a pot bottom that is thick enough to allow time for heat to diffuse horizontally as it rises vertically.

The pan should also respond promptly when the

The silver teapot is a stylish but impractical solution for storing a hot beverage. Silver conducts heat better than most cookware, which is why the handles on this pot are insulated with hard rubber. Because of its high conductivity, the pot will cool quickly. The popularity of the silver teapot created the market for insulating tea cozies.

For more on the relative contributions of pans vs. burners, see page 2·52.

Ceramics make superior baking dishes because they are poor conductors and store more thermal energy than metals do. Their slow response to heat tends to buffer the inevitable temperature fluctuations in ovens.

For more on the thermal characteristics of common kitchen materials, see From Pan Bottom to Handle, page 280.

cook turns the burner up or down yet not be so sensitive that it fails to hold a stable temperature despite minor fluctuations in the heat source. To put it in scientific terms, the heat capacity of the material is just as important as the conductivity of the cookware. Manufacturers don't advertise the heat capacity of their wares, unfortunately, and it's a little tricky to calculate because you need to know the thickness of the bottom, the specific heat of the material it's made from, and its density.

Density is surprisingly important. Consider aluminum, which has the highest specific heat of any material commonly used in cookware. That means you must pump a lot of energy per unit of mass into aluminum to raise its temperature. Yet aluminum is famously fast to heat. Why? The reason, in large part, is that the metal is lightweight; it has a low density and thus a relatively small amount of mass to heat.

Cast iron, in contrast, has a low specific heat, half that of aluminum. By that measure, you might expect it would be easy to heat. Instead a cast-iron skillet warms slowly and delivers remarkably even heat because it's so dense and thus heavy.

Fortunately, there is a single measure that takes into account all three of the properties that matter in cookware: conductivity, specific heat, and density. It's called diffusivity. Diffusivity indicates how fast a material transmits a pulse of heat.

This all-encompassing trait gives rise to the macroscopic behavior that we praise or condemn in our pots, pans, and utensils. People say that copper cookware "conducts" heat well, and in fact copper is an excellent conductor. But what they actually mean is that its high conductivity and low specific heat are balanced by considerable density. They mean that it heats not only quickly but also evenly. They mean, in a word, that it has high diffusivity.

THE HISTORY OF

Fourier and the Heat Equation

In the early 19th century, the French mathematician Jean Baptiste Joseph Fourier developed a formula that describes how heat travels through solids by conduction. Now known simply as the heat equation, Fourier's elegant discovery has contributed to advances in modern physics, chemistry, biology, social science, finance—and now cooking.

The heat equation helps to answer a question chefs often ask themselves: is it done yet? What we want to know, in more technical terms, is how the heat is distributed in the food we're cooking. The answer is

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T$$

In this equation, $\frac{\partial T}{\partial t}$ represents the rate at which temperature is changing with time, $\nabla^2 T$ is the temperature gradient in the food, and α is the thermal diffusivity of the food (a measure of how fast heat spreads in that particular food at a particular temperature).

The heat equation tells us that the steeper the temperature gradient between the inside and the outside of the food, the faster heat will flow to its interior. Our instincts tell us that, too—but our instincts don't tell us the actual temperatures in specific parts of the food at exact times. Fourier's model does.

Or rather it could if the complexity of food did not defy our ability to model it mathematically. Solid foods typically consist of an elaborate assemblage of different substances with different heat-transfer properties. Heat moves differently in muscle, bone, and fat, for example. And each piece of food has its own unique patterning of components. It would take extraordinary effort to represent those individual patterns in a heat-transfer model. Fortunately, even simplified models that provide approximate figures can be very useful to cooks.

Conduction in Food

Conduction is the slowest form of heat transfer. It's especially slow in food, in which the structure of cells thwarts the movement of heat. The thermal diffusivity of food is typically 5,000 to 10,000 times lower than that of copper or aluminum! Hence conduction, more than any other means of transferring heat, is the rate-limiting step that determines the cooking time for solid food.

For that reason, it's a good idea to understand how the geometry of food affects the conduction of heat. Yes, we said "geometry:" the rate of heat flow in a solid food depends not only on the size of the food but also on its shape.

Generally, when cooking, you want to move heat to the core of the food—or at least some distance into the interior. And you're usually able to apply heat only directly to the surface of the food. Heat conducts inward slowly, so the outside warms faster and sooner than the inside.

Most chefs and home cooks develop an intuition for how long a given cut of meat, say, needs to sizzle in the pan. Trouble arises when a cook tries to use that intuition to estimate a cooking time for a larger or smaller cut, however, because conduction scales in counterintuitive ways. A steak 5 cm / 2 in thick, for example, will take longer to cook than a cut that is only 2.5 cm / 1 in thick. But how much longer? Twice as long?

That's a good guess—but a wrong one. In fact, the thicker cut will take roughly four times as long to cook. This scaling relationship comes from a mathematical analysis of an approximation to the Fourier heat equation (see previous page).

So the general rule for estimating cooking times for flat cuts is that the time required increases by the square of the increase in thickness. Two times thicker means four times longer; three times thicker means nine times longer.

This scaling rule breaks down, however, when the thickness of a food begins to rival its other dimensions, as when foods are more cube-shaped or cylindrical. (Think of a roast, for example, or a sausage.) Then the heat that enters through the sides does contribute significantly to conduction.

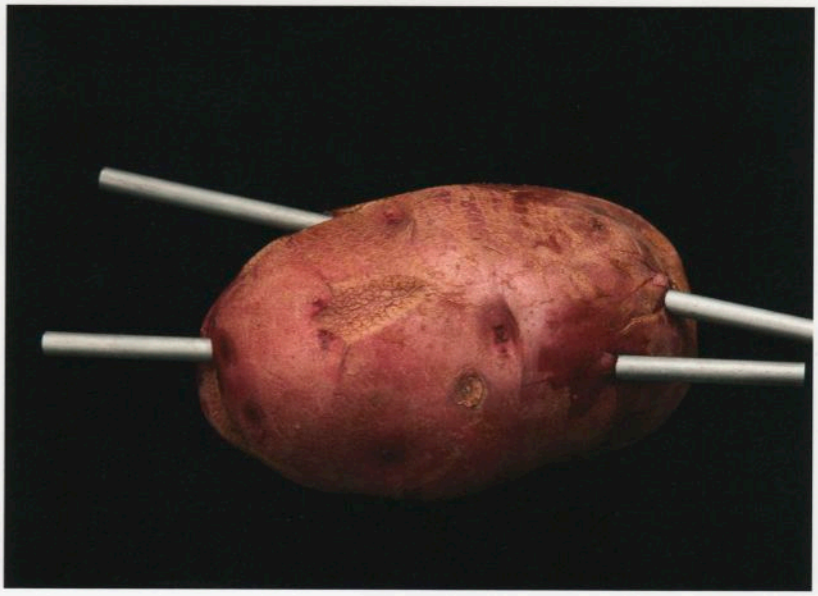
We have done extensive computer simulations that demonstrate that when the length and width are five times the thickness (for a block of food) or when the length is five times the diameter (for a cylinder), then the simple scaling rule works well. Outside these boundaries, however, the situation is more complicated. The heat equation still works, but the result has to be calculated individually for each shape.

No general rules apply across all varieties of "three-dimensional" foods. Mastering this kind of cooking is a matter of judgment informed by experience and experimentation. Rest assured that you won't be the first chef (or physicist) to dry out a thick chop waiting for conduction to heat the center.

Clearly, it's important to consider shape as well as size when you're buying meats. Bear in mind that, like many other worthy endeavors, cooking it will probably take longer than you think.

When Hot Particles Move

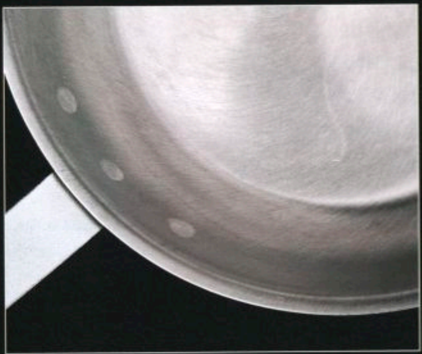
Convection is the second most commonly used mode of heat transfer in cooking. In liquids and gases such as air, molecules are not locked in place as they are in solids—they move. So hot molecules in fluids do not have to collide with adjacent, cooler molecules to transmit energy as heat. They can simply change position, taking their energy with them. That process is convection, the movement of hot particles.



A potato impaled with aluminum rods cooks more quickly because the metal helps to conduct heat to the interior of the food. This principle inspired the "fakir grill," a Modernist device named for the Near Eastern mystics who lie on beds of nails. The analogy is imperfect, of course, because the spikes of the grill are meant to stab the overlying food, whereas the recumbent mystics remain unscathed.

FROM PAN BOTTOM TO HANDLE

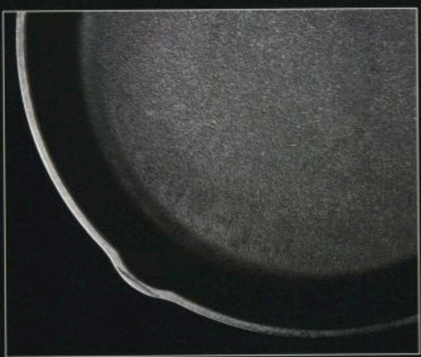
Each material in your kitchen responds to heat slightly differently. The four values listed below reflect different properties that affect heat conduction in a substance. Thermal diffusivity is the most useful among them: the higher the diffusivity of a material, the faster it transmits a pulse of heat.



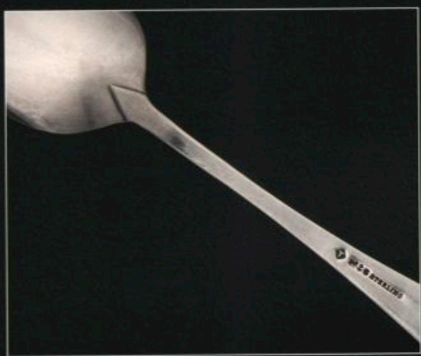
Aluminum
Specific heat: 910 J/kg · °C
Density: 2,700 kg/m³
Thermal conductivity: 120–180 W/m · K
Thermal diffusivity: 48.84–73.26 mm²/s

Copper
Specific heat: 390 J/kg · °C
Density: 8,960 kg/m³
Thermal conductivity: 401 W/m · K
Thermal diffusivity: 114.8 mm²/s

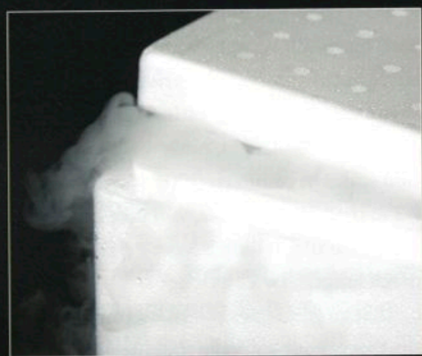
Stainless steel
Specific heat: 490 J/kg · °C
Density: 7,849 kg/m³
Thermal conductivity: 12.1–45.0 W/m · K
Thermal diffusivity: 3.15–11.7 mm²/s



Cast iron
Specific heat: 460 J/kg · °C
Density: 7,210 kg/m³
Thermal conductivity: 55 W/m · K
Thermal diffusivity: 16.58 mm²/s

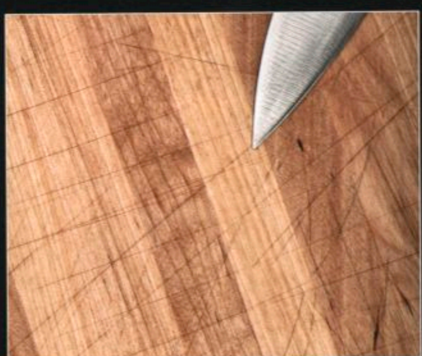


Sterling silver
Specific heat: 245 J/kg · °C
Density: 10,200–10,300 kg/m³
Thermal conductivity: 418 W/m · K
Thermal diffusivity: 167.3 mm²/s



Styrofoam cooler
Specific heat: 1,300 J/kg · °C
Density: 100 kg/m³
Thermal conductivity: 0.03 W/m · K
Thermal diffusivity: 0.23 mm²/s

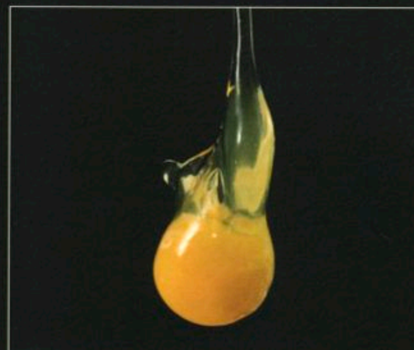
Pyrex glass
Specific heat: 84 J/kg · °C
Density: 2,230 kg/m³
Thermal conductivity: 1.01 W/m · K
Thermal diffusivity: 5.37 mm²/s



Wooden cutting board
Specific heat: 2,010 J/kg · °C
Density: 590–930 kg/m³
Thermal conductivity: 0.17 W/m · K
Thermal diffusivity: 0.09–0.14 mm²/s

Silicone oven mitts
Specific heat: 1,460 J/kg · °C
Density: 0.97 kg/m³
Thermal conductivity: 0.15 W/m · K
Thermal diffusivity: 105.9 mm²/s

Orange juice
Specific heat: 3,930 J/kg · °C
Density: 1,042 kg/m³
Thermal conductivity: 0.33 W/m · K
Thermal diffusivity: 0.08 mm²/s

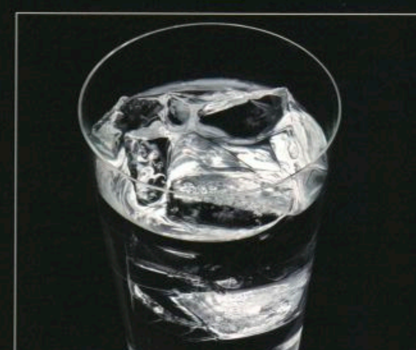


Egg white
Specific heat: 3,849 J/kg · °C
Density: 1,065 kg/m³
Thermal conductivity: 0.60 W/m · K
Thermal diffusivity: 0.15 mm²/s

Beef
Specific heat: 3,431 J/kg · °C
Density: 1,029 kg/m³
Thermal conductivity: 0.47 W/m · K
Thermal diffusivity: 0.13 mm²/s

Fish (cod)
Specific heat: 3,598 J/kg · °C
Density: 1,100 kg/m³
Thermal conductivity: 0.48 W/m · K
Thermal diffusivity: 0.12 mm²/s

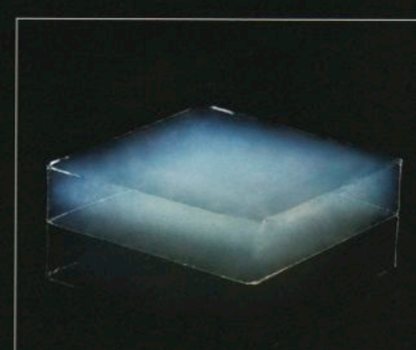
Cucumber
Specific heat: 4,100 J/kg · °C
Density: 950 kg/m³
Thermal conductivity: 0.60 W/m · K
Thermal diffusivity: 0.15 mm²/s



Water
Specific heat: 4,190 J/kg · °C
Density: 999 kg/m³
Thermal conductivity: 0.56 W/m · K
Thermal diffusivity: 0.13 mm²/s

Fiber glass insulation
Specific heat: 844 J/kg · °C
Density: 1.07 kg/m³
Thermal conductivity: 0.04 W/m · K
Thermal diffusivity: 44.3 mm²/s

Diamond
Specific heat: 628 J/kg · °C
Density: 3,513 kg/m³
Thermal conductivity: 900–2,320 W/m · K
Thermal diffusivity: 400–1,100 mm²/s



Silica aerogel
Specific heat: 837 J/kg · °C
Density: 1.9 kg/m³
Thermal conductivity: 0.004–0.04 W/m · K
Thermal diffusivity: 2.5–251.5 mm²/s

If you hold your hand over a gas burner, you can feel the warmth without touching the flame. The flame heats nearby molecules of air, which then rise from the flame, carrying some of its heat toward your hand.

The air near the flame rises because it is hotter than surrounding air. Nearly all solids expand when they warm and in doing so become a little less dense. This effect is more pronounced for liquids and is quite dramatic for air and other gases. As fluids heat and expand, they become more buoyant; as they cool, their densities increase so they tend to sink.

In the kitchen, convection almost always leads to turbulence: the roiling boil, the swirls of steam and fog, the billowing of oil in a deep fryer. The flow is so turbulent in large part because cookers usually apply heat unevenly, such as to the bottom of a pot or deep fryer. The heated fluid cools as it moves away from the source so its density increases, its buoyancy drops, and it falls, only to be heated and rise again. In **natural convection,** in which heat alone is the driving force, the fluid thus tends to circulate in a pattern of loops called convection cells.

In the world at large, natural convection kicks up winds, drives ocean currents, and even slowly moves the earth's crustal plates, which rise from the planet's molten center, creep across the surface, then cool and sink toward the core again.

Even though the warmed walls of an oven apply heat from every side, the heating is not perfectly even, so natural convection happens inside an oven, too. Large baking platters or pieces of food disrupt the flow of air, however, which reduces efficiency, creates hot spots, and makes cooking less predictable.

Forced convection ovens (often simply called convection ovens) attempt to overcome the drawbacks of natural convection by using fans to blow the air around the oven interior. Although the fanned air can accelerate drying and thereby

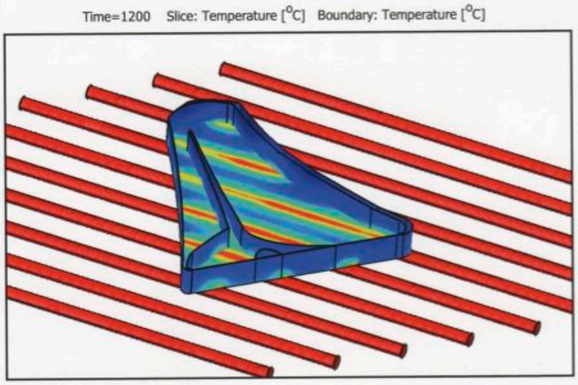
Warm air expands considerably when it's heated, a fact captured mathematically in an equation known as the ideal gas law. The law informs us that the volume of air in an oven will increase by about half when it's heated from room temperature to 177 °C / 350 °F. In a typical domestic oven that holds 140 liters / 5 ft^3 of air, some 70 liters / 2.5 ft^3 will go out the vent.

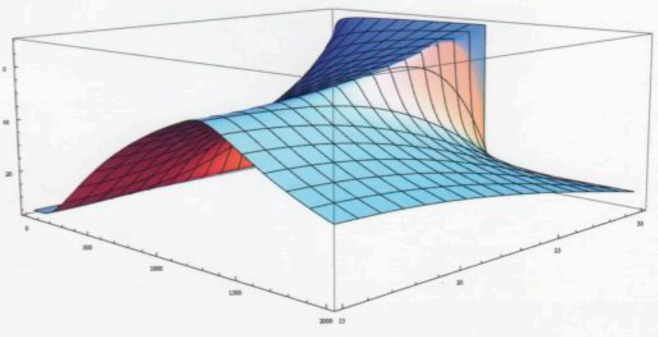
THE TECHNOLOGY OF

Cooking *In Silico*

Because the mathematics of heat flow is so well understood, computer programs such as COMSOL (below left) and Mathematica (below right) can model it with terrific accuracy—to within a fraction of a second or a fraction of a degree. Food presents special challenges to heat-flow models, however, because it's not usually made of uniformly conducting materials but instead is a sloppy mixture of fats, sugars, and proteins, solids and liquids, and muscle and bone.

Nevertheless, simple models can give results that are accurate enough to be useful. By augmenting off-the-shelf programs with custom software, we've been able to do virtual cooking experiments *in silico* that would be physically difficult or would simply take too much time in the kitchen. The results are highly informative—if not edible.





speed cooking for certain kinds of foods, the results vary widely depending on the size, shape, and water content of the food.

Convection is also at work when foods are cooked in water, wine, broth, or other liquids. Convection in liquids moves heat much more efficiently than convection in air does because the density of water or other cooking liquids is a thousand times higher than that of air. Far higher density translates into far more collisions between hot molecules and food. That's why you can reach your hand into an oven without burning it, but if you stick your hand in a pot of boiling water you'll get scalded—even though the oven may be more than twice as hot as the water.

Efficient as natural convection in liquid is, forced convection—also known as stirring—is still worthwhile. Stirring helps disrupt a thin sheath of fluid called the **boundary layer,** that surrounds the food and insulates it somewhat from the heat. A boundary layer forms when friction slows the movement of fluid past the rough surface of the food.

The boundary layer can be the most important factor that determines how quickly your food bakes or boils at a given temperature. Add a circulating pump to your water bath, or stir a simmering pot of food, and you can disturb the boundary layer and greatly hasten cooking.

To quantify just how quickly convection moves heat from source to food, we need a measure that takes into account the density, viscosity, and flow velocity of the fluids involved—much as thermal diffusivity incorporates the analogous information for heat conduction in solids. The **heat transfer coefficient** is just such a quantity; it conveys in a single number just how quickly heat passes from one medium or system to another. Convection ovens cook some foods faster because they have a higher heat transfer coefficient than conventional ovens do. In general, forced convection increases the heat transfer coefficient by tenfold or more.

For more on the actual effects of forced convection during baking, see Convection Baking, page 2·108.

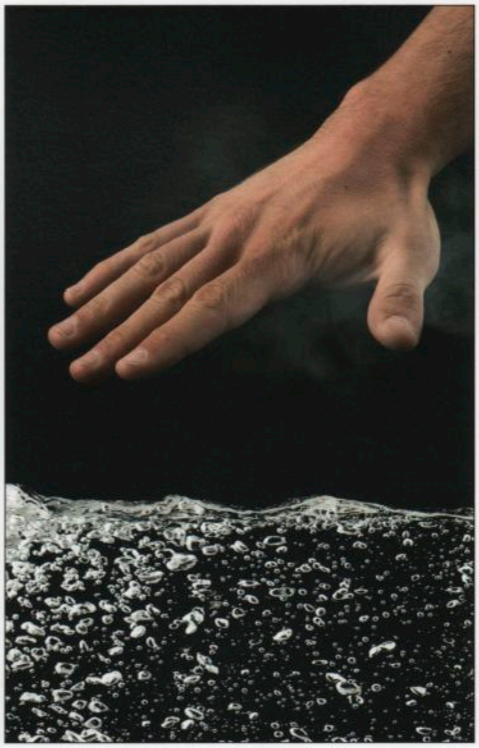
It Matters How You Heat

Some cooking methods move heat into the food faster than others. The heat transfer coefficient is a measure of the speed of heat flow from the cooking medium to the surface of the food.

Heating method	Heat transfer coefficient ($W/m^2 \cdot K$)
natural convection from air	20
forced convection from air	200
water bath	100–200
condensing steam	200–20,000
deep-frying	300–600

Heat rises from a hot griddle through convection. As the hot air expands, it becomes more buoyant, then lifts and churns the surrounding air. The resulting turbulence is captured in this image by using a photographic technique that reveals variations in the density of fluids. The same scintillation is visible to the naked eye in the air above a hot, paved road on a sunny summer day.

The wind chill factor takes into account the effect of circulating air on the temperature we perceive. Wind disturbs the boundary layers enveloping our bodies, creating a cooling effect.



You can put your arm in a 260 °C / 500 °F oven for a moment or two without getting hurt. But you can't hold your arm over a pot of boiling water for even a second (left). The reason is the difference in the heat transfer coefficient, a measure of how readily thermal energy will pass between a fluid (the air in the oven or the steam above the pot) and a solid (your arm). In an oven, it's 20 $W/m^2 \cdot K$; in boiling water, it's 100–1,000 times higher because of the terrific amount of heat released when water changes from vapor to liquid (see table at left).

Heat Rays

Every source of heat also radiates light—and vice versa—but that light isn't always the visible kind. In fact "heat rays" typically fall into the part of the spectrum that lies outside the relatively narrow band to which human eyes are sensitive. The wavelengths of light used to cook food, for example, are mostly in the microwave and infrared range, longer than the longest wavelengths of visible red light (hence the "infra" in infrared).

For more on the effects of reflectivity in broiling food, see page 2·18.

Broilers and grills cook mainly by **radiation,** also called radiant heat. Both visible and infrared radiation emanates from the heating elements or glowing coals. Atoms in the food absorb some of the light waves and convert the light energy into faster motion or more energetic vibrations, and on the macroscopic scale this is heat. How much energy the food absorbs thus depends on how much light it absorbs versus how much of the light that hits the food is scattered or reflected, a fraction called **reflectivity.**

A dark food with a dull surface will absorb more of the heat rays hitting it than will a light-colored or shiny food. Everyone who has worn T-shirts in the summer has discovered that a black shirt gets much warmer in the sun that a white one. That's because black objects absorb roughly 90% of incident light, whereas white things reflect about 90%. Indeed, it's precisely these differences in absorption and reflectivity that make black look black and white look white.

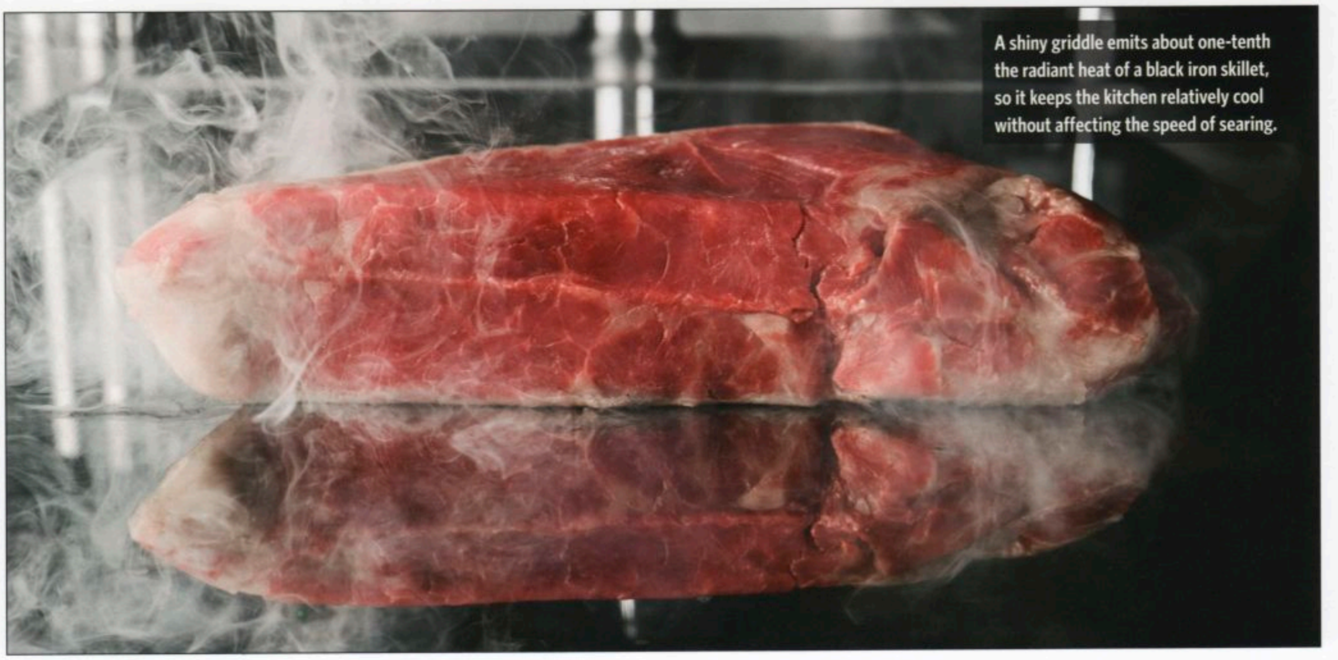
Reflectivity can make cooking challenging when it changes during the cooking process. As a piece of bread darkens while toasting, for example, its reflectivity decreases, and it absorbs more radiant energy from the coals—which is why the

THE PHYSICS OF

Why Good Griddles Are Shiny

Some high-end griddles and planchas have a mirror-like chrome finish. It's for more than good looks. At high heat, the average griddle radiates a large amount of energy into the kitchen in the form of (usually invisible) infrared light. This emission wastes energy and makes the kitchen uncomfortably hot.

Enter chrome. Shiny objects make good reflectors and bad emitters of radiant heat. If the griddle's surface is coated with a layer of reflective chrome, energy is reflected back into the griddle instead of out into the kitchen. You don't lose any of the intense conductive heat you want for cooking. So get out the chrome polish. It's worth it to keep your griddle gleaming.



A shiny griddle emits about one-tenth the radiant heat of a black iron skillet, so it keeps the kitchen relatively cool without affecting the speed of searing.

Toasting bread takes much longer to go from white to brown than it does to go from brown to burnt. That's because the bread absorbs more than 10 times as much radiant energy from the heating elements when its surface has darkened and its reflectivity has fallen. The darker it gets, the more energy it absorbs.

bread can go from light brown to flaming in the blink of an eye. Changes in reflectivity are usually to blame when a food at first responds slowly to radiant heat and then suddenly overcooks.

What's less obvious, maybe even counterintuitive, is that objects that absorb more radiation also *emit more radiation*. Your black T-shirt is beaming out almost as much radiation as it's taking in. This equivalence has been proven in a set of calculations known as Maxwell's equations, which have the curious property of working just as well when the direction of light is reversed. That means, essentially, that absorption and emission are two manifestations of the same fundamental phenomenon.

Physicists call a substance that absorbs every ray of light that strikes it a blackbody. Any light coming off the object, called **blackbody radiation,** is thus emitted by the object itself rather than reflected or scattered from some other source.

The mathematics of blackbody radiation reveals that you can tell how hot a completely nonreflective object is by the spectrum of the light its emits. At room temperature, a blackbody emits mostly infrared wavelengths, but as its temperature increases past a few hundred degrees Celsius, it starts to give off visible light, beginning with the red wavelengths—see What Makes a Hot Wok Glow, page 287.

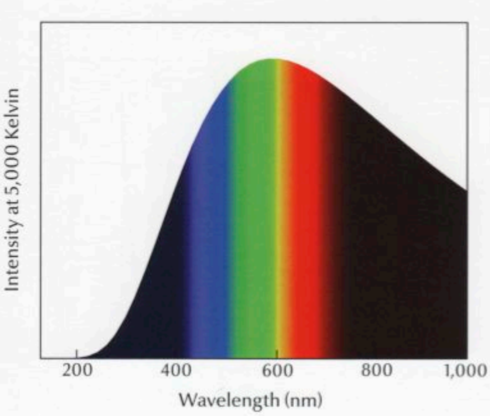
Blackbodies aren't the only objects to emit light spectra that vary with temperature. Every solid object behaves this way to some degree. So as a broiler element gets progressively hotter, it radiates ever shorter wavelengths of light and transmits energy ever more intensely. That statement may seem obvious, but the way that the energy output rises with temperature is not.

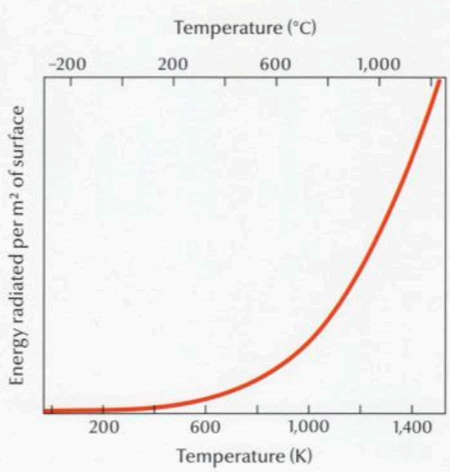
Radiant heat is proportional to the temperature *raised to the fourth power.* It's important to note that this relation holds only for temperatures in absolute scales such as Kelvin, but not for those in Celsius or Fahrenheit. That fourth-power relationship means that the radiant energy of an object grows by leaps and bounds as the temperature of the object increases by smaller increments. At low

The terms absorption, emissivity, albedo, and reflectivity all refer to the same property of a material: that is, its ability to emit or absorb electromagnetic waves.

The Scottish physicist and mathematician James Clerk Maxwell made extraordinary contributions to the understanding of electromagnetism in the 19th century. One peer described Maxwell as having a mind "whose superiority was almost oppressive."

The emission of a blackbody is more intense at some wavelengths than at others. The most intense wavelength depends on the temperature of the object. By analyzing the spectrum of a blackbody, scientists can thus tell how hot it is. Radiant heating power rises very rapidly with increasing temperature. According to the Stefan-Boltzmann law, the energy radiating from a body per unit area and unit time is proportional to the fourth power of its temperature (expressed in Kelvin).





The term "graybody" was coined to describe the many objects that excel at absorbing and emitting light—ceramics and the fire bricks in pizza ovens among them—but aren't ideal blackbody emitters.

temperatures, the object emits long-wavelength light that carries little energy; heat transfer is such a small effect that we can effectively ignore it. But when the object's temperature (in Kelvin) doubles, its radiant energy goes up 16 times; when the temperature triples, its capacity to transfer heat increases by a factor of 81!

This property of radiant heat shows up in ordinary cooking ovens. At 200 °C / 392 °F / 473 K or below, most of the heat is transferred by convection from the cooker's element. But increase the temperature to 400 °C / 750 °F / 673 K, and radiant energy becomes a significant fraction of the heat transfer that's occurring.

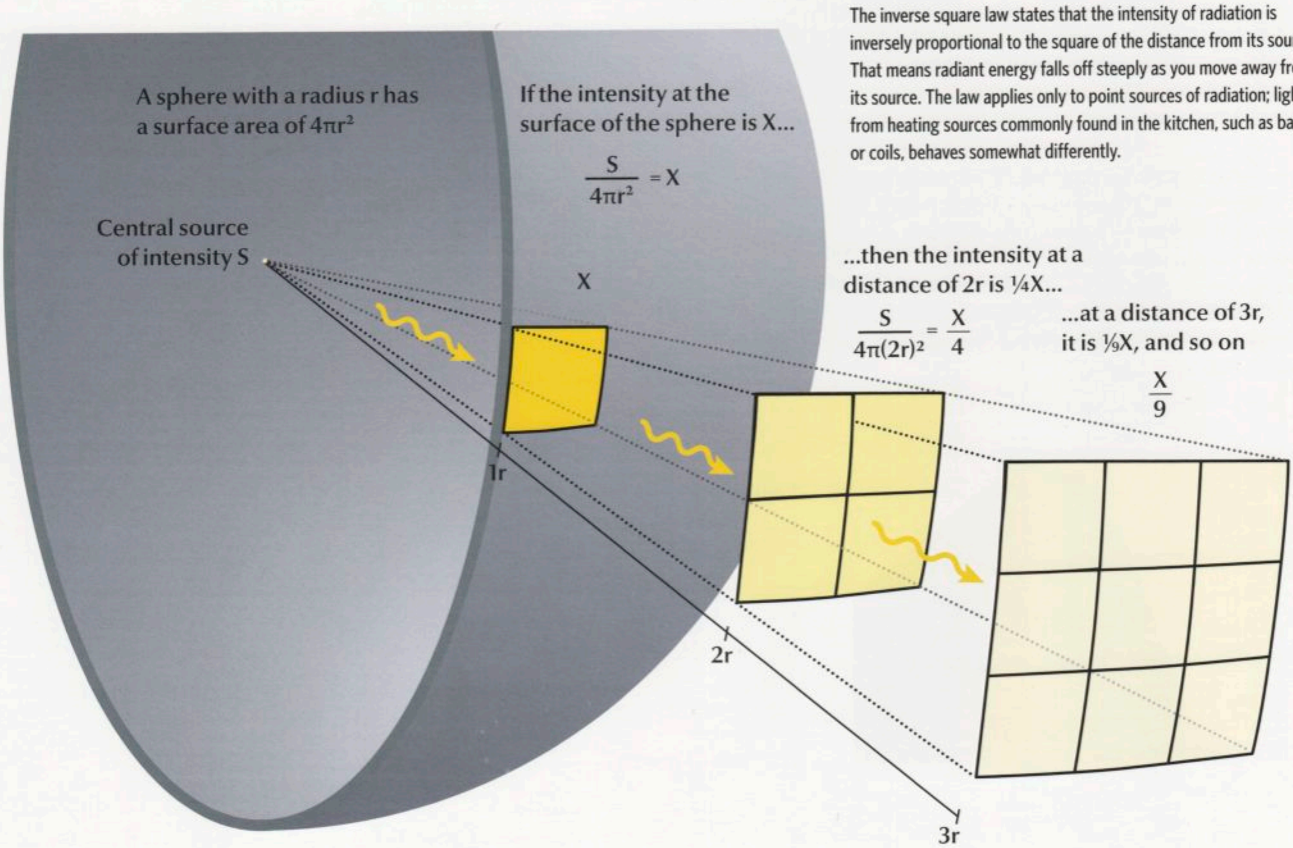
At 800 °C / 1,470 °F / 1,073 K, the tables are turned. In such blistering heat, the contribution from convection is negligible; radiation—having increased some 26-fold from the starting point—overwhelms all other means of heat transfer.

That's why blazing-hot, wood-fired ovens used to bake pizza or bread really are different from their conventional domestic cousins. They cook primarily by radiation, not convection.

Radiation differs from conduction and convection in yet another way: how it decreases over distance. As a form of light, heat rays obey the inverse-square law of light, meaning that intensity falls off as the square of the distance from a point source (see illustration below). A light bulb looks only about a quarter as bright from two meters away as it does from one meter; the distance doubled so the brightness fell by a factor of four (2^2). Back up to a distance of three meters, and now the brightness is down to a ninth of its intensity at one meter.

Most people grasp this property of radiative heat transfer intuitively but tend to overestimate its importance in the kitchen. The heating elements used in grills or broilers aren't point sources like light bulbs; instead they tend to be linear bars (like an oven element) or flat planes (such as a bed of coals) spread over a relatively wide area. For more on how radiative heat transfer from these more complicated heat sources works, see Grilling, page 2·7; Broiling, page 2·18; and Roasting, page 2·28.

The inverse square law states that the intensity of radiation is inversely proportional to the square of the distance from its source. That means radiant energy falls off steeply as you move away from its source. The law applies only to point sources of radiation; light from heating sources commonly found in the kitchen, such as bars or coils, behaves somewhat differently.



THE PHYSICS OF

What Makes a Hot Wok Glow?

You may have noticed that your normally deep-black cookware glows orange or red when heated to extreme temperatures. The black coils of an electric range or oven also turn bright orange when cranked up to the high setting. The source of this color change, thermal radiation, is also the source of most of the light around us, including illumination from the sun and from incandescent light bulbs.

In truth, everything has a thermal glow. But most objects are not hot enough to glow in the visible light range. People emit infrared light, which has a longer wavelength than visible light. Food glows in the infrared spectrum, too. Infrared thermometers work by analyzing the light to determine the temperature of a person or a piece of food.

As objects are heated, their glow moves from infrared into shorter and shorter wavelengths. Red light has the longest wavelength of visible light, so deep red is the first glow we can see as an object gets hotter. As a pan or electric coil heats further, the glow turns orange then yellow, white, and finally blue—hence the terms "red hot" and "white hot." Eventually an object can become so hot that it emits wavelengths of light too short to be seen by the human eye: ultraviolet radiation.

Not all objects emit light equally well. A perfectly black object absorbs nearly all visible light and reradiates the most light, too. In practice, there's no such thing as a pure blackbody, but some materials, like soot and other forms of carbon, get pretty close.

A perfect blackbody will start to glow red at 1,000 K, or near 728 °C / 1,340 °F. At any given temperature, an object emits a range of wavelengths (see chart on page 285). The color we perceive is the wavelength that has the peak intensity, which varies with the temperature of the object.

Josef Stefan, a 19th-century Austrian physicist, discovered that the energy emitted by an object as thermal radiation is directly proportional to its temperature (in Kelvin) raised to the fourth power. So the hotter an object, the more energy it radiates as light. Stefan was able to use this principle, along with previous work that calculated the sun's radiant energy, to correctly estimate that the temperature of the surface of the sun is about 5,800 K, or 5,527 °C / 9,980 °F, which gives it a white-hot color.

THE PHYSICS OF

Why We Blow on Hot Food

Why does blowing on hot food cool it? Your breath is warmer than the air in the room, after all. Shouldn't that warm-blooded puff make the food cool more slowly?

The answer, we all learn as children, is no: blowing on a bowl of hot soup or a piping cup of tea does actually work. The reason it works is that the motion of the air passing over the food matters more than the temperature of the blown air. The motion accelerates evaporation—and evaporation, much more than the simple transfer of heat from food to air, is the main phenomenon that sucks energy out of a hot liquid or any steaming food.

So the question is really: why does blowing on a hot liquid make it evaporate faster? The answer is the wispy layer of "steam" (fog, actually) that covers the top of the cup. Like the smothering humidity of a sultry summer day, it blankets the liquid and makes it harder for water molecules to escape into the air. With the help of this so-called boundary layer, some of the steam actually condenses back into the tea, redepositing part of the energy it initially carried away.

Your breath, like a cooling breeze, removes this saturated blanket of air and allows drier air to take its place. With less dampening, the energetic molecules on the surface of the tea break free more readily, and the liquid cools more rapidly.

Most solid foods contain lots of water, so blowing on them works as well. The effect is not as pronounced as it is with liquids because convection currents naturally stir a liquid and bring the hottest parts to the surface; that doesn't happen in solid food. Blowing on a potato thus cools the surface but not the interior. And blowing on a hot object that contains no water at all, such as a strip of bacon, has no appreciable effect.

Steaming cool soup? Evaporation cools hot liquid, but a humid layer quickly forms over the surface of hot soup, slowing evaporation. Blowing across the soup moves that humid layer aside, allowing more dry air to come into contact with the liquid. That speeds the cooling.

THE PHYSICS OF

When to Add the Cream to Your Coffee

Say you're waiting for a friend to join you for lunch, and the waiter has poured two cups of coffee. You remember that your friend likes her coffee white and consider adding the cream before she arrives to impress her with your thoughtfulness. But you stop yourself when you consider that the added cream could make her coffee go cold faster. Will it?

The cream-in-the-coffee conundrum is a classic physics problem, if not a classic dining problem. The answer hinges on whether the addition of cream will make the coffee cool more quickly or more slowly while you wait for your friend.

Several factors come into play. First, the rate of heat loss due to radiation emitted by the coffee varies with temperature. According to the Stefan-Boltzmann law, hotter coffee should radiate energy faster than coffee cooled slightly by the addition of cream. So that's one reason to add it early.

Second, black coffee, being darker, should emit more thermal radiation than *cafe au lait.* That reinforces the notion that waiting to add the cream is the wrong approach.

The third factor may be the clincher: coffee with cream in it is likely to evaporate less quickly than black coffee does. Evaporation can carry off a lot of heat quickly, so this is a big win for advocates of adding the cream right away.

The factors all point in the same direction, and experiments confirm that white coffee cools about 20% less quickly than black coffee does. Interestingly, the experimenters who came up with this measurement were unable to determine which of the three mechanisms just mentioned is the most important.

If you want to impress your friend, go ahead and put cream in her coffee before she shows up. Just hope she doesn't ask you why it's still warm.

To keep your coffee warm as long as possible, should you add cream right away or just before you drink it?

Entering a New Phase

For more on distance effects in broiling and grilling, see page 2·14.

Conduction, convection, and radiation are the classic modes of heat transfer described in every textbook. But there's another, largely unsung, form of heating that plays a big part in cooking: the thermal energy that comes from melting or freezing, evaporation or condensation. These transitions of matter among its principle states—solid, liquid, and gas—are called **phase changes.** Whenever such a change occurs, the substance releases or absorbs a considerable amount of thermal energy that can be used to warm food or to cool it.

In the kitchen, steaming offers the most common example of heat transfer by phase change. Water consumes a tremendous amount of thermal energy when it boils off to steam. You can imagine the water vapor taking that energy along with it as a kind of latent heat. In fact, that's what physicists call it: the **latent heat of vaporization.**

The vegetables in a steamer basket don't cook because they're surrounded by piping-hot steam; it's the latent heat released when steam condenses to liquid water on the cooler surface of the vegetables that does the cooking. Subtle changes in how steam condenses on food can have such surprising effects on the speed of steaming that in many cases it is, counterintuitively, a slower way to cook than boiling is (see Why Steaming Is Often Slower Than Boiling, page 2·72).

Blowing on food is an example of how phase transitions can also cool food by hastening the evaporation of water and other liquids (see Why We Blow on Hot Food, page 288). In vacuum assisted cooling, lowering the pressure makes evaporation occur more quickly, and the transition consumes so much heat that you can freeze food this way. The fog that emanates from liquid nitrogen or dry ice also signals an energy-devouring shift from liquid to vapor. Any food that comes in contact with this maelstrom will have the heat sucked right out of it.

The next chapter discusses phase transitions in more detail. The point here is that the large quantity of energy involved in matter's shift from one state to another offer a powerful resource for rapidly heating and cooling food; it can have an astonishing impact on culinary techniques, for better and for worse. To manage these effects, it helps to understand the most versatile and abundant constituent of food, and the only one you can find as a solid, liquid, and gas in nearly any working kitchen: namely, water.

Further Reading

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THE PHYSICS OF

When Color Indicates Temperature—and When It Doesn't

All objects change color as they heat from very low temperatures to very high ones. That is what is meant by the term "color temperature," which is used in photography and even in rating fluorescent bulbs.

But temperature is just one of the properties that can determine the spectrum of light an object radiates. Some colors are only incidentally related to temperature. The blue flame of a gas burner is a good example; so is the yellow-orange aura of a sodium streetlamp.

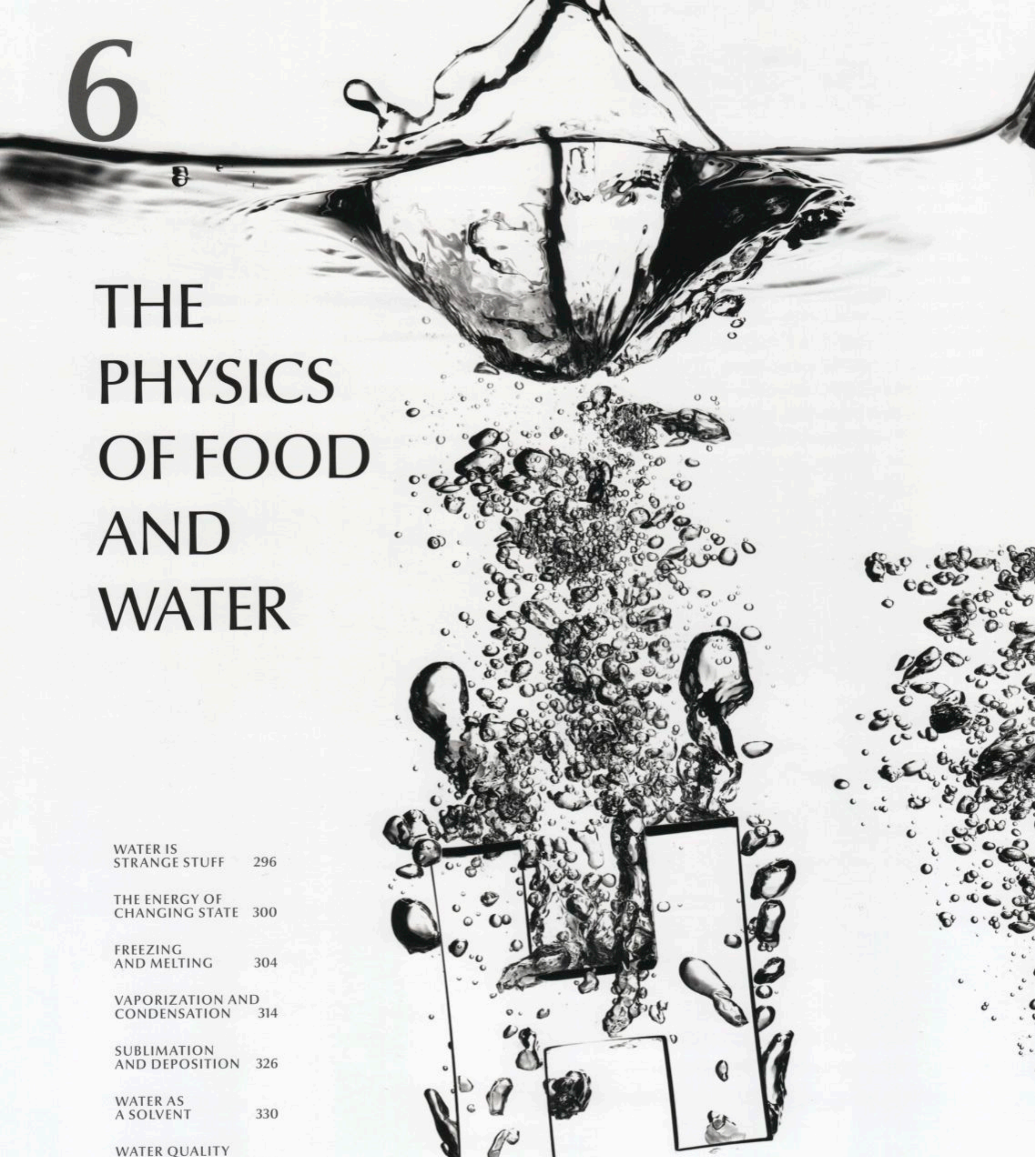
These colors are determined by the so-called emission spectra that arise during the combustion of elements. Emission spectra are bursts of colored light that issue from heated atoms as their electrons bounce from a high-energy state to a lower-energy ground state. Each element in the periodic table has a characteristic emission spectrum recorded in carefully controlled experiments.

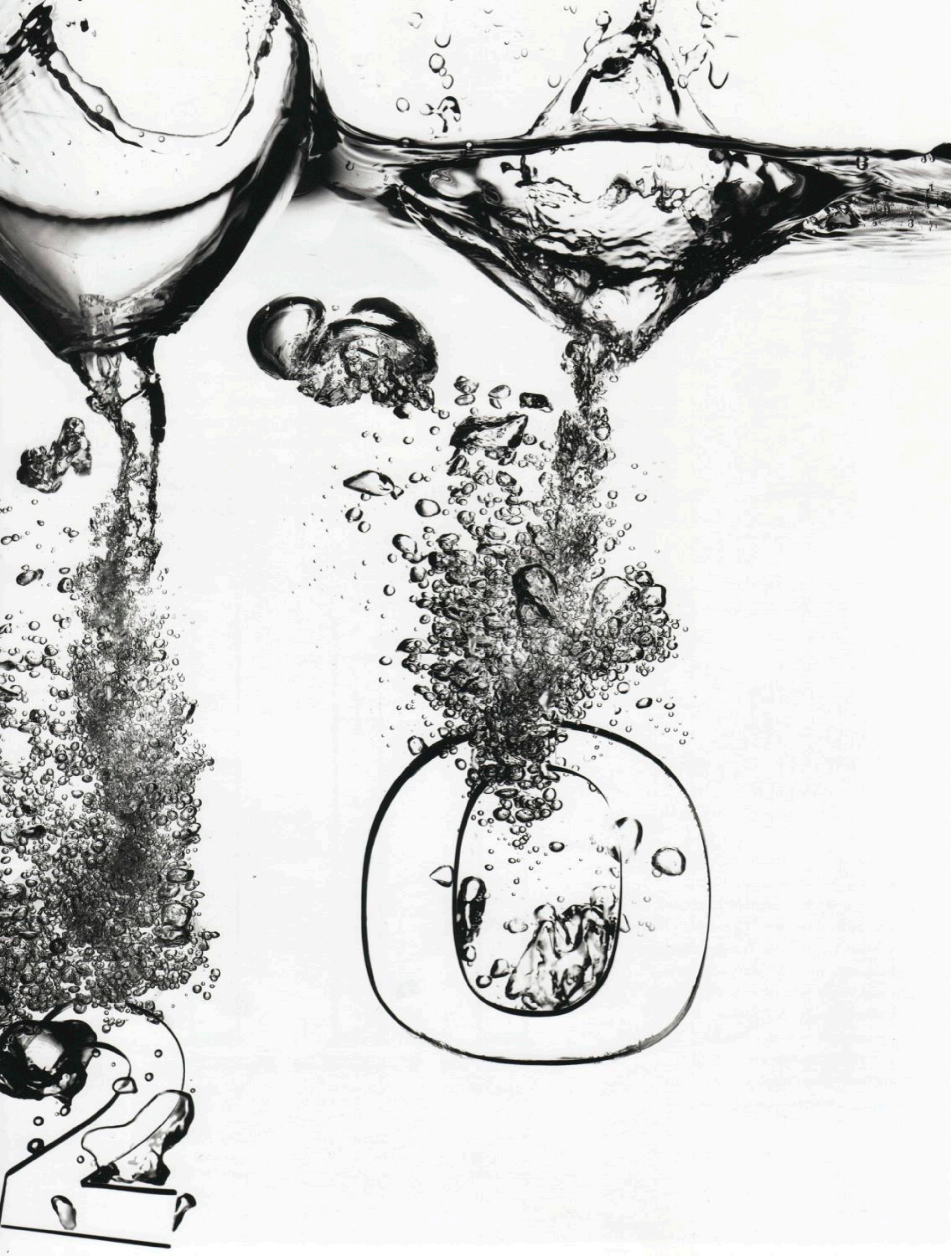
Some differences are obvious to the naked eye, however. You can easily distinguish the yellow-orange sodium streetlight from a blue-green mercury-vapor lamp. One isn't substantially hotter than the other; their different colors simply indicate the presence of elements with different emission spectra. Likewise, the blue flame on the stove top signals the combustion of hydrocarbons in natural gas or propane.

Methane (natural gas) | Calcium sulfate dihydrate (gypsum) | Calcium phosphate (bone / tooth enamal) | Sodium chloride (table salt) | Potassium phosphate (brining salt) | Sodium borate (Borax)

6

THE PHYSICS OF FOOD AND WATER

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THE PHYSICS OF FOOD AND WATER

Our foods are mostly water. We don't think of them that way, but in the context of cooking, we should. Virtually all fresh foods have very high water contents. Most fruits and vegetables are more than 80% water by weight; many are more than 90%. A carrot (88%) has roughly the same proportion of water as milk, and a fresh cucumber (95%) contains more water than many mineral-rich spring waters do. Essentially, you can think of fresh food as being composed of water plus "impurities" called proteins, fats, carbohydrates, and micronutrients such as minerals and vitamins. So it's not surprising that the properties of water can dominate the way food responds to cooking.

Throw some raw, chopped onions and dried spices into a hot frying pan together, and the spices will scorch even while the onions are still heating up. That's because onions are 89% water, and water heats more slowly than most other common liquids and solids. Moreover, the onions

WATER, WATER (ALMOST) EVERYWHERE

The human body is 50%–60% water, and most of the foods we eat are at least as "wet." Fresh produce is commonly high in water; baked goods and fatty foods tend to have less. Some fruits and vegetables contain a higher percentage of water than is in beverages such as milk or soda. Water exists in even the most unlikely foods: "dry" powdered milk, for example, still contains 3%–5% water. Percentages given at right are for typical samples of the foods, uncooked where appropriate.

Carrot
Water: 88%
Fat: 0.24%

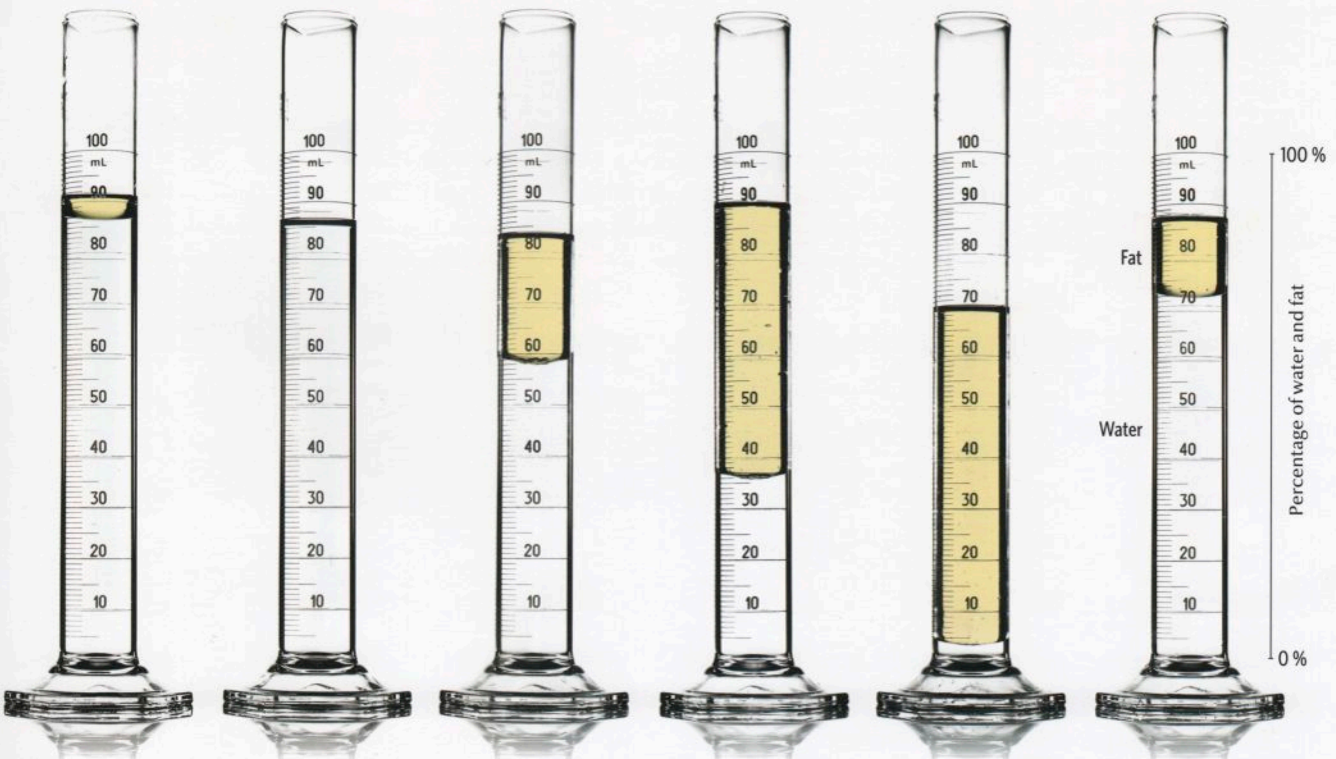
Cucumber
Water: 95%
Fat: 0.11%

Cherry
Water: 82%
Fat: 0.2%

Bread (whole wheat)
Water: 39%
Fat: 3%

can't get any hotter than the boiling point of water (100 °C / 212 °F) until all of the water in them has been driven off. That's why heating wet foods won't turn them brown, which requires substantially higher temperatures, until they've dried out. And of course, water content largely determines how well a food will withstand freezing because ice crystals are a key factor in frozen foods.

Water is also the medium in which most cooking is done. Sometimes we use it directly, as when boiling, steaming, extracting, or cooking sous vide. Water plays a role in ostensibly "dry" processes such as roasting and baking as well, yet many chefs fail to account for its effects. Whether it's a liquid boiling or simmering in a pot, a vapor rising from a steamer, the humidity in an oven's air, the liquid circulating in a cooking bath, or the crushed ice in a blender, the unique properties of water come into play in all manner of culinary operations. Faced with such powerful and ubiquitous phenomena, cooks must learn how to manipulate water or risk being foiled by it.



Whole milk
Water: 88%
Fat: 3%

Red wine
Water: 86%
Fat: 0%

Pork loin
Water: 59%
Fat: 24%

Pork belly
Water: 37%
Fat: 53%

Walnut
Water: 4%
Fat: 65%

Avocado
Water: 73%
Fat: 15%

WATER IS STRANGE STUFF

Water droplets are round because of **surface tension,** in which chemical attraction among molecules of a liquid draws those at the surface toward the center. Among common liquids, only mercury has a higher surface tension than water does.

The hydrogen bonds that form between water molecules are strong enough to confer many of water's unusual properties. But they are transient and much weaker than the bonds that hold atoms together within molecules: covalent bonds in sugars, fats, and carbohydrates; ionic bonds in salts; or metallic bonding among the copper, aluminum, and iron atoms in our cookware.

The properties and behavior of water are so familiar to us that we may not realize what a truly unusual substance it is. Everyone knows that a water molecule consists of two hydrogen atoms bonded to a single oxygen atom—H_2O, in the shorthand of chemistry. But it's how those molecules interact with each other that gives water its uniquely peculiar properties.

The molecules of most liquids are fairly free to move around, bumping past one another as the liquid takes on different shapes. But water molecules tend to stick together, and that's why water shows such quirky behavior.

Water begins to boil, for example, at a much higher temperature than do other liquids made of similarly lightweight molecules. Its freezing point is also surprisingly high. Droplets of water bead up into spheres because its surface tension is greater than that of any other common liquid except mercury. Water expands when it freezes and shrinks when it melts—just the opposite of almost all other substances.

And the weirdness doesn't stop there. You must pump an unusually large amount of heat into water to raise its temperature by even a small amount. That's why it takes so long to heat a pot of water to its boiling point. (Watching the pot has no effect.)

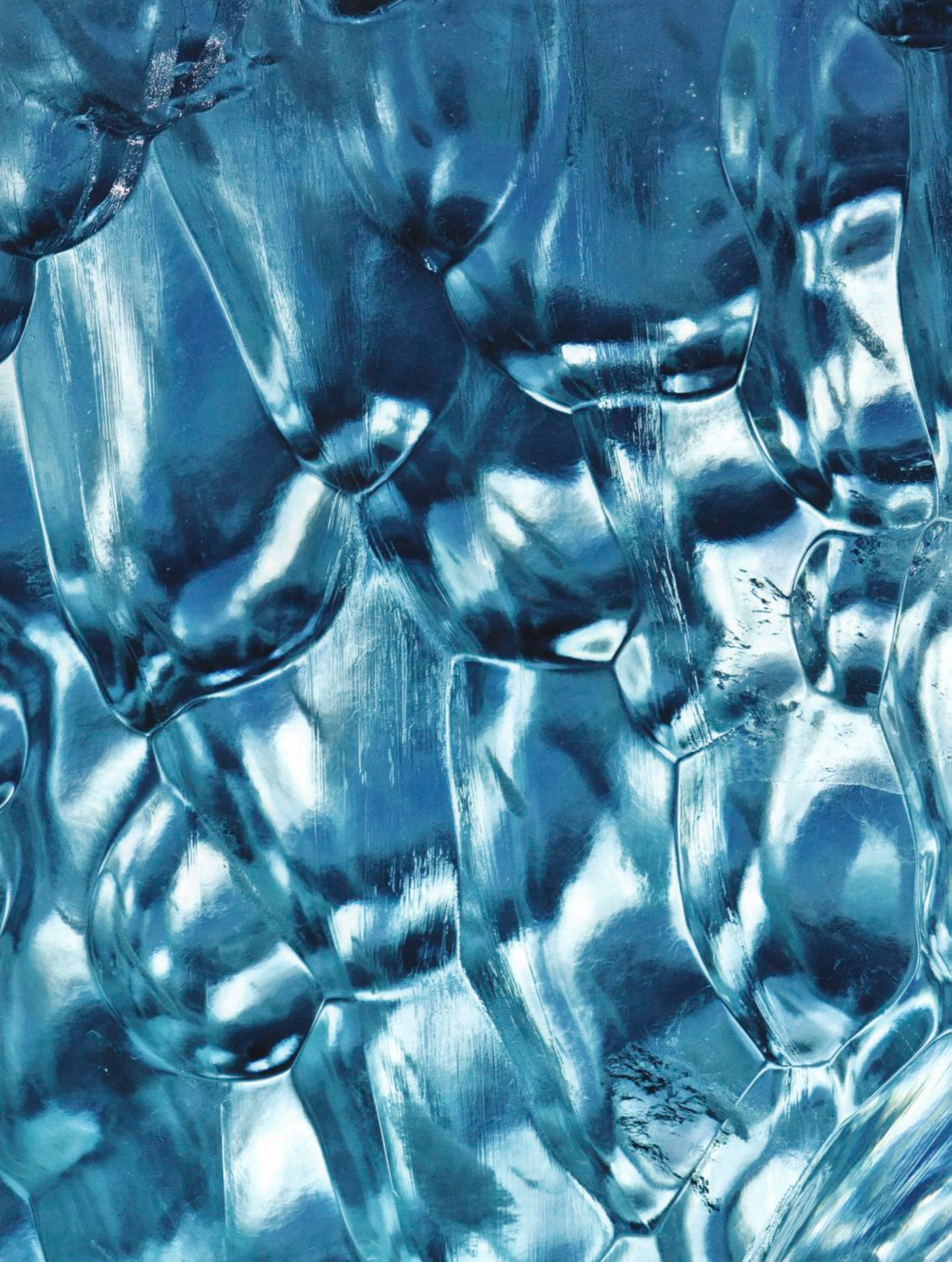
Even after it has reached its boiling point, liquid water soaks up a very large amount of heat—called laent **heat of vaporization**—before it transforms into **steam**. That's why it takes so long to reduce a stock. The energy barrier between water's ice and liquid states, called the latent **heat of fusion**, is similarly high.

The stickiness that is primarily responsible for all these quirks is the **hydrogen bond**: the attraction between a hydrogen atom in one water molecule and the oxygen atom in an adjacent one. Hydrogen bonds are only about one-tenth as strong as the bonds that hold atoms together within molecules. But they have a persistent, collective effect, discouraging motion enough as they constantly form and break to give rise to all of those odd properties just mentioned (see Why Water Is Weird, page 298).

Beyond their effects on the properties of pure water and ice, hydrogen bonds are responsible for many of the ways that water interacts with other substances. The bonds help to make water an exceptional solvent. For example, sugar and ethyl (grain) alcohol dissolve readily in water because their molecules can form hydrogen bonds with the water molecules. The same phenomenon helps gelatin and pectin thicken water-based solutions.

Take the water out of a food, and the texture of the dehydrated substance changes, in part because **proteins** change their structure or even fall apart when hydrogen bonds are removed. That is why raw dehydrated foods like jerky often look cooked.

Icebergs (left and next page) float on seawater because frozen water is less dense than liquid water. The ice appears blue because hydrogen bonds absorb red and yellow light preferentially, acting like a filter that screens out all but blue and blue-green colors.



THE CHEMISTRY OF

Why Water Is Weird

Water is an unusual chemical in many ways, and the main reason for its weird behavior is the ability of the H in one H_2O molecule to link up with the O in a neighboring water molecule to form a hydrogen bond. These bonds, which are constantly breaking and re-forming in liquid water, play starring roles in the formation of water droplets, steam, and ice. They also deserve credit for water's high heat capacity.

When a raindrop condenses out of a cloud, for example, molecules in the body of the droplet stick to their neighbors in all directions, whereas molecules on the surface, having no such neighbors outside the droplet, devote all their hydrogen bonding power to just those neighbors beside and beneath them. The net result is surface tension, which forces the droplet to assume the most compact, minimal-surface shape that it can: a sphere. If you could view the tiny water particles in fog up close, you would see that they, too, are spheres.

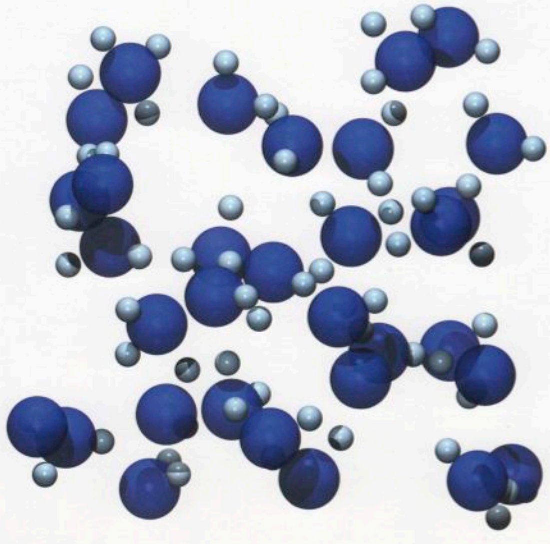
The main reason that the boiling and freezing points of water are hundreds of degrees higher than one might expect from its low molecular weight is that hydrogen bonds impede its molecules from leaving its surface while it is heated. Only with a large bump of energy, which we perceive as a high temperature, can they break away. In contrast, liquid nitrogen—another simple, lightweight molecule (N_2)—boils at −196 °C / −321 °F.

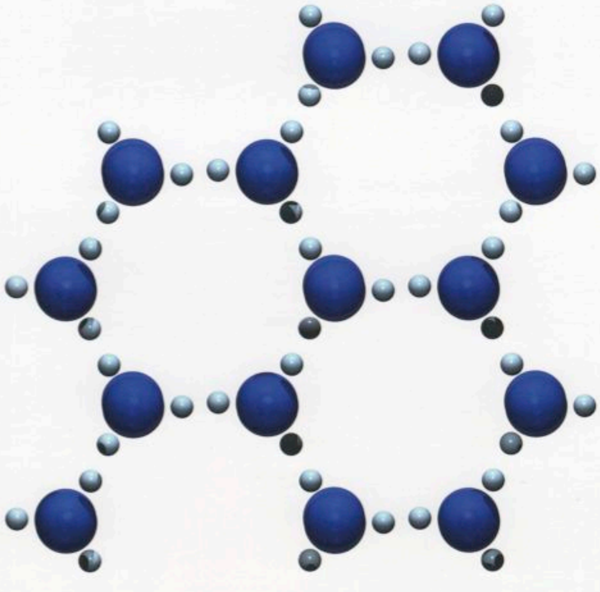
Water expands as it freezes because of hydrogen bonding. These hydrogen bridges have a certain length, but because they are constantly flickering on and off in liquid water, the molecules don't have to stay at such fixed distances from one another. When the water cools down to freezing temperature, however, the molecules snap into relative positions that make all the bonds the same length: the distance that minimizes the strain and energy in the bond. The resulting latticework of water molecules contains hexagonally shaped hollow spaces. These open spaces lower the density of ice to about 92% of that of liquid water. That's why ice floats on water.

A pot of water, watched or not, takes so long to boil because the heat capacity of this liquid is oddly large. Hydrogen bonds are again at work here. Heat makes molecules move faster, but if the molecules are entangled by hydrogen bonds, it's harder to speed them up—and thus to raise their temperature.

For more on heat capacity—the amount of energy needed to warm a substance—see page 266.

Molecules of water form a jumble when in liquid form (below left). Each molecule is H_2O: two hydrogen atoms (light blue) joined to one atom of oxygen (dark blue). The electrons in the molecule are skewed more toward the oxygen atom than toward the hydrogen atoms, so the oxygen atom is somewhat more negatively charged than the hydrogen atoms, resulting in two electric poles like the two poles of a magnet. A hydrogen bond forms between two close water molecules when a (positive) hydrogen atom in one molecule is attracted to the (negative) oxygen atom in the other. In ice, the molecules are arranged into a lattice of hexagonal cells (bottom right).





THE PHYSICS OF

How Water Freezes

Have you ever put a can of soda into the freezer for a quick chill, only to forget about it until it bursts hours later? The soda expands as the water in it turns to ice, exerting pressure against the walls of the can until it ruptures at its weakest point, spewing sweet shrapnel all over the place.

Water expands in unpredictable directions when it freezes. And since freezing is inherently idiosyncratic, no two ice cubes look exactly the same. For example, ice cubes may look cloudy because freezing squeezes dissolved air out of the water in certain places but not others, forming clusters of tiny bubbles that get trapped in the crystal lattice (see Water as a Solvent, page 330).

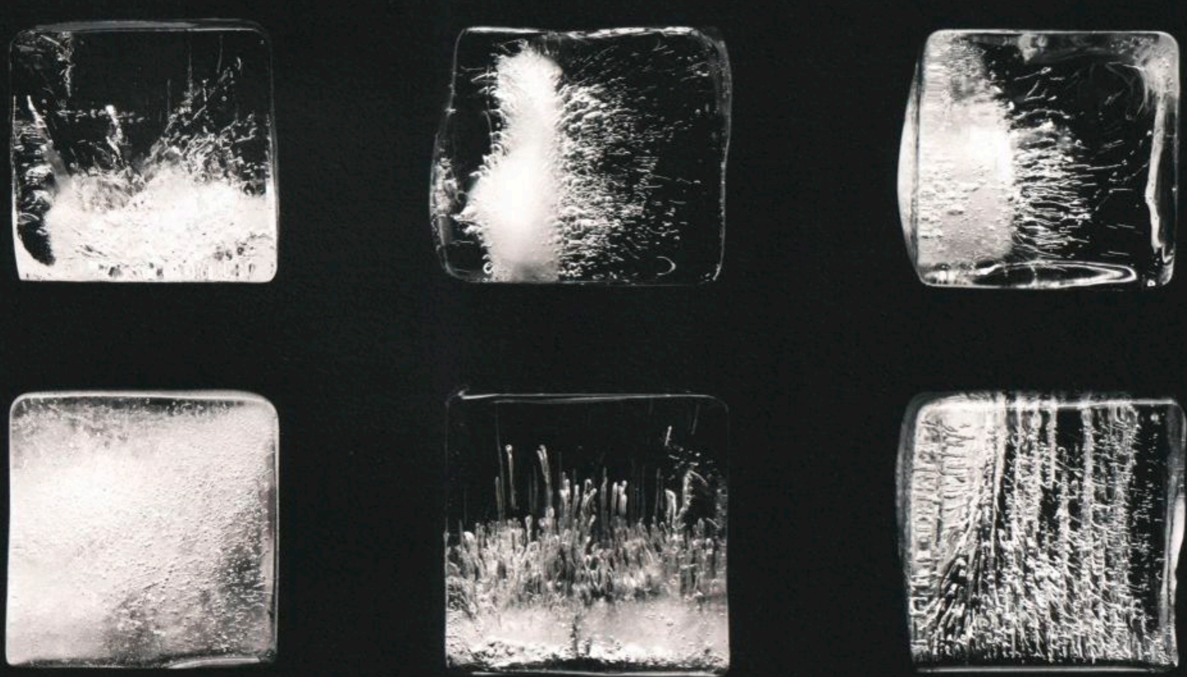
A freezer carries heat away from the water by a combination of convection and conduction. **Convection** occurs when temperature inhomogeneities produce moving currents in the air surrounding the water. As the warmer air rises and the cooler air sinks, the net effect is that heat is carried away from the water's surface, thereby freezing it from the outside in.

Conduction, on the other hand, is the removal of heat through direct contact of the water with anything that is colder, such as the air in the freezer or the freezing coil itself. This also tends to freeze the water from the outside in, but it rarely happens uniformly, and any initial asymmetries take root and tend to grow bigger as more ice crystals form.

An interesting fact is that because the heat conductivity of ice is almost four times that of liquid water, heat flows out of ice more quickly than it does from liquid water. Thus, as ice begins to form, existing crystals grow faster than brand new ice crystals form in the liquid. In other words, ice begets ice faster than water begets ice, under the same conditions. This disparity also tends to cause initial minor asymmetries to be magnified as freezing progresses.

Dissolved substances such as alcohol, sugar, or salt may be thought of as getting in the way when the temperature drops and the water molecules try to find their proper places in the solid lattice. It's like trying to maneuver your way through a crowd. That's why water solutions freeze at lower temperatures than pure water does.

Each sugar solution or brine may therefore freeze quite differently from another, depending on the kind and concentration of additives in the water. Stirring or agitating the liquid makes a difference, too. The pattern of freezing thus varies from one container to the next and, even in the same container, from one freezing cycle to the next.



Ice turns white where air bubbles get trapped as freezing squeezes the air dissolved in water out of the crystal lattice (see page 304).

THE ENERGY OF CHANGING STATES

Because of its anomalous properties, water is the only chemical compound on Earth that occurs in the natural environment in all three of the primary states of matter: solid, liquid, and gas. The states of water—also called its phases—are so familiar that we have a specific name for each: "ice" (solid water), "water" (liquid water), and water vapor, which we call "steam" when it's hot.

"Vapor" means the same thing as "gas." People often use the word "vapor" to emphasize that the gas arose from a liquid or contains suspended droplets (a mist or fog) of liquid. For more details, see page 313.

Ice, water, and steam each respond differently to heat—that is, they have different thermodynamic properties. And when the substance changes from one form into another, its molecules either absorb or release heat, which can either cool or warm a food in its vicinity. Steam, for example, warms food in two distinct ways: not only by imparting some of its high temperature directly but also by depositing some of the heat that emerges when it condenses from a vapor to a liquid on the surface of the food.

Ice similarly cools food both by being cold and by absorbing heat as it changes from solid to liquid. The same amount of heat that goes into ice when it melts must comes out of water as it freezes. You may have noticed that the air turns warmer when it begins to snow.

The well-defined plateaus shown below happen only with pure water; in food, both freezing and boiling occur over a range of temperatures, owing to the presence of fats, solutes, and other components.

So this hidden heat somehow emerges when water (or, for that matter, any other substance) shifts form from one state to another—and even odder, the heat doesn't change the temperature of the water itself; it only heats or cools its surroundings. So the heat we're talking about here is qualitatively different from the familiar, sensible heat that we measure by touch and thermometer. How do we make sense of this?

Remember that all matter contains internal energy, which is the potential energy inherent in all its molecular bonds and motions (see page 260). Whenever water passes through a phase transition, it either spends some of that internal energy or borrows some from its surroundings in order to rearrange its molecules into the new state of matter. The energy thus isn't hidden so much as it is latent: it is always there, just in a form that is not easy to perceive.

When latent energy is spent or borrowed, it doesn't change the water's temperature—the energy all goes into accomplishing the transition from one state to another. For example, when pure water boils to steam, the boiling water stays at 100 °C / 212 °F, no matter how much external heat you blast into it. (But a warning: once the steam has formed, the vapor can quickly get much hotter than that.)

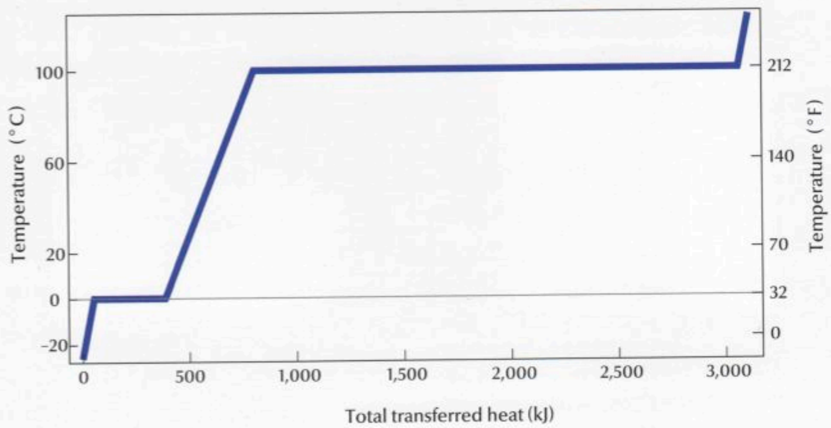
Latent heat is hard to measure. There is a quantity called **enthalpy,** or heat content, that is related to it, but there's no such thing as an enthalpy meter; you can't just stick a probe in your cooking system to measure it. We can,

How Water Heats

Heat water and its temperature rises; cool the water, and the temperature falls—simple, right? Unfortunately, no. In fact, one of the greatest sources of frustration for cooks is the counterintuitive behavior of water as it thaws and boils or condenses and freezes.

The chart at right illustrates the essence of the problem. As you pour joules of heat into a kilogram of ice, moving left to right along the blue curve, the ice warms for a while, then halts at the melting point. Energy continues to pour in, but the temperature does not start to climb once more until the last sliver of ice has melted. The temperature plateaus again at the boiling point, and here the temperature stays until every drop turns to steam. The pattern applies in reverse, too: from right to left as steam condenses and water freezes.

Notice that it is the amount of heat energy—not the power, temperature, or rate of energy transfer—that matters. You can double the heating power to speed up the process, but the phase changes will occur at the same temperatures.



however, measure the large quantities of energy we have to expend or extract to make water boil, melt, condense, or freeze. That heat is the change in enthalpy, and it is almost always very close to the change in internal energy of the water.

For every kilogram of water you put into an ice cube tray, for example, your freezer needs to take out 334,000 J / 317 BTU of energy—roughly the energy content of a kilogram of AA batteries—to transform it from puddles to cubes. That is the heat of fusion, and it is the same amount of latent heat that the kilogram of ice cubes absorbs as it melts. Ethyl alcohol freezes more cheaply, in energetic terms, at the price of just 109,000 J/kg (47 BTU/lb).

When you boil 1 l / 34 oz (one kilogram) of water into steam, your burner must first heat the water to the boiling point, which takes at least 419,000 J / 397 BTU if the water is ice-cold at the start. But once the water has reached 100 °C / 212 °F, the burner must pour in at least 2,260,000 J / 2,142 BTU more to evaporate it: this is the heat of vaporization. It takes more than five times as much energy, in other words, to boil a pot of hot water as it does to heat it in the first place!

Other states of matter are known to science: the charged gas known as plasma found in the atmosphere of the sun, the ultradense matter in a neutron star, and a rarefied entity called a Bose-Einstein condensate that forms at temperatures near absolute zero. None of these is likely to wind up on your dinner plate.

THE PHYSICS OF

Lectures, Festivals, Space, and Freedom

The reason that it takes so much energy to turn ice into water and water into steam is that each of these states stores different amounts of internal energy. Generally speaking, solids contain the least energy, gases hold the most, and liquids fall somewhere in between.

The differences in energy content arise from constraints on the infinitesimal motion of atoms and molecules, which vary from one phase to the next. A gas has fewer constraints—or more **degrees of freedom**—than a solid does.

Imagine sitting in a lecture hall at a formal presentation. You can fidget all you want in your seat, but you're not free to get up and dance or move around the room. A molecule in a solid is similarly locked into position in a fixed structure and enjoys very few degrees of freedom in its movements.

Molecules in liquids are more like people milling about at a street festival. They're free to walk around, and any one of them could wind up anywhere in the area, but their feet can't leave the ground, and their movement may be impeded by social clusters that keep disbanding and re-forming.

Molecules in a gas are the most liberated. Like astronauts "floating" in three dimensions in the nearly weightless free fall of orbit, gas particles have the most degrees of freedom.

HOW TO Read the Phase Diagram of Water

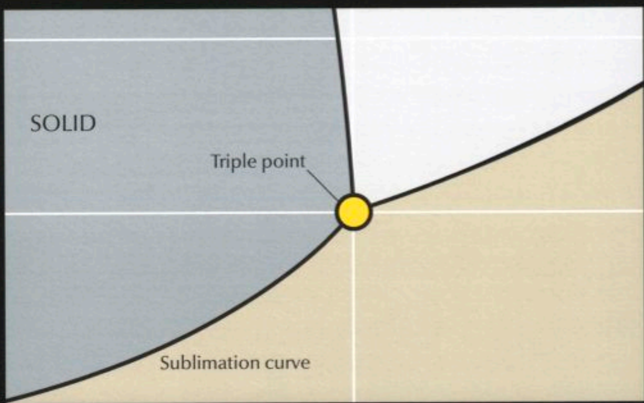
Whenever you use a pressure canner, concentrate or distill under vacuum, or freeze-dry food, you exploit the energetic phenomena that occur when water changes from one state of matter to another. To better understand these transitions, it helps to look at a phase diagram.

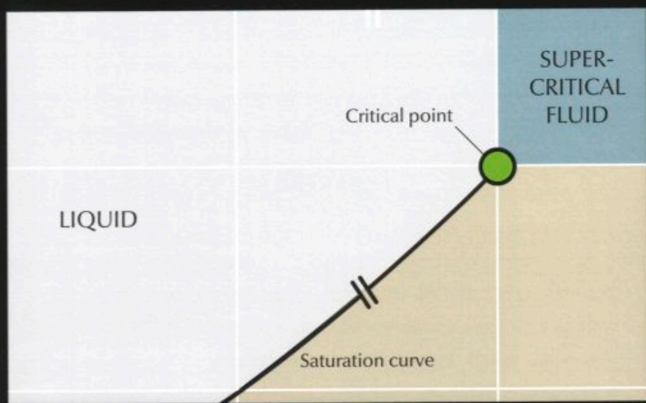
A **phase diagram** is a map that shows what form a substance will assume at a range of pressures and temperatures. The phase diagram at the right illustrates the behavior of pure water. By convention, colder temperatures are on the left, hotter temperatures on the right, low pressures (such as vacuums) near the bottom, and high pressures (such as those in a pressure cooker) toward the top.

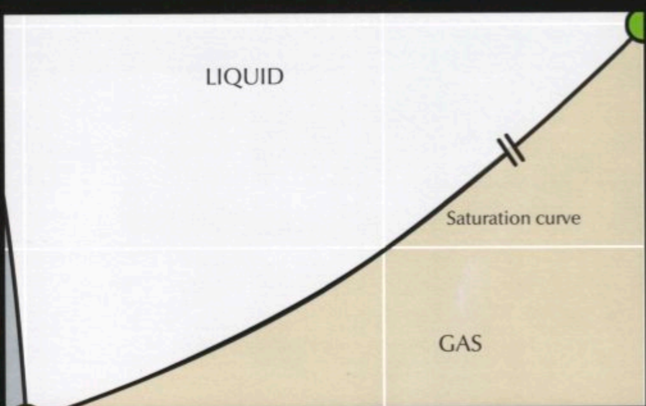
Solid lines delineate the boundaries between the realms of solid, liquid, and gas. At temperature/pressure combinations beneath the solid lines, the phases on either side can exist together—that is, the lines trace the melting and boiling points, which shift as the pressure changes. (The "normal" freezing and boiling points of water at 0 °C / 32 °F and 100 °C / 212 °F actually apply only when the ambient pressure is 1 bar / 14.5 psi.)

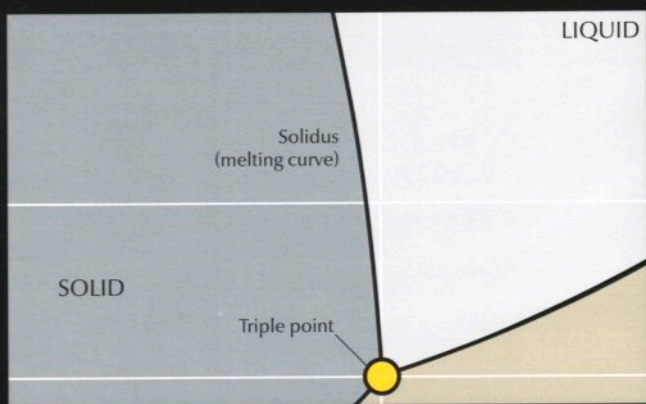
1 **The triple point is the unique combination of temperature and pressure at which all three phases of a substance exist in equilibrium—that is, with no further melting or freezing taking place.** For water, the **triple point** occurs at 0.01 °C / 32 °F and 6.1 mbar / 0.089 psi. The triple point of water is so reliable that it's been used for centuries to calibrate thermometers. If you put ice and water into a closed container and let them come to **equilibrium**, the water vapor will automatically assume its triple point pressure. (Note that this is the pressure of the water vapor alone, regardless of what other gases may be present in the container. It's called the **partial pressure.**)

2 **The critical point marks the region on the phase diagram where liquid and gas become indistinguishable.** Beyond the **critical point**, the material exists as a **supercritical fluid** that displays features of both a liquid and a gas. Like a gas, a supercritical fluid is compressible and expands to fill its container, but substances dissolve in it as if it were liquid. The critical point of water falls at 221 bar / 3,205 psi and 374 °C / 705 °F. Supercritical water is unlikely to be found in the kitchen, but supercritical carbon dioxide is used in industrial processes with food. Unlike the boiling and freezing points, the triple and critical points are fixed; they do not vary with pressure.



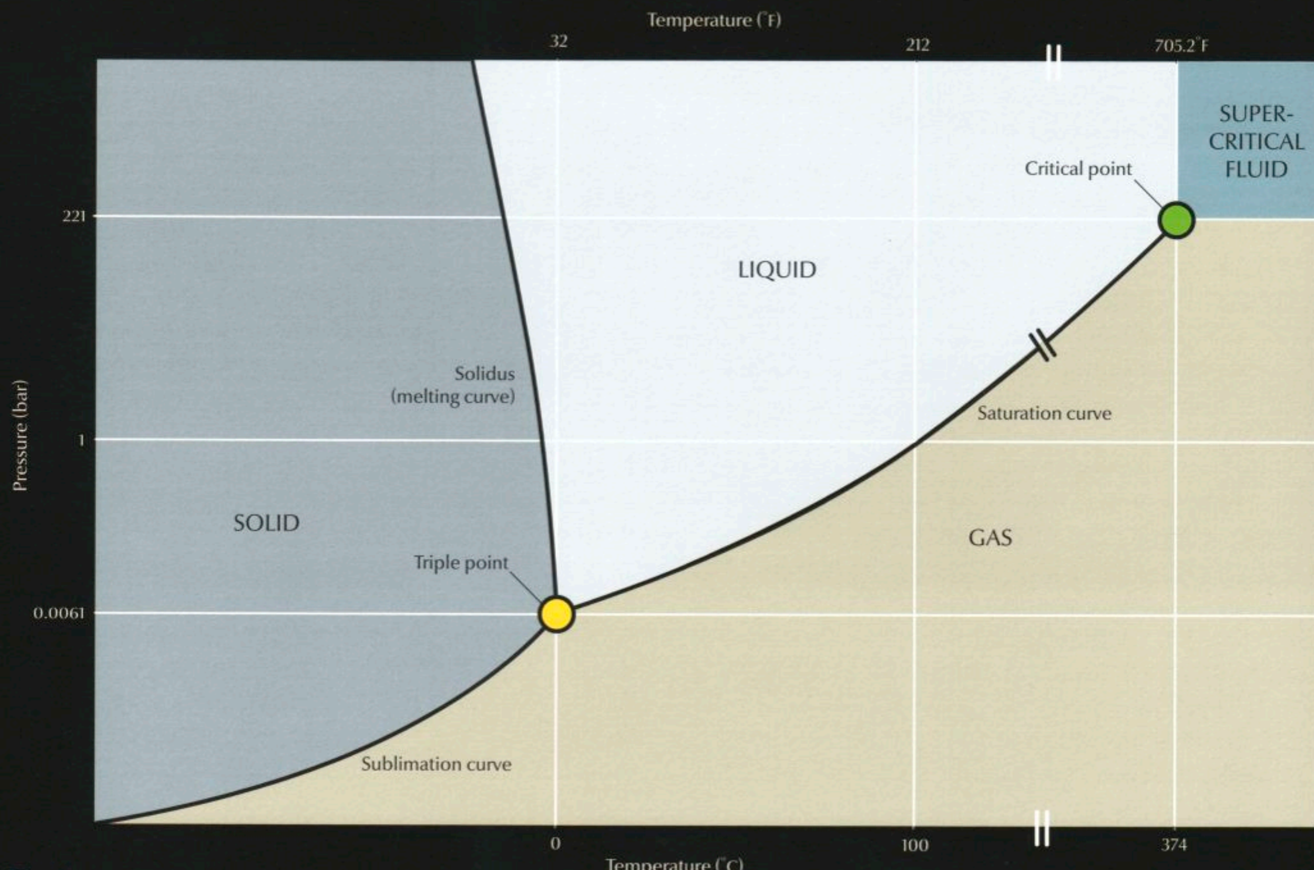






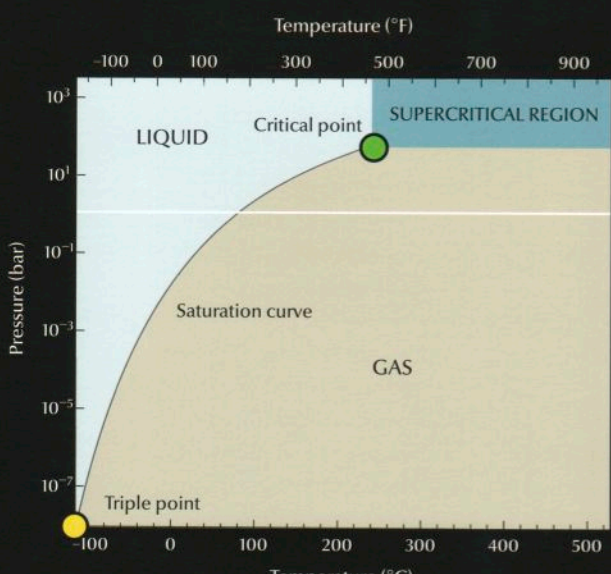
3 **The so-called "boiling point" is not a point—it depends on pressure, so on a phase diagram it is a curve, called the saturation curve, that runs from the triple point to the critical point.** On one side is liquid, on the other, gas.

4 **The conditions for freezing also depend on pressure, so there is no "freezing point"—instead there are two curves.** Above the triple point there is the solidus or melting curve. On one side is solid, on the other, liquid. Water has an unusual solidus that curves back to the left. This means you can freeze water by lowering the pressure, a property exploited by pressure-shift freezing (see page 309). Below the triple point is the sublimation curve that separates solid from gas.



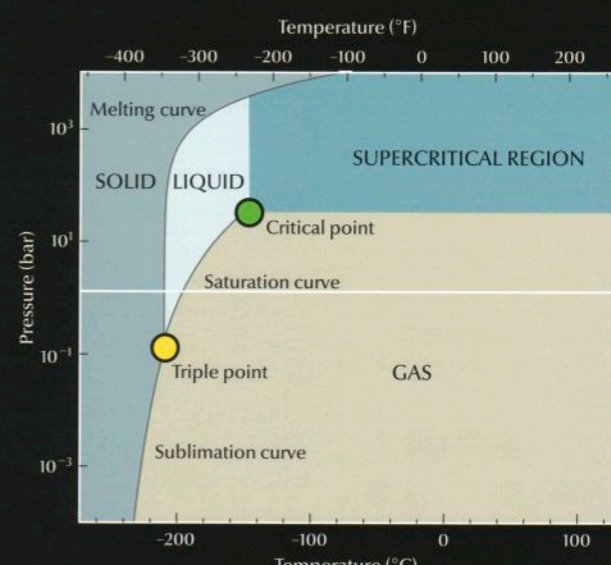
Water

Triple point: 0.01 °C / 32 °F and 6.1 mbar / 0.089 psi. Critical point: 374 °C / 705 °F and 221 bar / 3,205 psi



Alcohol (ethanol)

Triple point: −114 °C / −173 °F and 8.8 × 10⁻⁶ mbar / 1.3 × 10⁻⁷ psi
Critical point: 241 °C / 466 °F and 61 bar / 885 psi



Nitrogen

Triple point: −210 °C / −346 °F and 127 mbar / 1.8 psi
Critical point: −147 °C / −233 °F and 34 bar / 493 psi

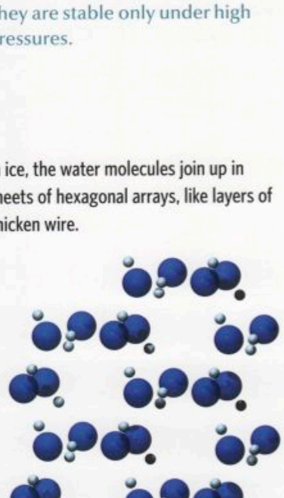
FREEZING AND MELTING

Besides the familiar form of ice, frozen water can take on seven other forms of ice that differ in the details of their crystal structure. They are stable only under high pressures.

The ability to freeze foods, both raw and cooked, has revolutionized the ways in which we preserve, distribute, and cook them. Freezing preserves food because it slows down most (but not all) of the biological and chemical reactions that cause spoilage. Among cooks, however, freezing often has a bad reputation because of the damage it can do to the texture, flavor, and appearance of a food. You can blame most of this damage on ice crystals: on when, where, how, and how fast they were formed. So it is useful to look closely at the process of ice formation during the freezing of foods.

Under everyday conditions, the molecular structure of an ice crystal is hexagonal. The water molecules are fixed in place at the junctions of a sheet of abutting hexagons, like chicken wire, with many such sheets piled upon one another to form a three-dimensional crystal.

In ice, the water molecules join up in sheets of hexagonal arrays, like layers of chicken wire.



This highly structured solid begins to grow in liquid water only at specific spots called **nucleation sites**: microscopic regions in which chance hexagonal arrangements of a few water molecules remain ordered long enough for other water molecules to join their assemblage.

In food, a tiny gas bubble or a speck of dust can serve as a nucleation site by providing a surface on which ordered clusters of water molecules can remain stable for a short time. The nucleating structure makes it energetically favorable for surrounding water molecules to fall into this same ordered arrangement. Nucleation sites are therefore where phase changes begin, not only from liquid to solid but also from vapor to liquid, as in the condensation of water vapor into fog. A very pure liquid such as filtered, distilled water has no potential nucleation sites, and for that reason it resists freezing so much that it can be **supercooled**: it can remain liquid even when chilled below its freezing point.

Suspended specks of solid material encourage nucleation, but oddly enough, dissolved materials actually discourage the formation of ice. For example, when salt dissolves in water, the sodium chloride splits into ions. When sugar dissolves in water, it does not break into ions. Instead, individual sucrose molecules dissolve.

Dissolved ions and molecules get in the way of water molecules trying to freeze into ice. Because it is harder for the water to freeze, the freezing point of the solution drops below that of pure water. This phenomenon, called **freezing point depression**, explains why brines have much lower freezing points than plain water does.

The more molecules or ions of a dissolved

Perito Moreno Glacier in the Patagonian region of Argentina is a dramatic example of natural ice.

substance—any dissolved substance—present in the water, the more they get in the way, and the lower the freezing point becomes. Note that the effect depends on the number of molecules or ions, not on their mass. A substance like salt that dissolves into light ions has many more of those ions for a given mass than a substance like sugar, which has much heavier molecules. Pound for pound, salt causes more freezing point depression than sugar does—by more than a factor of ten. The principal reason that ice cream doesn't freeze as solid as a block of ice is that it contains a lot of dissolved sugar. In practice, other constraints may apply, such as how much of a substance can be dissolved in a liquid before it reaches its limit of solubility (see Water as a Solvent, page 330).

Fish don't freeze in polar oceans because antifreeze proteins dissolved in their bloodstream lower the freezing point of their blood, tissues, and organs. Many insect, plant, and bacteria species have these proteins. Antifreeze proteins are also known as **ice-restructuring compounds** because they bind to the surfaces of small ice crystals, preventing the crystals from growing large. Ice-restructuring proteins derived from a northern Atlantic fish called the ocean pout are used in ice cream to prevent the growth of large, crunchy ice crystals during storage.

From Fresh to Frozen

Raw foods contain two kinds of water. The water outside the cells—the **extracellular fluid**—is relatively pure, whereas the water inside the cells—the **intracellular fluid**—contains all the dissolved substances that are necessary for life and therefore has a lower freezing point. Ice crystals form first, at a temperature of about -1 °C / 30 °F, in the extracellular fluid outside the cells. The temperature drops slowly to around -7 °C / 19 °F during this phase change—not cold enough to begin freezing the intracellular fluids, which typically start to freeze around -10 °C / 14 °F. Until all of the extracellular fluid has frozen completely, water inside cells cannot begin to freeze.

As water in the food freezes, there is less liquid water for dissolved substances to inhabit, so they become more concentrated and the freezing point of the remaining liquid drops further.

This concentration effect can be put to culinary use: see Freezing Out the Good Stuff, page 2·396. One side effect of the concentration, however, is to dehydrate the cells (via a process called **plasmolysis**), which renders them unpleasantly flabby. Another consequence is that even when food is stored frozen at -20 °C / -4 °F—the lowest operating temperature in most domestic and professional freezers—a small but significant portion of the extracellular water often remains liquid.

Within food stored in this incompletely frozen condition, extracellular ice crystals grow larger day by day, feeding their expansion with water drawn out of cells. Eventually, this leaves many cells dried out or broken, while the food becomes riddled with growing ice crystals that further damage the texture. Thawing turns these ruptures into channels through which precious juice drips out.

When food is frozen at a low enough temperature, any remaining liquid in the cells will turn so viscous that it actually becomes a glass—a solid in which molecules sit in random arrangements rather than lining up in orderly rows as in a crystal. The word "glass" evokes images of windows and certain polymers, but water saturated with dissolved proteins, carbohydrates (sugars), and salts can become glassy as well. When food gets colder than its **glass-transition temperature**, it takes on these glass-like properties. For honey, for example, this transition occurs around −45 °C / −50 °F. For most foods, the glass-transition temperature occurs in the range from −80 °C to −20 °C / −110 °F to −4 °F.

Storing food below its glass-transition temperature greatly helps to preserve its quality. Unfortunately, almost all freezers found in homes or restaurants are way too warm to store food below its glass-transition temperature. As a result, the food slowly degrades in the freezer. The shorter the time they are held, the less of a problem this poses.

For long-term freezing, it's best to store food below its glass-transition temperature, the temperature at which the remaining water in the frozen food solidifies without the damaging crystals of ice. Few consumer- or restaurant-grade freezers can hold such temperatures, however.

Ultra-low temperature freezers are available from laboratory equipment companies. It is easy to get them go down to −80 °C / −110 °F, and some go so far as −150 °C / −238 °F.

This loss of food quality does not happen if you buy an ultralow-temperature freezer. These units are widely used in laboratories. For many foods, −60 °C / −76 °F is cold enough, and −80 °C / −112 °F is sufficiently cold for just about all foods.

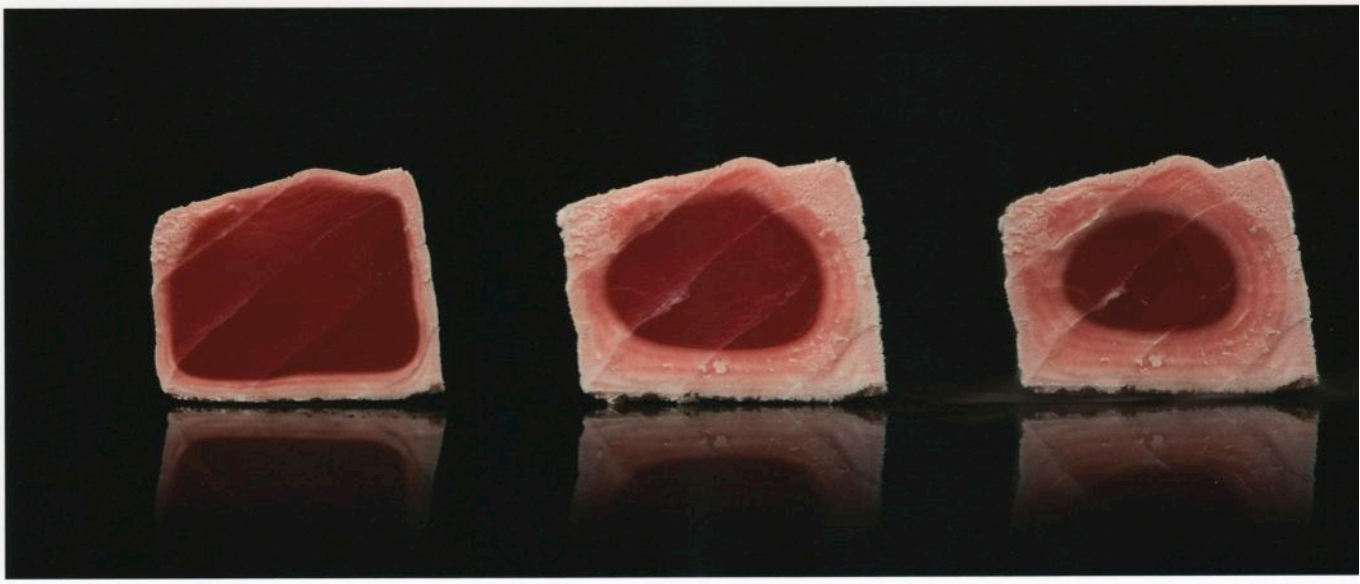
Unfortunately, the oxidation of fats continues even at very low temperatures, a point at which many other chemical reactions have ground to a halt. The oxidation generates a rancid flavor—some call it "freezer taste."

The Many Ways to Freeze

Techniques for freezing food have a long and storied history. In the 1920s, an American taxidermist, biologist, inventor, and entrepreneur named Clarence Birdseye developed a machine that could "**flash-freeze**" vegetables and fish in such a way as to preserve a good part of their flavor and appearance. The machine packed fresh food into waxed cardboard boxes and froze the contents using chilled metal plates.

Birdseye reportedly took inspiration from the way that Inuit people in the Canadian Arctic preserved their fresh-caught fish using ice, seawater, and cold winds. After obtaining his patent in 1924, Birdseye test-marketed his frozen foods in Massachusetts before he rolled them out nationally—literally rolled them out, by transporting them to retailers in specially refrigerated

A freezing front moves through tuna in these cross sections, showing clearly how freezing takes place from the outside in. The tissue at the very center of the fish may never freeze completely.



boxcars. By the late 1940s, freezers were increasingly common home kitchen appliances in the United States, and the frozen food industry began to take off.

Today, you can choose among many types of freezers, each of which has different advantages and disadvantages. The most common type of home freezer uses static air to cool its contents to about −20 °C / −4 °F. A commercial **plate freezer** works more like Birdseye's machine and also a bit like a frying pan in reverse: two flat plates sandwich the food and draw heat from it via a coolant pumped through them at around −40 °C / −40 °F. This approach is best for foods with uniform shapes, such as burgers, fish fillets, and fish sticks.

Restaurants can use **blast freezers**, which include a fan to increase the flow of cold air around the food to speeds of about 2–5 m/s (6.6–16.4 ft/s), in much the same way that the fan in a convection oven circulates hot air. This technique can freeze foods in a half hour or less but can dehydrate them somewhat in the process unless the food is tightly wrapped or vacuum-sealed.

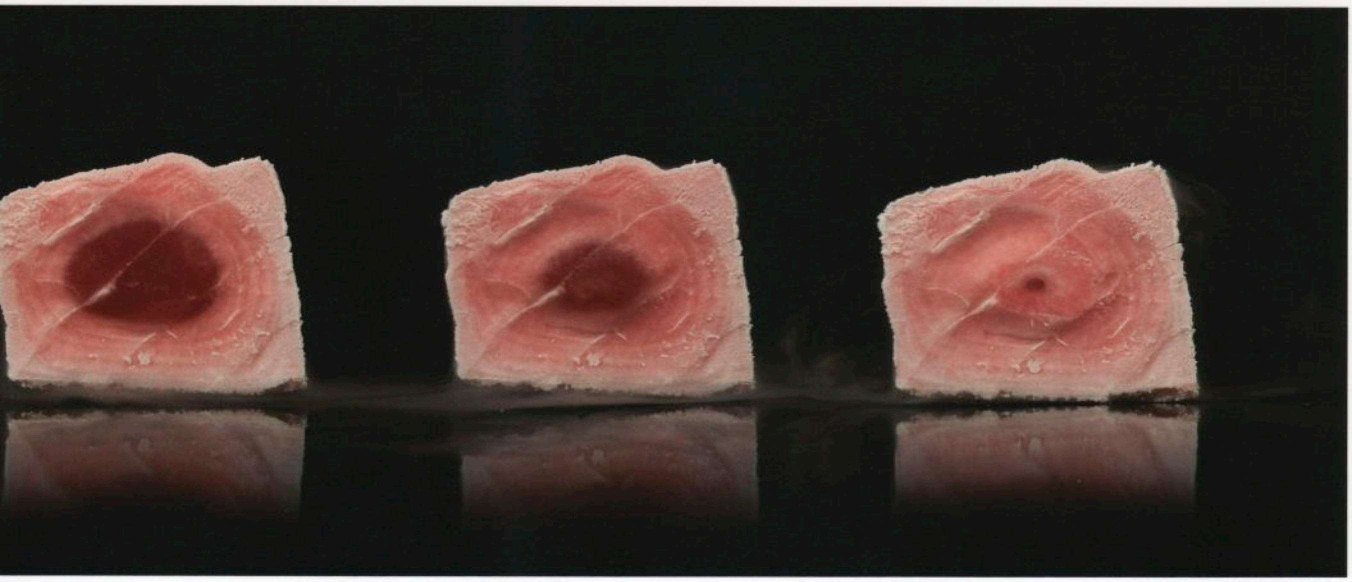
In the early 1960s, frozen food makers developed a modified form of blast freezing called **fluidized bed freezing**. A mesh conveyor belt carries small pieces of food to a freezing zone, where a fan blows cold air at about −30 °C / −22 °F upward through the mesh, tossing and tumbling the pieces so they stay separated and flow like a fluid. The fluidized bed freezes food very uniformly and minimizes clumping, so it is often used for **individual quick freezing** of small food items, like peas, diced vegetables, shrimp, and French fries. The benefit to the cook is obvious: you can take just the amount you want to thaw from the package instead of having to thaw the whole box at once.

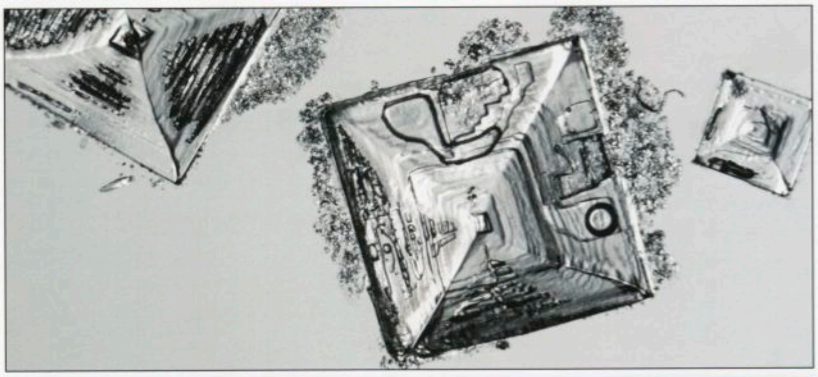
At the extreme end of the quick-freezing spectrum is cryogenics, from the Greek word *kryos*, meaning cold or frost. In physics, the term generally applies to research done at temperatures below

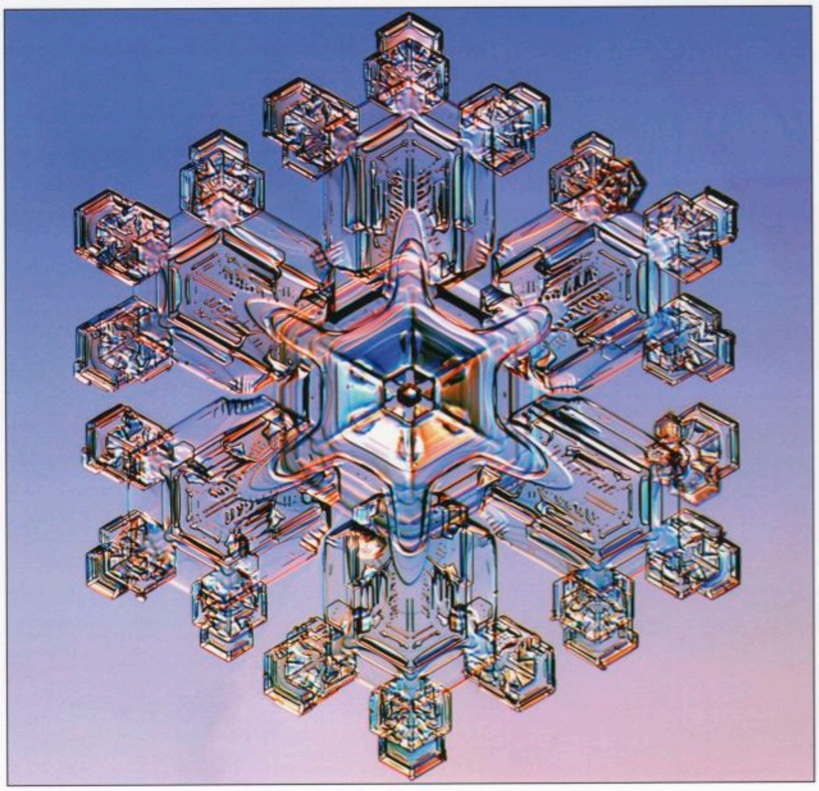
THE PHYSICS OF

Water Activity

Water molecules in a solution are often bound to the molecules dissolved in the water. This makes them unavailable to participate in other chemical reactions or for either drying (evaporation) or freezing. **Water activity** is a measure of the amount of free water, which is not bound to other molecules. Water activity is usually denoted as a_w. The a_w of pure water is 1.0, and the a_w of juices, milk, and raw meat is 0.97–0.95. Honey has an a_w of 0.6, which is low enough that most microorganisms cannot survive in it. As a result, honey keeps well at room temperature. At the low end of the scale, dry powders like powdered milk or instant coffee have an a_w of 0.2–0.3. Water activity is very important for drying foods (see Drying, page 2·428).







Crystalline solids such as ice, salt, and quartz consist of characteristic orderings of atoms or ions that are reflected in the shapes of the macroscopic crystals. A snowflake clearly shows the hexagonal geometry of ice crystals (bottom image at left). Salt grains (middle) reflect the cubic ordering of their ions. And the spiraling tetrahedrons of vitamin C give rise to long, pointy obelisks (top).

−150 °C / −238 °F, but in food handling, −80 °C / −112 °F will usually suffice. Research on cryogenics in the U.S. started in the 1950s, in research on materials science, advanced electronics, superconductors, and rocket fuels for the space program.

More recently, **cryogenic freezing** has been used by Modernist chefs to achieve unusual effects (see page 2·456). The most common cryogenic freezing medium is liquid nitrogen, which boils at −196 °C / −321 °F.

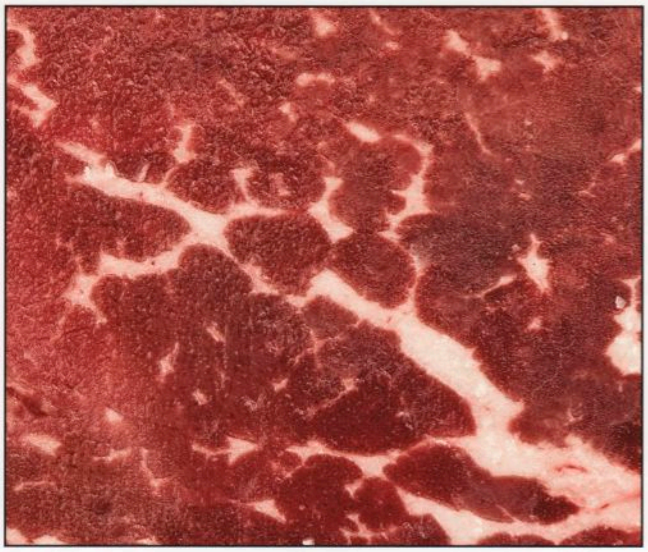
The freezing method used is very important for food quality. In general, the smaller the ice crystals, the less damage to the cells in food and the closer its quality to that of fresh food. In most cases, the best way to get small ice crystals is to freeze food quickly: the faster, the better.

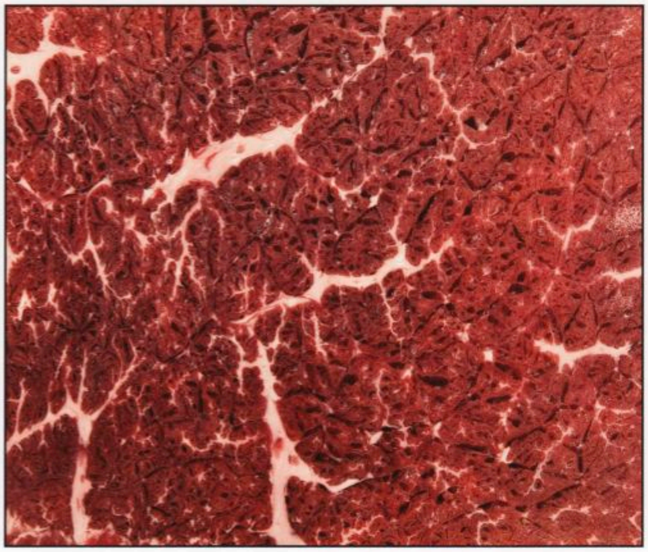
Unfortunately, there are some problems in implementing this strategy. Heat diffuses through food by conduction, which is a slow process no matter how cold you make the outside of the food. Just as it does during cooking, the thicker the food, the longer it takes—and like the cooking time, the freezing time increases directly with the increase in the square of the thickness. All else being equal, a piece of food that is twice as thick takes four times as long to freeze.

In a thick piece of food, no matter how quickly you remove heat from the outside, the inside will freeze at a rate determined by the diffusion of heat. This dependence on heat diffusion makes it difficult to quickly freeze the inside of a very thick piece of food (such as a whole beef carcass).

To maximize its quality, food should be cut as thin as possible before freezing—perhaps into individual serving portions. To protect them from **freezer burn** (see page 326), the slices should be vacuum sealed in sous vide bags. Liquids can be sealed at weak vacuum in sous vide bags then laid flat so that they will freeze into thin, flat plates.

The absolute worst way to freeze food is to simply place it in an conventional home or restaurant freezer. This technique freezes the food slowly, and the heat introduced into the freezer by the warm food can cause ice crystals to grow in the





Freshly frozen beef (left) and the same beef after two and a half months of storage in a standard commercial freezer (right) illustrate the damaging effects of improper handling. The stored beef is riddled with holes caused by large ice crystals, which grow slowly in the spaces between cells. When the beef is thawed after having been stored for months, it loses about twice as much fluid as it would have if it had been frozen for just 48 hours.

THE PHYSICS OF

Pressure-Shift Freezing

A quick dunk in liquid nitrogen, a blast of superchilled air, or contact with an ultracold slab of metal are not the only ways to freeze food quickly. A relatively new approach is to use a quick drop in pressure, rather than in temperature, to suck the heat out of the food and produce the very small ice crystals that will preserve its texture better.

The technique, called pressure-shift freezing, exploits the fact that the physical state of water depends not only on its temperature but also on the pressure (see How to Read the Phase Diagram of Water, page 302). If the pressure on a food is raised to 2,000 times atmospheric pressure, for example, the water in it will remain liquid even when supercooled to −22 °C / −8 °F.

The food won't be crushed by the pressure because the liquid water inside it is incompressible and thus uncrushable. Suddenly release the excess pressure on the supercooled water, and it freezes to the core almost instantly. You may have witnessed this phenomenon if you have ever opened a very cold can of soda and seen it freeze instantly in your hand.

Conventional freezing must rely on conduction to transfer heat out of the food, but a wave of pressure release, called a rarefaction wave, will travel through the food at the speed of sound. Ice crystals form so quickly as the wave passes that they just don't have time to grow very large.

A 2002 study found that the ice crystals in tofu frozen this way were a mere one-thirtieth to one-hundredth the size of those in blast-frozen tofu. Results with cubed potatoes and whole eggplants were similarly promising.

Pressure-shift freezing is not yet widely used because it is expensive. It is being evaluated for use with foods of very high value, however, such as sushi-quality bluefin tuna.

Blast chillers and freezers are available in small undercounter models, which are a good choice for homes or restaurants that do a lot of freezing.

Immersing food in liquid nitrogen is in some sense the direct opposite of deep frying. At −196 °C / −321 °F, liquid nitrogen is about the same number of degrees below freezing as the frying oil is above 0 °C / 32 °F, in the range of 160–200 °C / 320–392 °F.

For more on using an ice brine, including a step-by-step procedure, see page 2·260.

other food in the freezer. Unfortunately, the worst method is also the one most commonly used! Even putting food into a proper ultralow-temperature freezer at −80 °C / −112 °F is not a very good way to freeze food. The general rule is that *a freezer is for holding food, not for freezing food*. You should always freeze food before you put it in a freezer.

There are three good ways to freeze food. The simplest is to buy a blast chiller/freezer, which is specifically made to freeze reasonably fast. To use a blast chiller, you simply put the food in, close the door, and press the button. Advanced models have programmable freezing or chilling modes and built-in temperature probes and ultraviolet sterilization.

A second way, which is a bit messier but also works well, is to create an ice brine. To make the brine, put some ice into a container (preferably an insulated one like a plastic ice chest), and add a little water and an amount of salt equal to 23% of the weight of the ice. The salt will cause the ice to melt, thus lowering the temperature of the brine.

You must use plenty of ice—enough to equal at least 1.5 times the mass of the food you want to freeze, although you may need more depending on the shape of the food and the container you use. The brine must cover the food, so be sure to vacuum seal the food in a sous vide bag before immersing it. If you use ordinary table salt, the temperature of the brine should reach −22 °C / −8 °F. If you use calcium chloride instead of regular salt, the temperature can reach −40 °C / −40 °F. Ice brine works best if you have an ice maker that can supply you with a lot of ice.

Brine freezing causes additional mess and trouble, but it also lets you freeze things with a minimum of equipment: an ice chest, ice, and salt. You must stir the mixture to dissolve the salt, however, or the brine will not reach the desired temperature.

The third way to freeze is perhaps the most dramatic: using liquid nitrogen or dry ice. Because these media are extremely cold, this method freezes faster than others. This rapid speed of freezing isn't always a good thing because the outside of thick pieces of food freeze before the inside can. This difference causes a problem because the interior of the food expands as it freezes, but the exterior is already frozen, and this problem can lead to freeze-cracking and other distortions of the food. This problem occurs less frequently in thin pieces of food (which you want anyway to maximize quality).

To freeze food with liquid nitrogen, simply immerse it in an insulated container (such as an open dewar or a Styrofoam ice chest) filled with the liquid. If your container has a lid, make sure it fits loosely to allow the nitrogen gas that boils off the liquid nitrogen to escape. Use a 2:1 or 3:1 ratio by weight of liquid nitrogen to the food you want to freeze.

Because liquid nitrogen is transparent, you can easily watch the process. As long as bubbles are still forming on the outside of the food, it is not yet frozen. When the bubbles stop forming, the food is fully frozen.

You can similarly use liquid nitrogen to freeze high-end animal products such as foie gras immediately after slaughter, then store them below their glass-transition temperatures. Traditionally, foie gras has been refrigerated rather than frozen. That is less than ideal, however, because an animal's liver is chock full of enzymes. Those biochemicals start degrading the organ rapidly after the animal dies, a process that, before long, produces off-flavors and a grainy texture. Refrigeration merely slows the chemical reactions, whereas cryogenic freezing all but halts the degradation. A rule of thumb is that every 10 °C / 18 °F decrease in temperature cuts chemical reaction rates roughly in half. Conversely, a 10 °C / 18 °F increase of

HOW TO Make Exceptional Ice Cream with Liquid Nitrogen

Quick freezing makes small ice crystals, which produce a smooth ice cream. In most ice cream machines, the ice cream base contacts a cold metal surface scraped by a dasher. The Pacojet (see page 2·406) creates small ice crystals by mechanically shearing larger ones with a spinning blade. But the smallest ice crystals and, to many, the finest-textured ice cream is made by using liquid nitrogen. (For the long and interesting history of liquid-nitrogen ice cream, see page 60).

1 **Prepare the ice cream or sorbet base by using an existing recipe.** Note that, although this is not a dessert book, we do make one exception—see page 4·236 for our creamless pistachio ice cream.

2 **Use a 3:1 ratio of liquid nitrogen to ice cream by weight.** Because liquid nitrogen is not very dense, that ratio by mass corresponds to roughly a 5:1 ratio by volume, so 5 l of liquid nitrogen are needed to make 1 l of ice cream. Be sure to have extra liquid nitrogen on hand because it evaporates from the dewar during storage.

3 **Put the ice cream base in a stand mixer.** Ideally, use a "planetary" geared mixer such as those made by Hobart or Kitchen Aid. Use the paddle mixing blade, and set the initial speed to medium.

4 **Carefully pour a thin stream of liquid nitrogen into the mixer as it runs.** When the mixture starts to get stiff, turn the speed to low. Continue pouring and mixing until you reach the desired consistency.

5 **Eat immediately!** If you store the ice cream in a freezer, the ice crystals will grow, and your creation will become more like conventional ice cream.

temperature roughly doubles these rates.

The wide range of freezing technologies puts cooks in the happy position of having many good options for preserving high-quality ingredients. If you want the just-picked flavor of corn for a creamed corn dish or the sweetness of fresh peas for a soup, buying Birds Eye frozen vegetables that were picked and frozen within two hours after harvesting is, far and away, a better choice than canned alternatives, which have very different flavors. Very often, flash-frozen vegetables such as these have a fresher flavor than so-called freshly picked vegetables sold at a market: hours or even days have passed between picking and purchasing, plenty of time for enzymes to deplete natural sugars and alter the fresh flavor.

Dry ice can also be used for freezing food. Because it is a solid, however, it is more difficult to apply to food. When dry ice pellets are available, they can be poured over food.

Alternately, the food can be placed on slabs of dry ice, and more slabs can be put on top of it. This is not as convenient as using liquid nitrogen, but it will work if liquid nitrogen is not available.

As soon as food is frozen by one of these methods, transfer it to a freezer for storage—ideally one that is colder than the glass transition temperature, or at least −60 °C / −76 °F.

Thawing

Except for a few foods like ice cream that are eaten frozen, most foods must be thawed before use. Unfortunately, thawing takes much longer than freezing because ice conducts heat four times as fast as liquid water does.

As the surface of a food freezes, it provides a faster path for the escape of heat, and freezing deep in the food is expedited. During thawing, however, the opposite occurs. The surface warms and thaws quickly, and the resulting layer of liquid water conducts heat into the food more slowly than the ice did, so thawing deep in the food takes longer.

There is some debate among cooks about how best to thaw food. Some contend that it should be

HOW TO Supercool Water

Water can't freeze without nucleation points, which provide something for ice crystals to form on. Very pure water in a clean container can be chilled to well below the freezing point; it is then called supercooled water. Such water freezes very quickly when it encounters dust or other particles on which ice crystals can form. Even shaking or disturbing the water can cause it to freeze because it creates small bubbles that can act like nucleation points. Here are some ways to explore these properties.

1 **Start with a clean bottle of pure water.** The simplest approach is to use an unopened bottle of drinking water. Remove the label to make it easier to see what's going on.

2 **Place the bottle in a freezer for 2–3 h.** The exact time required depends on the freezer temperature and the size of the bottle. It may take some trial and error to get the timing right. If the water freezes, you left it in too long. Thaw it completely, and try again. If you want to be more precise, poke a hole in the cap, stick a needle-style thermocouple probe in the hole, and seal the probe onto the cap with tape so you can check to make sure that the temperature is well below 0 °C / 32 °F.

3 **Remove the bottle from the freezer.** Move it very slowly; avoid abrupt movements. For the first experiment, rap the bottle sharply on a tabletop, and watch it freeze in a couple of seconds. For the second, carefully unscrew the cap, and pour the water from a height into a glass. It will freeze upon contact with the glass.

done slowly at around refrigerator temperature to allow the water in the food to warm to ambient temperature and redistribute itself before cooking. Others say it's best to cook the food as quickly as possible from a frozen state. From our own experience (and our experiments), we find that the best approach is to thaw quickly or not at all (by cooking directly from frozen), although there are some important exceptions.

For example, if you're thawing raspberries for a puree or tomatoes for a ragù it doesn't matter whether you thaw quickly or slowly, because the texture of the thawed food isn't important. For a puree, you may even want to freeze and thaw the berries repeatedly, using a domestic freezer because that method will damage more of the cells, making it easier for the blender to release all of the juices contained in individual cells. Damaging tissues is pretty much the point of a puree, after all.

But slow thawing can be disastrous for food meant to be served intact. Food does not thaw uniformly for two reasons. First, different parts of the food inevitably reach different temperatures at different times. And second, the smaller ice crystals melt before the larger ones do.

If thawing doesn't proceed quickly once meltwater begins accumulating in the food—or if the temperature falls and the food starts to refreeze—then the ice crystals that remain actually freeze some of the meltwater and grow larger, damaging the quality of the food. Refreezing isn't a major problem for small or thin pieces of food because they thaw rapidly. But for large pieces of food, thawing can take hours—more than long enough for small ice crystals to melt into water and be refrozen onto the surrounding large ice crystals. This tendency is one reason that it's best to avoid freezing overly large foods in the first place.

Thin foods can be cooked directly from frozen. This advice is particularly true for cooking sous vide in a bath set just above the target core temperature of the food, when there is no possibility that the outside layers can overcook while the inside remains frozen. The main problem with this approach is that it is hard to predict the cooking times accurately, and it is difficult to get a temperature probe into frozen food.

Thin foods can also be cooked at high heat while frozen. Frozen slices of foie gras are often seared in a very hot pan or on a *plancha* while frozen, then put into an oven whose temperature readings are accurate at low temperatures (62–65 °C / 145–149 °F) to continue to thaw and cook.

Freezing thick foods is generally not a good idea. But if you must use thick frozen foods, then it is probably better to thaw them before cooking them. Thawing is best accomplished in cold water in the refrigerator.

Cooking from a frozen condition works fine for small or thin foods that were frozen for short periods of time or were held at very low temperatures.

The technique of cryosearing uses liquid nitrogen or dry ice to partially freeze food prior to searing or cooking. Cryosearing also works with food that starts out completely frozen. For a step-by-step procedure, see page 3·124.

A fresh strawberry loses much of its texture when conventionally frozen and defrosted.

VAPORIZATION AND CONDENSATION

For more on vapor pressure, see Canning, page 2·75.

In between its freezing point and its boiling point, water exists as a liquid. But while you'd be surprised to see a few tiny icebergs floating in water at room temperature, you should not be surprised to know that some of the liquid is turning into vapor right before your eyes. Your eyes can't see the vapor, but it's always there. That goes for all liquids: some of their molecules have an irrepressible urge to fly off into the air as a gas or a vapor in a process called **evaporation** or **vaporization**.

As explained in chapter 5 on Heat and Energy, **temperature** is a measure of the molecules' (or other particles') velocities within a substance. But a temperature indicates only an *average* velocity. Some of the fastest particles that happen to find themselves at the surface of the liquid will simply fly off and evaporate. Even cooking oil evaporates at room temperature but slowly enough that it is not noticeable.

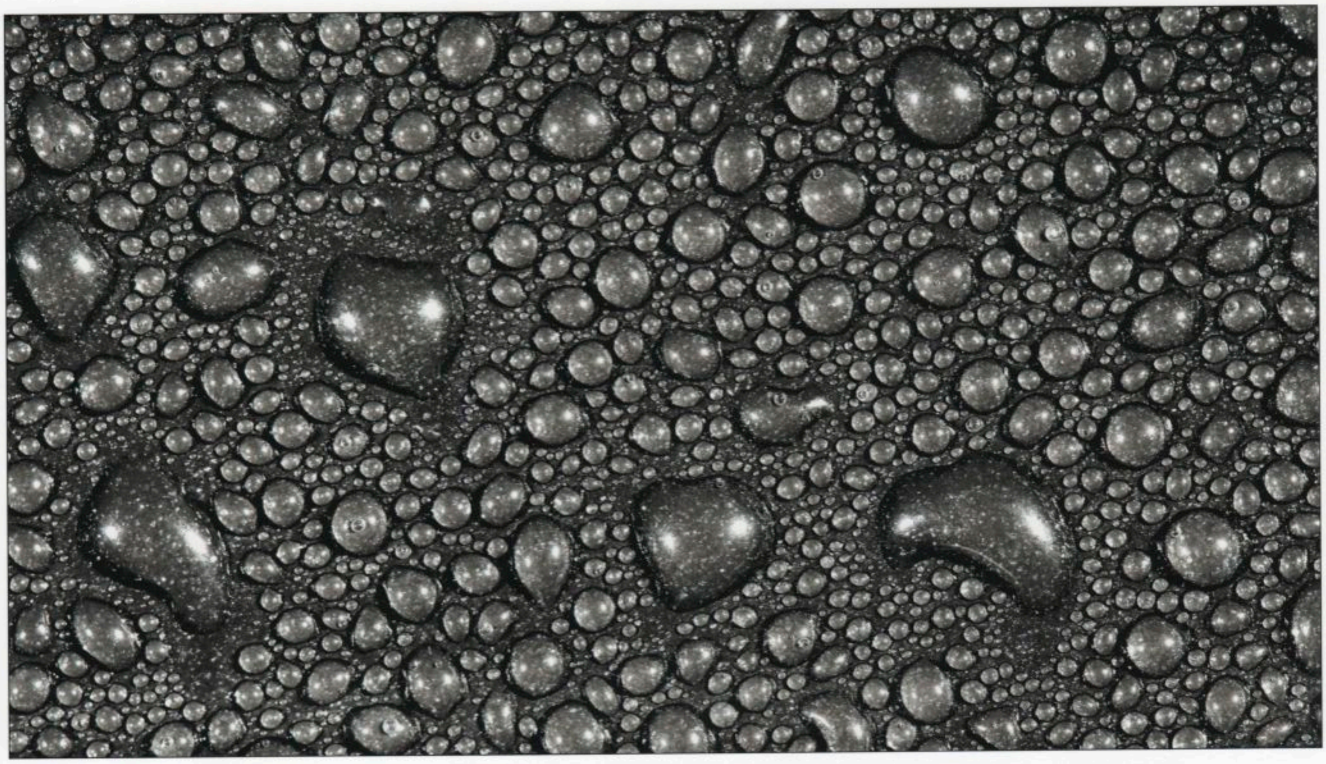
For more on the physics of temperature, see The Nature of Heat and Temperature, page 264.

How many of a liquid's molecules are evaporating at any given temperature? The degree of evaporation is expressed in terms of the **vapor pressure** of the liquid because the flying molecules that leave it bounce off the walls of its container, thereby exerting outward force on it. Inside any given container at any given temperature, the pressure of a gas is directly proportional to the number of its molecules.

The more strongly the molecules are bound to one another in a liquid, the less they tend to evaporate and the lower the vapor pressure of the liquid. Because of its hydrogen bonds, water requires a lot more energy (a higher temperature) to evaporate than other liquids do. That is, it has a relatively low vapor pressure. Alcohol and gasoline have higher vapor pressures than water and thus evaporate faster.

As we heat a liquid, more and more molecules acquire enough energy to escape from the surface. The evaporation rate and vapor pressure therefore increase. When the vapor pressure reaches the pressure exerted on the liquid's surface by its

Water vapor condenses into droplets of liquid water. Small droplets are roughly hemispherical, but as they grow by merging with other droplets, they become less regular in shape.



Green beans show the two kinds of bubbles common to the boiling process. The large, free-floating ones are pockets of steam released from the bottom of the pot. The smaller bubbles clinging to the sides of the beans are air being forced by the rising temperature from the spaces between the cells of the beans.

surroundings (most often the atmosphere), evaporation becomes vaporization, and the liquid boils. The boiling point is the temperature at which the vapor pressure equals ambient pressure. We can't see the vapor pressures, of course, but at this stage many molecules well below the surface have enough energy to escape. Trapped as they are in the depths, however, all they can do is form bubbles, and that's our visual clue as to what's going on.

Boiling

In stove-top cooking, where the heat source is typically beneath the pot, vaporization happens first at the bottom, then at the sides of the vessel. Inside the pot, slight temperature differences arise between water at the bottom and at the top. The water at the bottom is hottest and rises to the surface to be replaced by falling pockets of cooler water. These movements are called **convection currents**. They are slow at first and become more vigorous as the water gets hotter. Stir a few grains of ground black pepper into a pot of cold water, wait until the stirring motions stop, then turn on the burner. As the water grows hotter, you will see the grains rising and falling with the currents.

If you look closely, you can see other changes occurring as the water gets hotter. The first thing you may notice is that large numbers of tiny bubbles form on the bottom and sides of the pot. But wait! They have nothing to do with the boiling process; they're simply dissolved air being forced out of the water because gases are less soluble in hot water than in cold.

Then an odd thing happens: the pot begins to make sizzling and rumbling noises. The very first vapor bubbles form in microscopic cracks or protuberances on the inner surface of the pot—no matter how smooth it may appear—that act as

THE PHYSICS OF

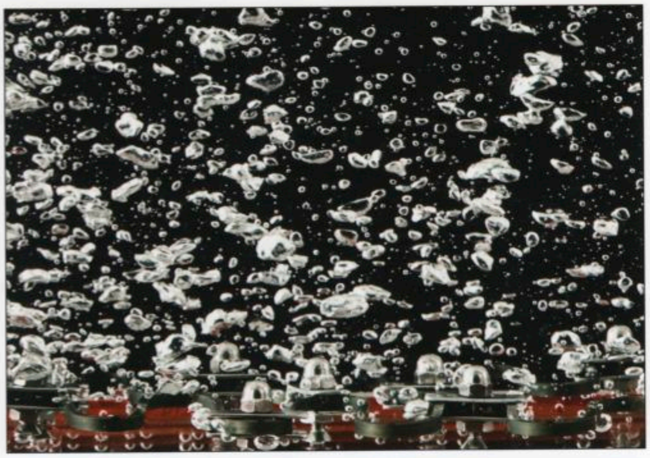
The Stages of Boiling

Boiling is evaporation that happens at the hot bottom of the fluid rather than at the cooler surface. Boiling begins at nucleation sites: small, rough surfaces where tiny pockets of air become trapped by the surface tension of the liquid. Steam inflates these pockets into bubbles that eventually break free.

Throw a handful of salt into a pot of simmering water, and the boiling will accelerate, not because the salt changes the boiling point but because it adds more nucleation sites. (Sand works equally well.)

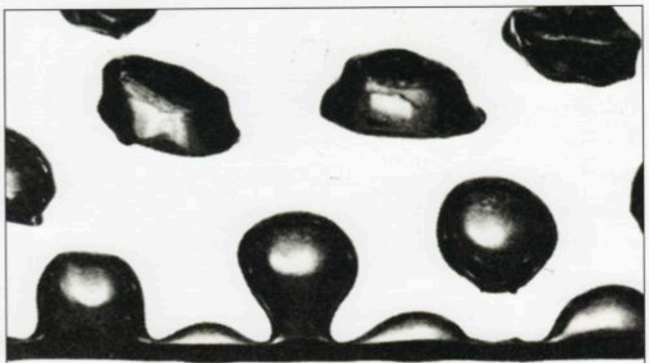
Boiling is not a single, uniform phenomenon. Simmering, for example, is not actually boiling, and two qualitatively different stages of boiling exist beyond the familiar rolling boil. These advanced stages only occur in superheated water that is beyond the capacity of professional gas burners, so in the kitchen they occur only rarely and out of view.

1 **Simmering is not boiling, although it does occur when the temperature is near the boiling point.** Bubbles of steam form on the hot bottom, but most collapse quickly as surrounding water cools and condenses the vapor inside of them. As the temperature rises to approach the boiling point, some of the bubbles float to the surface.



2 **Nucleate boiling produces the familiar, everyday rolling boil.** All of the heat that moves from pot to fluid goes into vaporizing molecules of liquid near the bottom, sending them upward inside innumerable steam-filled bubbles. Turning up the burner power doesn't increase the temperature of the water; it simply generates more bubbles.

3 **Slug-and-column.** Slug-and-column boiling happens when steam bubbles stream off the bottom of the pot so quickly that they blur into continuous "columns" of steam, often with several columns feeding into one larger "slug" of steam. This stage of boiling happens only in liquid that has been superheated above its boiling point; in the kitchen, this usually only happens when boiling thick sauces (see page 2·68).



4 **Film boiling.** Film boiling is the rarest of the stages because it only occurs in fluid so superheated that a continuous blanket of steam covers the entire heating surface. Because enormous amounts of heat must be marshaled to produce film boiling, it never occurs in the kitchen, with one rare exception: Leidenfrost droplets (see next page).

Photos courtesy of: John H. Lienhard IV and John H. Lienhard V "A Heat Transfer Textbook" 4th edition, 2011, http://web.mit.edu/lienhard/www/ahtt.html nucleation sites. The earliest of these bubbles collapse almost as soon as they are formed, as they encounter the still-colder water above them. This phenomenon is known as **cavitation collapse;** the tiny implosions sound like sizzling or rapid ticking.

As the temperature of the water continues to rise, the rumble is muted because air bubbles dotting the bottom and walls of the pot have grown large enough and buoyant enough to be swept away by the convection currents to higher and cooler levels within the pot at which the bubbles collapse. If you have already put some grains of pepper in the water as suggested above, this is the best time to watch the rising and falling currents. And if you look even more closely, you'll see that the surface is actually quivering (the French say *frémissant*) as one plume after another of hot water brushes gently against the surface before cooling and falling back down.

Finally, the rumbling and sizzling noises diminish as streams of bubbles form on the bottom of the pot and grow big enough to rise all the way to the surface, where they pop, releasing steam into the air. This is the beginning of the actual boiling process (see The Stages of Boiling, previous page).

As the bottom of the pot gets hotter, even bigger bubbles make it to the surface in large numbers, creating a full, rolling boil accompanied by a gentle burbling sound. Scientists call this stage nucleate boiling, because the bubbles have originated at nucleation sites. Water won't get much beyond this stage with the limited heating power of the average stove.

But at higher heating rates (more watts or BTUs per hour), the bubbles stream from the nucleation

What is a simmer? Some cookbooks attempt to define a simmer by the water's temperature: a certain number of degrees below 100 °C / 212 °F, although few seem to agree on just how many degrees. But the temperature of a simmering pot of food varies, depending on the characteristics of the pot, the burner, and the food (whose temperature is not uniform throughout).

So it makes more sense to define a simmer in terms of what you can see going on in the pot. Call it a simmer when only the occasional small bubble makes it all the way to the top.

For more on convection in cooking, see Heat in Motion, page 277.

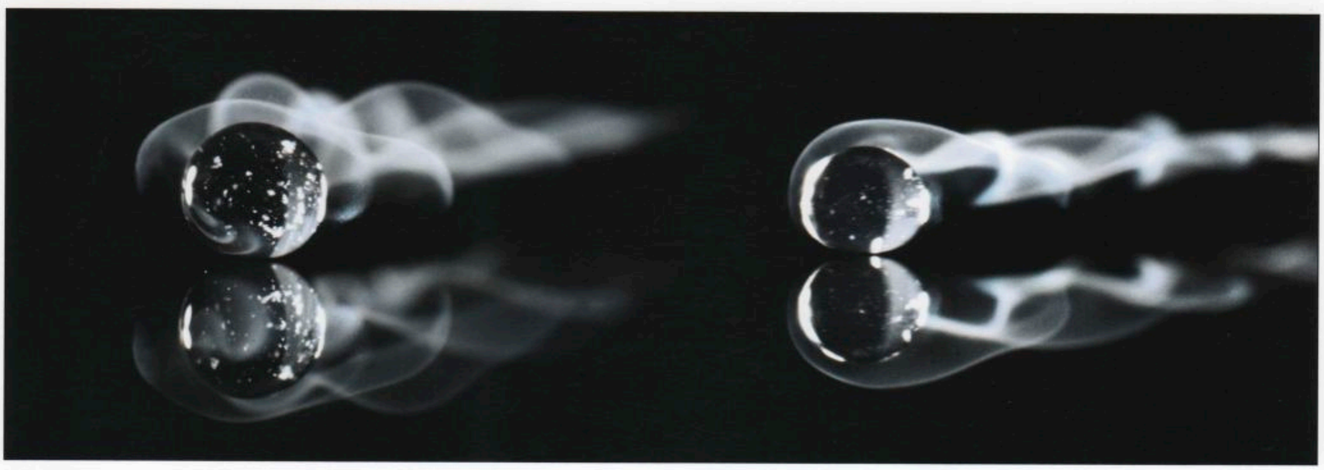
THE PHYSICS OF

Skating on Gas

Flick a little water on a medium-hot griddle, and the water hisses, bubbles, and boils quickly away. That's called **flash boiling.** But when the griddle gets much hotter than the boiling point of water, the droplets form small balls that skitter around without vaporizing for as long as a minute, as if they were on skates of shooting steam. You are watching the **Leidenfrost effect,** named after Johann Gottlob Leidenfrost, a German doctor who described it in 1756.

When a drop of water hits a metal plate at or above about 200 °C / 390 °F, called the Leidenfrost point, the part that first touches the plate bursts into steam, creating a paper-thin vapor layer that lifts the rest of the drop. The steam layer insulates the drop from the plate, so the drop can last for a long time and roll around the plate like a crazed ball bearing before evaporating. The same thing happens to drops of liquid nitrogen spilled on a plate or kitchen counter.

The next time you have some liquid nitrogen in your kitchen, throw a drop of water on the surface, and you'll see an upside-down Leidenfrost effect in which the vapor barrier comes from the nitrogen, not the water.



For an illustration of how microscopic cracks and roughness in cookware serve as nucleation sites for vapor bubbles in boiling—just as particles in solution serve as nucleation sites for ice crystals in freezing—see page 2·64.

For more on slug-and-column boiling in thick sauces, see Burning a Thick Sauce, page 2·68.

Normally we think of the temperature of boiling water as being 100 °C / 212 °F, and in general, that's true for pure water at sea level. But on the hot bottom of a pot where bubbles of steam are forming, the water can be superheated beyond its normal boiling point by 2–6 °C / 4–11 °F.

sites so thickly that they join to form big columns of steam. The columns coalesce into "superbubbles," or slugs of vapor. You can see this so-called **slug-and-column boiling** most prominently in thick sauces and stews, which belch up huge bubbles that splatter everything in the immediate vicinity.

Pure water and other thin liquids won't belch up on a stove top because convection prevents heat from building up on the pan's bottom to the levels needed to create vapor slugs. But power plants have special high-heat-transfer equipment that keeps the water in slug-and-column boiling to maximize the production rate of steam.

The temperature at which pure water boils depends on several factors. One is the atmospheric pressure, which makes small changes in the boiling point as the weather varies. But if you move to a kitchen at a much higher altitude above sea level, you will see a bigger difference in atmospheric pressure and therefore a bigger change in the boiling point: about a 1 °C / 2 °F decrease in boiling point for every 300 m / 1,000 ft increase in altitude. In Denver, Colorado (altitude about 1,600 m / 5,249 ft), water boils at only 93–95 °C / 199–203 °F, depending on the weather. At the top of Mount Everest, water boils at just 69 °C / 156 °F.

The boiling point also depends on what is dissolved in the water. Whereas you can lower the freezing point of water by dissolving salt or some other substance in it, dissolving a solute in water will *raise* its boiling point because it lowers the water's activity (see page 307), so fewer molecules are free to evaporate and the vapor pressure drops. This is called boiling point elevation. For example, seawater, which is 3.5% salt, boils at 103 °C / 217 °F at sea level. A very concentrated (95%) sugar solution, the kind used in candymaking, boils at 135–145 °C / 275–293 °F.

BLOWING OFF STEAM

Picture a classic tea kettle with water beginning to boil in it. The first inch or so past the end of the spout is pure water vapor, or steam, and because steam is invisible, that space appears to be empty. But beyond that region, the steam mixes with air, causing that air to expand. Any gas cools when it expands, and as the air cools, the water molecules in it slow down so much that some of them join together into tiny droplets, forming a visible fog or cloud. The plume you see spouting from your tea kettle is thus, in essence, a turbulent cloud.

Steam

Steam is a constant presence in the kitchen, but it's often confused with its close relative, fog. Understanding the difference can save you from serious injury, because steam and fog can exist at very different temperatures.

Any liquid produced by a phase transition from the gaseous state is called a **condensate;** if a condensate is in the form of droplets so tiny that they remain suspended in the air, it's a fog, sometimes referred to as a mist or cloud, depending on the size and dispersion of the droplets. Cooks may call the clouds that rise above kettles and pans "steam," but those clouds are not steam, which is invisible; they're fog: suspended drops of liquid water. In short, if you can see it, it's not steam (a synonym for vapor); it's either fog or a mixture of steam and fog.

The crucial difference for a cook is that fog can't be any hotter than the boiling point of water—if it were, its droplets would vaporize. Steam, in contrast, can be superheated almost without limit and can cause serious burns. Its invisibility only adds to the hazard. Not only is steam typically hotter than fog, but it also releases a terrific amount of heat (the heat of vaporization) when it condenses to liquid water, which it is likely to do if it comes in contact with your skin. In fact, almost everything that steam comes in contact with can be heated by condensation.

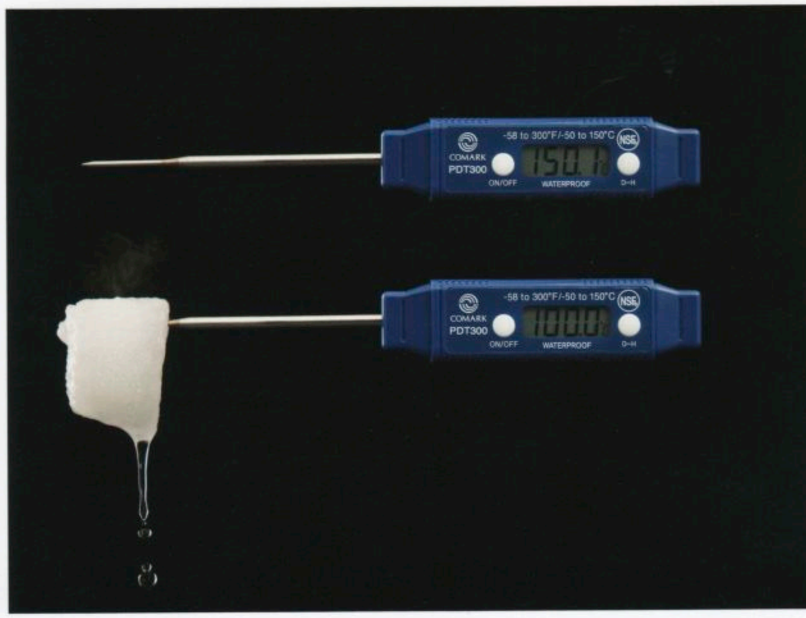
When you steam food, water vapor condenses on the food's surface, creating a thin liquid layer called a **film condensate**, which insulates the food and inhibits it from further cooking. In vegetables and other plant foods, the insulating layer of condensate also traps some of the air that has been forced out of the spaces between the cells, adding even more insulation.

For many vegetables, therefore, steaming can be a *slower* cooking method than boiling. Steam has less trouble cooking meat, which doesn't contain much air and has very different surface properties.

When the food is in a jar, can, or sous vide bag, on the other hand, steaming is actually much faster than boiling. The containers do develop film condensates, but the water traps no air and tends to drain off the smooth surfaces. The heat transfer rate depends on how the film forms and drains. Flat horizontal surfaces, like the top of a jar in a pressure steamer, will have a slower heat transfer rate than the vertical sides of the jar because of the puddle of condensate it retains. Commercial canneries often counter this tendency by using pressure steamers (called retorts) that rotate or otherwise keep the cans moving during the steaming process.

When cooking big foods, however, it doesn't matter whether you boil or steam: the bottleneck is the rate of heat transfer through the body of the food rather than through its surface.

There's much more to cooking than heat transfer. Steaming doesn't dissolve sugars, nutrients, and other soluble components the way boiling does. As a result, steamed vegetables are often more flavorful and nutritious than their boiled counterparts.



Dry-bulb (top) and wet-bulb (bottom) thermometers measure quite different properties. The dry-bulb temperature does not take into account the effect of humidity; the wet-bulb temperature reflects the effect of evaporative cooling. You can improvise a wet-bulb thermometer by wrapping the bulb of an ordinary thermometer in a piece of wet cheesecloth or muslin (see page 322).

For more on the difference in cooking speed between steaming and boiling, see Why Steaming Is Often Slower than Boiling, page 2·70.

Water In—and Out of—Air

Even in the driest desert climates, the air contains some water vapor. Put another way, all air has some degree of humidity. Humidity is not visible, of course, but you can tell it's there because it makes a hot kitchen feel even hotter.

Humans feel humidity the way we do because we maintain our normal body temperature partially by **evaporative cooling** of our skins. Even when we are not actually sweating, our skin is always moist. Some of the moisture continually evaporates, absorbing a lot of energy (again, the

You can breathe air at 100% relative humidity without drowning because the water in the air is still in vapor form. Even if it weren't, it would take the form of fog, which human lungs can handle just fine.

heat of vaporization) from our skin and keeping us relatively cool as it does so.

Even in a desert, water vapor molecules are also continually *condensing* back onto our skin, *depositing* their heat of condensation. But when our skin is warmer and moister than the air, more water molecules are departing per second than arriving. The net effect is to cool the skin. Daub a little rubbing alcohol on your hand, and you'll feel the same effect even more dramatically, because alcohol evaporates into the air faster than water does.

In a hot and humid kitchen (or on a muggy summer day), however, the rate at which water molecules land on our skin rivals the rate at which water is evaporating from it. We then feel hotter than the air temperature alone would indicate. It's not the heat, as they say; it's the humidity.

More specifically, what matters to us—and for food as it cooks in a steamer or an oven—is the **relative humidity**, which is the ratio of the amount of water vapor in the air to the maximum amount of water vapor that pure water could produce in a closed box at that temperature—the **equilibrium vapor pressure** (often also called the **saturation vapor pressure**).

Imagine that you have a tightly sealed pot of pure water at room temperature. A certain number of water molecules per second will be evaporating and gradually increasing the number of water

THE CHEMISTRY OF

How to Prevent—or Rescue—Stale Bread

If there is a higher percentage of water in the air outside a food than there is of water inside the food, the food is likely to absorb moisture. This won't happen, of course, in rind- or shell-protected foods or in those with very wet interiors. But it happens to bread.

People normally think of stale bread as dried out because they are accustomed to dried foods becoming harder. But in fact, the bread has *absorbed* moisture from the air. (This is why stale bread weighs more than the same volume of fresh bread.) The crust absorbs water and loses its crispness, whereas water absorbed by the bread inside makes its starch granules crystallize, thus hardening it.

Low temperatures speed this crystallization, which is why the refrigerator is the worst place to store bread. But at even lower temperatures, below -5 °C / 23 °F, the formation of crystallization nuclei stops, so fresh bread stored in the freezer will keep quite well.

You can reverse staling damage by heating the bread in an oven for a few minutes. Heat both melts the starch crystals and drives the water out.

molecules in the air. The more molecules go off into the air, the more they'll be bouncing onto the liquid's surface and condensing back into it. Eventually, enough of them will be in the air that they will be condensing back onto the water at the same rate at which they are leaving it. In scientific terms, the water and its vapor are in equilibrium and the vapor pressure in the air is the equilibrium vapor pressure. The relative humidity in the pot is then 100%, and it won't go any higher unless you raise the temperature of the water or do something else to accelerate the evaporation rate.

Now imagine there is less water vapor in the air over an open pot, let's say 25% of the equilibrium vapor pressure. The relative humidity of that air is then 25%. For every 100 molecules of water evaporating per second from the water, only 25 molecules per second are condensing back onto it, and evaporation wins out.

Although it may sound esoteric or more relevant to weather than food, relative humidity actually has huge practical implications for cooking. Just as evaporation from the surface of your skin cools you, the evaporation of water cools your food as it cooks. So the temperature the food actually experiences may be much lower than the temperature you set your oven to.

Humidity is often to blame when recipes seem to be unreliable, giving different results at different times. A recipe may have you set the oven to 175 °C / 350 °F, for instance, and you might expect the food in the oven to eventually reach that temperature, at least on the outside.

But it doesn't. The food is moist, and the actual temperature at its surface will depend on the rate of moisture evaporation, as determined by the humidity inside the oven and the rate of air flow if it's a convection oven. Unless you're using a modern, high-tech oven with preset humidity—such as those discussed in chapter 8 on Cooking in Modern Ovens—the evaporation rate will be an uncontrolled variable in your cooking.

The relative humidity in a kitchen depends on several factors. First and most obvious is the rate at which steam is being emitted from boiling pots and hot foods. Another factor is the weather outside, with its many complex components: the air's temperature and pressure, the directions and velocities of air movements, the presence of any nearby bodies of water or precipitation, and so on. No kitchen is hermetically sealed against the outdoor humidity (although air conditioning does smooth out daily and seasonal variations in both temperature and humidity).

On a very hot, muggy summer day, when the temperature reaches 40 °C / 104 °F, the relative humidity could hit 90%. On a cold winter day, when the temperature dips well below freezing, the humidity in your kitchen will probably be very low as well. That's because even though the relative humidity outside may be 60%, the humidity drops substantially when the air warms to indoor temperatures. Inland cities such as Chicago, Madrid, and Beijing regularly experience dramatic annual swings in temperature and humidity.

The impact of humidity on cooking can be

Evaporation takes a lot of heat, and this can be used to cool food via vacuum-assisted cooling. Hot, wet food placed in a vacuum desiccator (see page 2·433) will cool very quickly as the vacuum pump lowers the pressure. The lower pressure reduces the boiling point of water greatly, which in turn increases evaporative cooling. This process is used commercially for chilling cooked hams. We employ a similar trick to freeze liquid nitrogen to a solid (see page 324).

For more on **how humidity affects cooking in ovens, see Baking, page 2·101.**

THE PHYSICS OF

Why Dehydrating and Rehydrating Are Imperfect

Two kinds of water exist in food: free and bound. Bound water is water attached to other molecules, such as by hydrogen bonds to sugars; it is slow to move or to react with other substances. Free water diffuses more readily than bound water, but it still moves through food much more slowly than heat does. This leads to one of the most vexing problems in cooking: food can burn long before it dries out.

When heat moves into food, water moves out, both by capillary action and, very slowly, by molecular diffusion. Drying food to the core takes a very long time. Moreover, tremendous hydrostatic pressure develops when water moves through food by capillary action, and the pressure can rupture cells, allowing flavors to leak out. That's why, even after rehydrating, dried foods often aren't as tasty as fresh; the water lost during drying has carried away much of the flavor.

You may want to try another strategy to dry food quickly. Instead of raising the temperature, you can lower the pressure. Vacuum-assisted dehydration is a great way to dry food that would be damaged by prolonged heating. For more on that topic, see Drying, page 2·428.

HOW TO Measure Relative Humidity

Humidity is a key factor in cooking, and measuring it is important. For many years, the best available instrument for measuring humidity was the sling psychrometer. It features two thermometers, one with the bulb kept wet, the other dry. With the aid of a psychrometric chart, the dry-bulb and the wet-bulb temperatures can be used to compute the humidity (see next page), or the wet-bulb and the dry-bulb temperatures can simply be used directly.

Today, kitchen humidity can be measured with a digital humidity meter. These are widely available, cheap, and much more convenient than sling psychrometers. Unfortunately, no inexpensive humidity meters are available for use in an oven or a smoker, so we have improvised one based on the psychrometer. It is simply a stainless steel measuring cup full of water that has mounted above it a thermometer probe kept wet with a cheesecloth wick.

This setup measures the wet-bulb temperature, which is crucial to know for many cooking tasks. It is particularly useful to know while smoking, for which we give ideal wet-bulb temperatures (see pages 2·132 and 3·210). Elsewhere in the oven or the smoker, a different thermometer sensor measures the dry-bulb temperature, which is also useful.

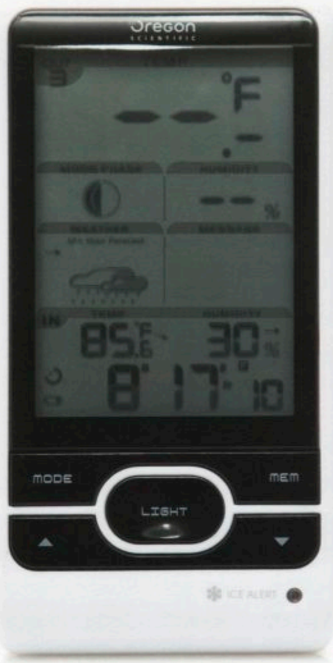
1. **Dip the thermometer bulbs in water, then wipe the bulb that does not have a sock on it with a paper towel to dry it.**

2. **Grasp the handle firmly.** Hold the gadget well away from your head and any walls or appliances.

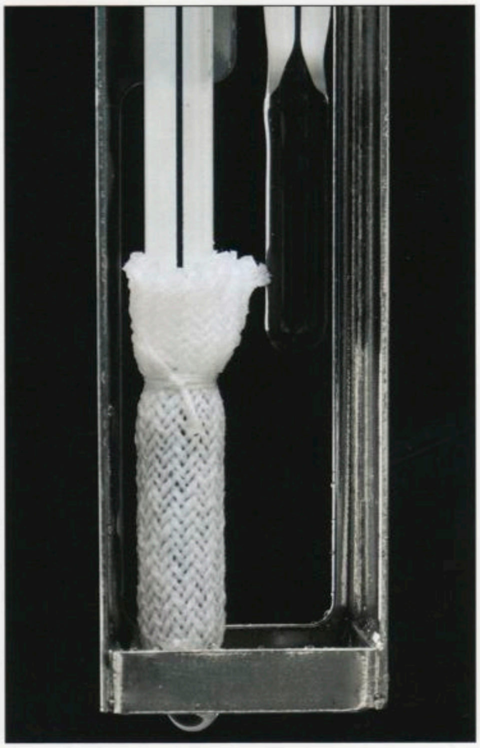
3. **Swing the thermometers about the handle vigorously for about 1½ min.** Reading times vary, so follow the manufacturer's instructions.

4. **Quickly read the temperatures indicated by the two thermometers.**

5. **Use the chart provided by the manufacturer (not shown) to determine the relative humidity.** On some psychrometers, the chart is printed directly on the handle.



A sling psychrometer (top) includes both a wet-bulb thermometer and a dry-bulb thermometer (right); the two readings can be used to calculate the relative humidity. You can improvise a similar setup with a steel cup, cheese cloth, and a regular thermometer (below right). A digital humidity meter (left) offers an inexpensive alternative.



HOW TO Read a Psychrometric Chart

A psychrometric chart depicts the properties of moist air at a given pressure. It can be a handy guide to the dew point, relative humidity, and wet-bulb temperature, parameters that determine the effective temperature at which food cooks in the oven or on the stove top.

1 **Find the dry-bulb temperature on the bottom axis.** Use an ordinary thermometer to measure the dry-bulb temperature.

2 **Find the relative humidity (RH) on the curves that fan from the bottom left upward across the graph.** You can get this measurement from a relative humidity meter (see previous page).

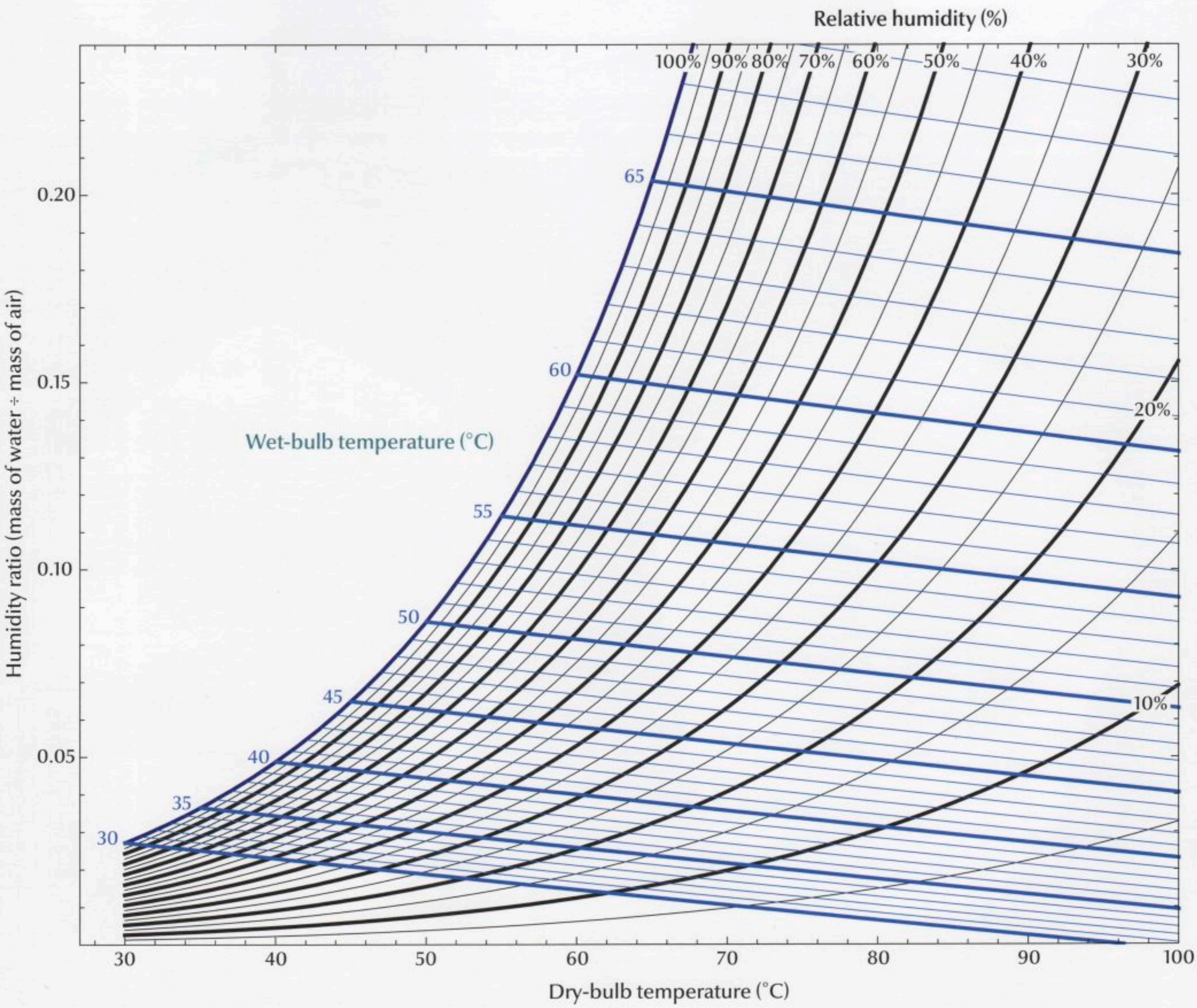
3 **Follow the relative humidity curve to the point that is directly above the dry-bulb temperature.**

4 **Find the nearest wet-bulb temperature line (the lighter blue lines that slope downward from left to right) and follow it to the left to read the the wet-bulb temperature.**

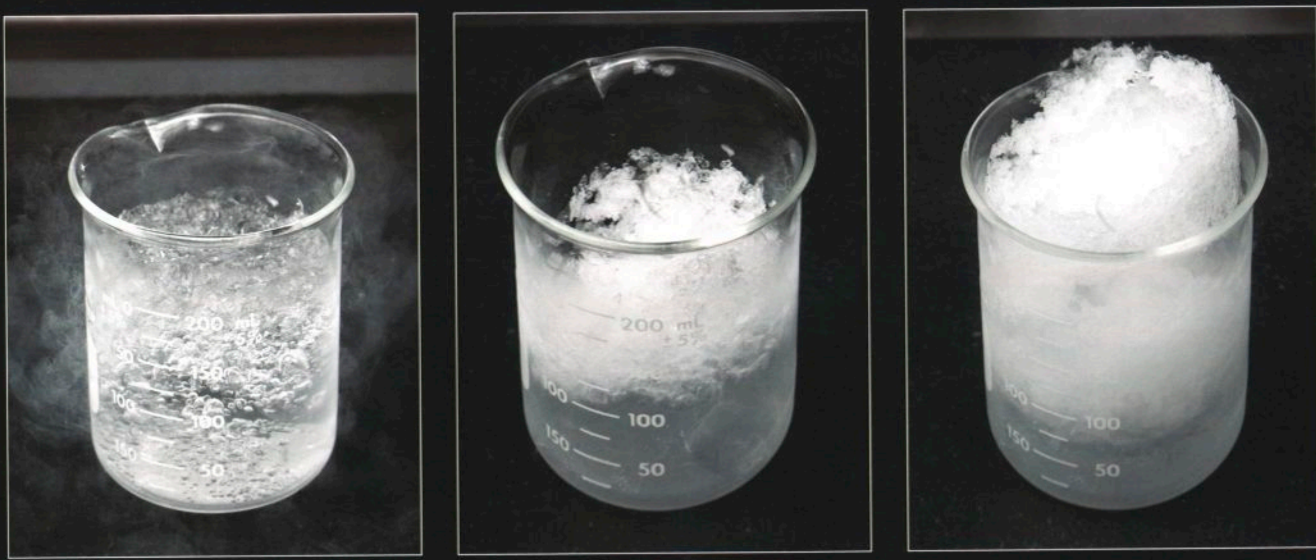
5 **To find the dew-point temperature, go back to the point on the appropriate RH curve that is directly above the dry-bulb temperature.**

6 **Now move to the left on a straight horizontal path (parallel to the temperature axis) until you intersect the 100% RH line (dark blue).**

7 **Drop straight down to the temperature axis to read the dew point.**



FREEZING LIQUID NITROGEN IN A VACUUM



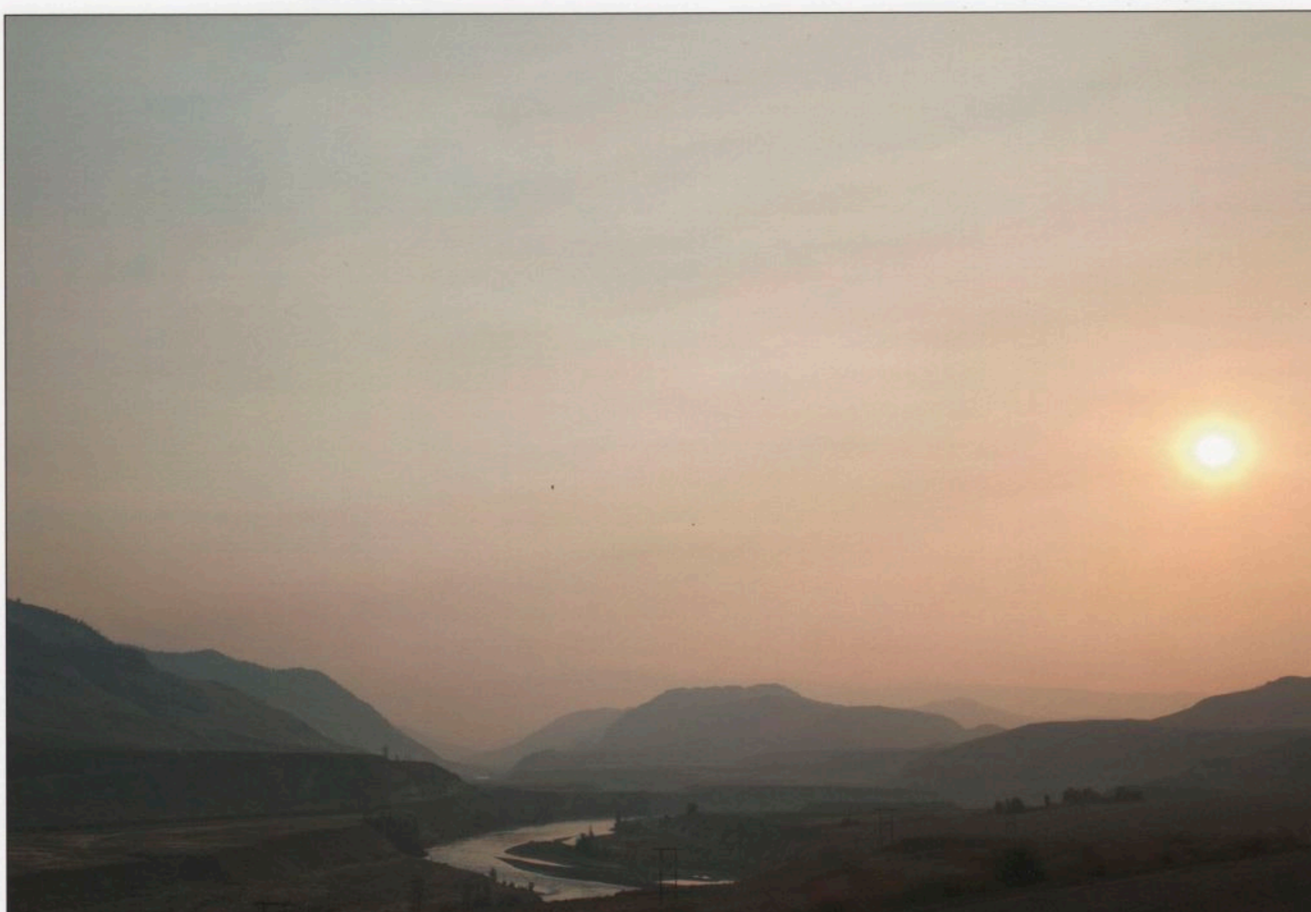
At 1 bar of pressure, nitrogen has a boiling point of –196 °C / –321 °F, and its freezing point is only a few degrees lower: –210 °C / –346 °F. In a vacuum chamber (such as the one in a chamber vacuum-sealing machine), you can easily decrease the boiling point enough to freeze the nitrogen into solid ice.

striking. On a summer day, when high humidity suppresses evaporative cooling, the surface of food can be as much as 9 °C / 16 °F hotter than it might be on a winter day. On the other hand, a piece of fish pan-frying in the dry, drafty air of a kitchen in winter may take longer to cook through without being turned than the same-size portion in summer. Hot foods resting on the counter in a winter kitchen may cool faster than you might expect because the air is not only cold, it's also dry. That's why, in cold seasons, it's a good idea to wrap your cooling foods in foil, which reflects radiating heat back toward the food.

When warm air cools, some of its water vapor may condense out onto solid surfaces. The **dew-point temperature** is the temperature at which the air, as it cools, begins to produce the familiar condensate called dew. In a comfortable room at 20 °C / 68 °F and 50% relative humidity, the dew-point temperature is 9 °C / 48 °F, so when you pull something from the refrigerator at 5 °C / 41 °F, beads of dew soon form on it.

Some dew-point condensation can also occur when you're cooking in air, especially in the initial stages of heating a cold food. Put a cold ham into a hot oven, and the moisture in the oven's air may condense on the ham's surface. Heating then proceeds rapidly until the temperature of the air exceeds its dew-point temperature, at which time it will begin reabsorbing the dew, and evaporative cooling will ensue. That's just one reason that it's a good idea to know the dew-point temperature as well as the relative humidity in your kitchen. You can determine both values with a humidity meter (see How to Measure Relative Humidity, page 322).

The weather phenomenon known as haze is neither water vapor nor water droplets. Meteorologists define it as a visibility-limiting suspension in the air of solid particles—from farming, road traffic, wildfires, etc.—or of wet particles such as sulfuric acid formed from sulfurous gases released by burning fuels. But water is not among the wet particles that cause haze. The reactions that form haze are intensified by sunlight, high humidity, and stagnant air, so they occur more readily in the summer. But when you see haze, you're not seeing the humidity.

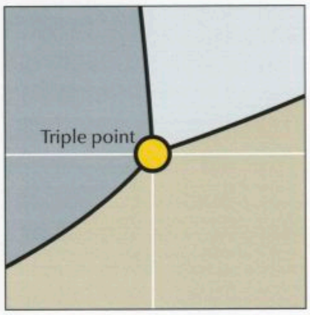


SUBLIMATION AND DEPOSITION

Melting and freezing, steam and fog, dew and humidity—these are all relatively familiar phenomena involving phase changes in water. The changes from solid to liquid to gas and back again from gas to liquid to solid happen daily right before our eyes. But there are two other phase changes that we don't often see. They take shortcuts: moving directly from solid to gas or from gas to solid. Liquids need not apply.

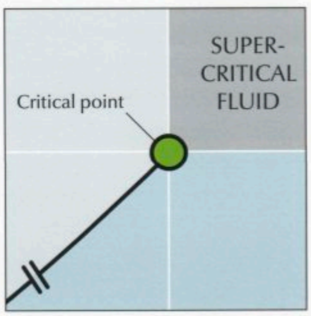
The direct transition of a solid to a gas with no intermediate liquid phase is called **sublimation**; the reverse transition, from gas straight to solid, is called **deposition.**

Most cooks would be reasonably confident that they have never seen these things occur in the kitchen. But if you haven't actually caught sublimation or deposition in action, you have undoubtedly witnessed their effects, perhaps more often than you would have preferred. Sublimation is largely responsible for freezer burn, the damage dealt to frozen foods by dehydration and subsequent oxidation. Deposition, on the other hand, is how the same water vapor that came out of your freezer-burned food winds up as thick deposits of ice and frost that cover the insides of your freezer, if it's not a self-defrosting model.



The triple point is the place where solid, liquid, and gas can all coexist. Every material has at least one triple point, and complicated materials with multiple phases can have more. At temperatures and pressures below the triple point, a solid sublimates directly into a gas without melting into a liquid first.

In a high school chemistry class or at a rock concert, you may have seen the "smoke" that pours off dry ice (solid carbon dioxide). That smoke is evidence the solid has sublimed to a chilly gas that cools the surrounding air enough to cause a fog of condensed water to form. You can't see the CO_2 gas itself, but the fog is quite noticeable, especially if you put the dry ice in a bucket of water. Before modern fog machines came into use, that's how special effects designers on scary movies and rock concerts made the "smoke." (You could always tell it was made with dry ice because the air holding the fog was so cold and dense that it hugged the ground.)



At temperatures and pressures above the critical point, a material becomes a supercritical fluid, which shares some properties of both liquids and gases.

Regular ice sublimes, too, but at colder temperatures than dry ice does. If you have a frost-free freezer, you may have noticed that your ice cubes slowly vanish from their trays after a few months, if left undisturbed. The ice has turned directly to water vapor that was then whisked away by the unit's humidity controller. If you don't have a frost-free freezer, the process takes longer, but it still happens—the water vapor drawn from the ice ends up deposited again as frost on the freezer interior.

Sublimation is the most energetically expensive of the common phase transitions. It uses up a lot of heat, called the **heat of sublimation:** 2,594,000 J/kg (1,115 BTU/lb). As you might suspect, this equals the heat of fusion plus the heat of vaporization because first the ice structure has to be broken down and then the resulting liquid water has to be evaporated. The energy balance is the same whether this takes place in two stages or in the single, liquid-free transformation of sublimation. Think of it this way: when you hike from a valley to a mountaintop, the net gain or loss of altitude is the same no matter how many hills and valleys you traverse along your way.

If the sublimation of ice demands so much thermal energy, how can it happen at freezing temperatures or even colder ones? And it does: you may have noticed that snow on the ground and icicles on trees slowly disappear, even when the air temperature remains well below freezing. The answer has to do with vapor pressure, which, you'll recall from the discussion above, arises from the difference between the rate at which water molecules depart from the ice into the air and the rate at which they arrive from the air and freeze to the ice. When the air is very dry or when the atmospheric pressure is very low (or both), the vapor pressure of water in the air can be so low that even molecules held tightly to the surface can escape, one by one, to enter the air as water vapor. In fact, so many more can depart from the ice than arrive from the air that the ice shrinks. It is a sublime process.

The main practical implication of this phenomenon is that cold, dry air alone can dehydrate food. The ice crystals in frozen food can sublime, leading to freezer burn. You can protect most foods from this withered-looking condition—or at least prolong the period of stable frozen

Dry ice sublimates under water, thereby creating cold CO_2 gas that pours out of the container. Water vapor in the air is cooled below its dew point, thereby creating a dense, cold fog.

Frost forms via deposition; water vapor leaves the air and directly forms ice crystals. Snowflakes grow in the same way while suspended in the air inside clouds.

storage—by sealing the food in vapor-tight pouches, containers, or wrappings. So-called freezer paper is made for that purpose, but vacuum sealing in a sous vide bag works better. It also helps to remove air (and the water vapor in it) from the package before freezing. Any empty space in the package creates a comfortable surface on which water vapor can refreeze, so it encourages sublimation.

Cold temperatures and dehydration are useful separately for preserving food, and together, they can make a powerful combination. Freeze food rapidly, then put it under vacuum to speed sublimation, and you have **freeze-drying.**

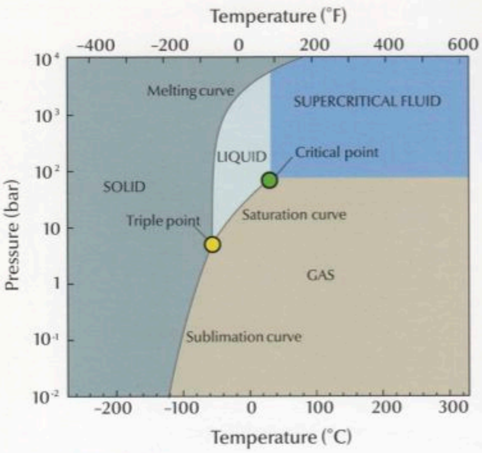
You might associate freeze-dried food mainly with instant coffee, the trail chow consumed by backpackers, and astronaut food. But it's much more useful than that. Freeze-drying came upon the scene in the 1960s as something of a technological marvel, but believe it or not, the Peruvian Incas used to freeze-dry their crops by taking them to the top of Machu Picchu, where both the temperature and the atmospheric pressure were low. Modern freeze-drying can preserve the appearance, flavor, aroma, and nutritional value of food, which can then be stored nearly indefinitely at room temperature. With its moisture gone, both microbial growth and chemical spoilage reactions in the food are substantially slowed.

In the freeze-drying process, the temperature of the food is first brought below the triple point of water, where only ice and vapor can exist, so that no liquid will form in subsequent steps. Ice crystals form; then the ice sublimes when the food is exposed to a vacuum, taking most of the food's water content with it. The absence of melting avoids many of the pitfalls of freezing food discussed earlier in Freezing and Melting. For more on the equipment and techniques involved, see Freeze-Drying, page 2·438.

Deposition is a more familiar phenomenon than sublimation is. You've seen deposition put frost on your windshield on a cold morning. You've seen it make frost in your freezer. You've seen the snowflakes it has grown in the clouds.

In all these cases, ice has been deposited straight from water vapor in the air, with no intermediate liquid state. Deposition is the reverse of sublimation, and as such, it releases a lot of heat, equal to the heat absorbed in sublimation.

The frost that forms on the inner walls of a freezer and that coats some frozen foods can come from loosely wrapped food itself, which releases water vapor, or, if the freezer is frequently opened, from the influx of humid kitchen air. Deposition in a freezer is never a good thing, because it signals adverse conditions for frozen storage. In order to preserve the quality of your frozen food, you need to store it in air-tight containers and avoid opening the freezer too often.



Carbon Dioxide

Triple point: –57 °C / –71 °F at 5.2 bar / 75 psi

Critical point: 31 °C / 88 °F at 74 bar / 1,073 psi

THE PHYSICS OF

Freeze-Drying

The words "freeze-drying" may prompt loathing in the hearts of cooks, but the technique can actually yield exquisite results if it's done right. The trick is to know which foods to freeze-dry. Many don't do well: juices, fruits, and sweet vegetables such as onions, for example, are too high in sugar. When these dried foods are subsequently exposed to air, they absorb water from it, which combines with the sugars to make them tacky and sticky. Meats and cheeses go soft and rubbery when their proteins absorb moisture, and fatty foods go rancid quickly when dried because they've lost the water that normally protects them from oxidative spoilage. Starches, in contrast, absorb water more slowly, so starchy foods make great candidates for freeze-drying.

The other trick is to know just the right way to do it. Freeze-drying, as the name implies, occurs in two stages: first you freeze, then you dry by pulling a vacuum. It's important to freeze food slowly to very low temperatures if you don't want to damage its texture. Specifically, you must bring the food below its glass transition temperature, which for most food means between -70 °C and -40 °C / -95 °F and -40 °F. If any water remaining in the food is not in a glassy state, it will vaporize quickly when the pressure is reduced, rupturing cells. You'll eventually get to the glass transition temperature, anyway, as the vaporization cools the water, but your food will pay the price.

Such low temperatures are outside the reach of domestic freezers, so proper freeze-drying requires a cryogenic commitment. If you're not concerned with preserving the texture of your freeze-dried food—if you'll be grinding the food, or making stock from it—then you need not take such extreme measures.

The cold trap of a freeze dryer is extremely cold, often as low as −70 °C / −94 °F. It must be cold enough to freeze out water vapor that sublimated from food in the freeze dryer.

For more on the ideal conditions for frozen storage of food, see Freezing, page 2·256.

WATER AS A SOLVENT

We all know that certain solid materials, like salt and sugar, dissolve in water. The scientific term for a substance into which other substances dissolve is **solvent.** The substance that dissolves into the solvent is called the **solute,** and the homogeneous mixture of solvent and solute is called a **solution.** Both solvents and solutes can be in any state of matter: solid, liquid, or gas. But in the kitchen, the solvent is usually a liquid—most often water but sometimes oil.

It's rare that we use a solid as a solvent for culinary purposes, but that's what perfumers do in the technique of **enfleurage,** where lard or another solid fat is used as a solvent to dissolve and trap volatile aromatic substances that give flowers their characteristic aromas. These aromatics dissolve in fats (even solid fats) but not in water.

For more on enfleurage, see page 2·323.

Gaseous solvents are also rare, but the air around us is one example. Air can be described as a gaseous solution of oxygen, carbon dioxide, and other gases dissolved in gaseous nitrogen, although that's stretching the concept a bit. All gases mix with or "dissolve in" all other gases. That is certainly not true of liquids and solids.

Broadly speaking, liquid solvents are of two types. **Polar solvents** are made of molecules in which the electrons are unevenly distributed, so that the molecule has a negative end and a relatively positive end. This **dipole** nature affects the behavior of polar molecules. Water is a highly polar solvent because its molecules' electrons are localized at the oxygen-atom ends, leaving the hydrogen-atom ends relatively positive (see Why Water Is Weird, page 298).

Nonpolar solvents are made of molecules that are not dipoles. Fats and oils are the classic kitchen examples of nonpolar solvents.

Like liquids, solid compounds can be either polar or nonpolar. In general, like dissolves in like. Sucrose and many other sugars are strongly polar compounds, and they dissolve only in a highly polar solvent because dipoles in the solvent (water) attract the dipoles of the solute (sugar). Put another way, polar solids are **soluble** in polar solvents.

Because it is polar, sucrose will not dissolve in oil or other nonpolar solvents. Oils and waxes, by the same token, dissolve in nonpolar (oily) solvents but not in water. Polar solvents are **insoluble** in nonpolar solvents and vice versa.

Ethanol, the common form of alcohol in the kitchen, is also a polar solvent, but it is a weaker dipole than water—a bit less than half as strong, by one common measure chemists use to measure polarity. As a result, ethanol dissolves some water-soluble compounds but not all of them or not very much of them. Sucrose, for example, does not dissolve in pure ethanol.

Cooks often talk about adding wine to a dish as "adding alcohol." But it's important to realize that wine, at perhaps only 13% ethanol, is more water than alcohol. Because its molecules are hindered by their hydrogen bonding to the water, wine does not dissolve substances that pure ethanol would.

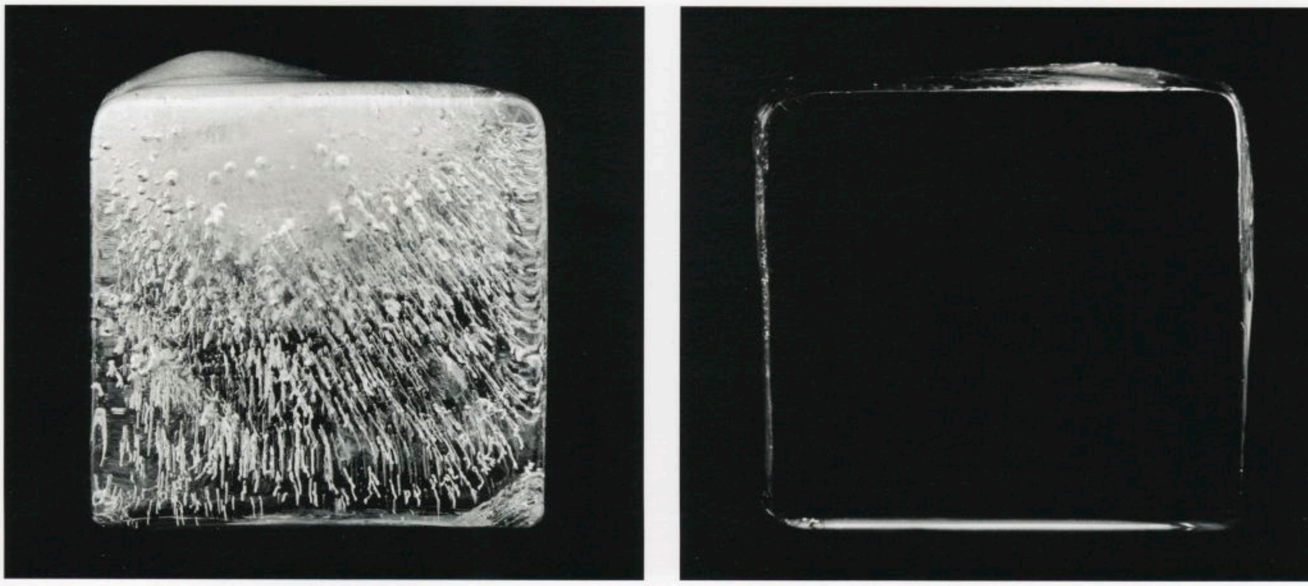
Sweet and Salty Solutions

Not every substance is polar or nonpolar. **Ionic compounds,** like table salt (sodium chloride), are composed not of molecules but of **ions**: atoms or groups of atoms that carry whole positive or negative electric charges, not merely the partial charge of a dipole. The charge attraction of the dipoles in a polar solvent can pull ions apart from one another, so ionic solids usually dissolve in polar solvents. Salt, for example, dissolves readily in water. As that happens, the dipolar water molecules pull the salt molecules apart into positively charged sodium ions (Na^+, in the notation of chemistry) and negatively charged chlorine ions (Cl^-). Although we say that the salt has dissolved, in reality there is no sodium chloride as such in the solution—only separated ions of sodium and ions of chlorine.

Nonionic compounds, such as sugar, are made of electrically neutral molecules whose atoms are bonded together by **covalent bonds** that form when the molecules share pairs of electrons. Dipoles can't tear covalent bonds apart, partly because they can't get an electric "grip" on them as they can on ions, so nonionic molecules remain intact when they dissolve. Sucrose is nonionic, so when you dissolve sugar in water, there really are intact sugar molecules in the water.

When a solid dissolves completely in a solvent,

Salt will not dissolve in a non-polar liquid like oil. Hervé This exploits this effect to prevent salt from dissolving when put on the surface of a tomato or other wet food. The salt is tossed in oil first, which protects it from melting and gives the salt a nice crunch when you eat it.



When you boil water, the first bubbles to appear at the bottom of the pan are not steam but gas escaping from the water. Two blocks of ice illustrate the point. The left block shows the gas still trapped. In the right block, the gas has escaped, leaving the water gas-free and the cube clear.

the mass of the resulting solution is the sum of the two—as it must be by the law of **conservation of mass.** The volume of the solution, however, is typically *not* the sum of the volumes of the solute and solvent prior to mixing—it is less.

The fact that volumes don't add when a solution forms makes sense if you envision the solute molecules fitting into spaces *between* the solvent molecules and vice versa. Because there are more molecules in each bit of space, the density of the resulting solution is greater than that of the solvent prior to mixing. If you dissolve salt in water, for instance, the mass of the solution will equal the mass of the water plus the mass of the salt. But the volume of the solution will be 2.5% less than the sum of the volumes of the salt and the water. The effect is even more startling in sugar solutions. With heating, you can actually dissolve two cups of sugar in one cup of water!

What's the limit—just how much sugar can you cram into a syrup that is fully **saturated** with sugar? The answer depends on the temperature and purity of the water, as well as other factors, but the concentration of the saturated solution—typically expressed as a percentage or as grams of solute per 100 g of solvent—is called its **solubility.**

If the solubility is zero, the two substances are completely **immiscible:** like oil and water, neither dissolves in the other. Water and alcohol, in contrast, do mix homogeneously in any proportions; they are said to be fully **miscible** with each other. Other pairs of substances are miscible—but only up to a certain concentration. There is a limit, for example, to how much salt will dissolve into even very hot water. Add more salt than that and further stirring or heating will not make any more dissolve; the extra salt just piles up on the bottom of the pot. The compound has reached its **solubility limit.** Another way of saying this is that you have made a **saturated solution.** A saturated solution of sodium chloride (table salt) in water contains just under 269 g / 9.5 oz of salt per liter of water at 50 °C / 122 °F.

In virtually all cases relevant to the kitchen, the higher the temperature, the higher the solubility. Salt is an unusual case, in that temperature makes very little difference in its solubility in water. Sugar, on the other hand, behaves more typically, in that solubility increases substantially with temperature—see the graphs on the next page. That is why you must heat a sugar-water solution to make a syrup.

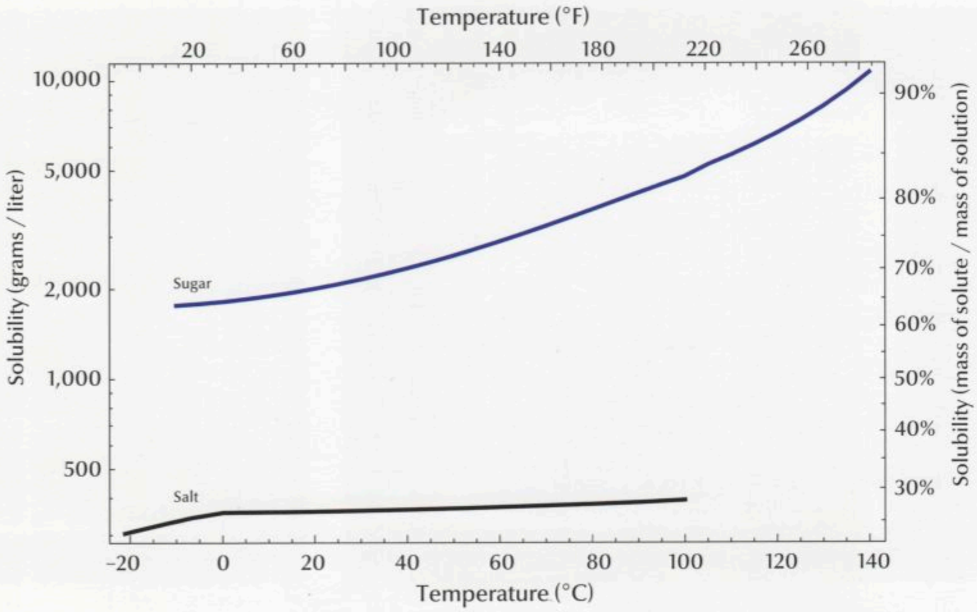
When you do make a hot sugar syrup, an interesting thing happens: the boiling point of the water in the solution rises from boiling point elevation (see page 318). So you can keep adding sugar to water even above 100 °C / 212 °F. When the temperature reaches 140 °C / 284 °F, the sugar is in what a confectioner would call the "soft crack" stage and the concentration is 95%—an amazing 19 kg / 42 lb sugar per liter of water.

What happens if you make a saturated solution

The primary gases in air, nitrogen and oxygen, are not very soluble in water: at normal atmospheric pressure, only a fraction of a gram dissolves per liter. Carbon dioxide is quite a bit more soluble. And unlike solids, all three of these gases become less soluble in water as temperatures rise. For example, 3.4 g / 0.12 oz of CO_2 dissolves in a liter of water at 0 °C / 32 °F, whereas at 60 °C / 140 °F, the solubility is 0.55 g / 0.19 oz, only about a sixth as much. This is why carbonated drinks are served cold.

The solubilities of table salt (sodium chloride; black curve) and ordinary sugar (sucrose, blue curve) in water depend on temperature. Sugar has a much higher solubility than salt, and its solubility varies much more with temperature. At 30 °C / 86 °F, at most 361 grams of salt will dissolve in a liter of water to make a 26.5% solution; at 80 °C / 176 °F, the solubility rises only slightly, to 380 g (27.5%). Only 19 g / 0.7 oz more salt dissolves in a liter of water at the higher temperature.

In contrast, you can dissolve 2.2 kg / 4.9 lb of sugar in a liter of water at 30 °C, and at 140 °C / 284 °F, that amount rises to more than 10 kg / 22 lb! (Note that dissolved sugar raises the boiling point of water.) In water at 100 °C / 212 °F, sugar is roughly 12 times as soluble as salt is.



at one temperature, then lower the temperature or evaporate out some of its solvent? You then have a **supersaturated solution** that wants to rid itself of the amount of solute that exceeds its solubility. The excess solute generally **precipitates** out by reverting to the solid state as crystals. Initially rather small, these crystals of the solute can grow to be quite large, especially if you allow solvent evaporation to continue in an uncovered container.

It's easy to make a supersaturated solution of sugar in water, simply by cooling a saturated solution or allowing it to evaporate. You can make those huge sugar crystals called rock candy in this way by adding thousands of crystallization nuclei (in the form of several suspended strings) and letting the setup stand around, evaporating away, for a couple of weeks.

Highly soluble gases used in cooking include carbon dioxide (CO_2), used in carbonated drinks and many other contexts, and nitrous oxide (N_2O), used in whipping siphons. They are much more soluble than oxygen or nitrogen at one atmosphere (1 bar) of pressure.

When cooks blend two liquids together, they often think of that as mixing. Sometimes, however, what they are really doing is making a solution. As when dissolving a solid in a liquid, the polarities of the components often govern what happens.

Most people know that alcohol (ethanol) is miscible in water; mix any proportions of the two liquids and they stay mixed, hence the wide range of wine and spirits at the liquor store. Ethanol thus dissolves in water—and water dissolves in ethanol.

For more on culinary techniques that exploit carbon dioxide's ability to dissolve into water, see Dry Ice, page 2·456.

But you may not know that if you mix 1 l / 34 oz of water with a 1 l / 34 oz of ethanol, the resulting solution has a volume of only 1.92 l / 64.92 oz. One plus one, in this case, does not equal two but rather about 4% less than two. That's because ethanol and water molecules form hydrogen bonds that draw them tightly to one another.

Oil and water, in contrast, are immiscible—as anyone who has made a vinaigrette knows. Still, with enough shaking you can break the oil and vinegar (which is essentially water) into droplets small enough that, for a while, they look like a homogeneous mixture. But the lighter oil droplets inevitably float to the top, and eventually, you're back to two separate layers.

To slow that natural separation, you need an **emulsifier**, a substance that induces the oil and water droplets to adhere to each other so tightly that they never, or almost never, separate. Add that ingredient and some vigorous agitation, and you can make an **emulsion**, which is so useful in cooking that we have devoted an entire chapter to the topic—see Emulsions, page 4·196.

Tiny Bubbles

Champagne—and fish—are possible because gases, too, dissolve in many liquid solvents. Marine creatures need oxygen just as land animals do, but instead of extracting it from the air via lungs, they extract it from the water by means of gills and other organs. Aquariums have air pumps and bubblers to provide a constant supply of dissolved oxygen. Without this, the fish would soon exhaust the oxygen and suffocate, just as a person would in a small, airtight room.

Some gases are highly soluble in water, others much less so. Oxygen is a relatively poor dissolver. At 25 °C / 77 °F and normal atmospheric pressure, only 40 mg / 0.0014 oz of oxygen will dissolve in 1 l / 34 oz of water—far lower than the solubilities of salt and sugar. Nitrogen, which constitutes 78% by weight of our air, is even less soluble: only about 16 mg / 0.0006 oz per 1 l / 34 oz at the same temperature and pressure. Carbon dioxide is very much more soluble in water than either of these: about 1,500 mg / 0.05 oz per 1 l / 34 oz—but that's a slightly different situation because CO_2 actually reacts chemically with water.

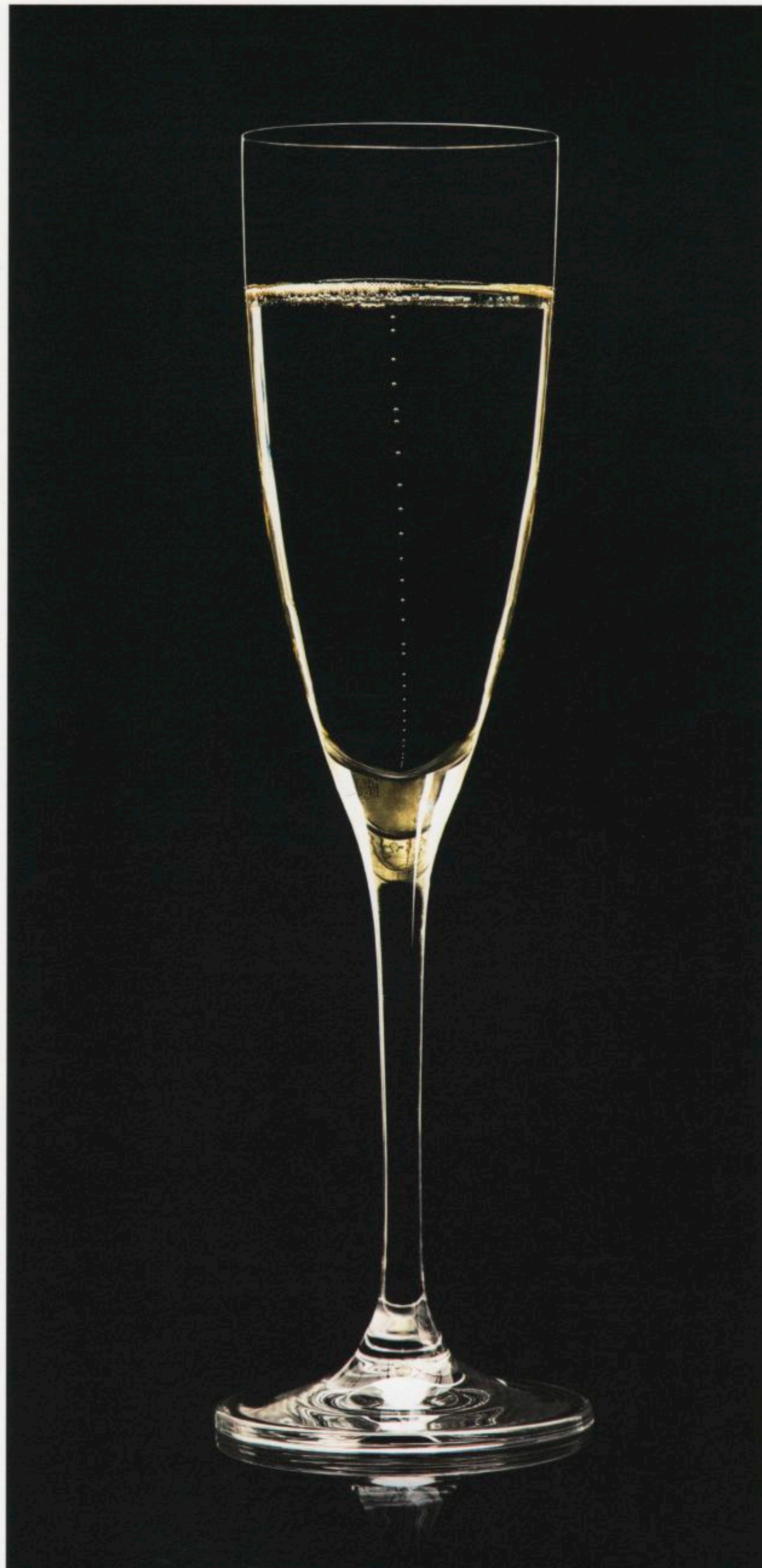
The solubility of gases in water depends on temperature, but in the opposite way from that of most solids: gases become *less* soluble as the temperature increases. When the water reaches its boiling point, all dissolved gas molecules are carried off along with the steam bubbles. So boiling a pot of water for several minutes will completely remove any dissolved air or other gases.

Conversely, the colder the water becomes, the more soluble gases become, all the way down to the freezing point. When the water freezes, dissolved gas molecules are expelled from the developing crystal lattice—except for those that are trapped with no way out. These often appear as tiny bubbles in ice cubes.

The solubility of gases also depends on pressure. At normal atmospheric pressures of around 1 bar / 14.7 psi, the solubility varies in a pretty straightforward way: double the pressure, double the solubility. But at very low pressures, such as in a partial vacuum, the dissolved molecules are essentially pulled out, and the water degasses.

You can exploit this effect to make clear ice cubes. Just boil the water for several minutes and let it cool without stirring (which could encourage air to dissolve in it) before you freeze it. If heat would alter the flavors in the liquid you want to freeze into clear ice cubes, you can boil it in a partial vacuum, which makes the boiling point lower. The setup used for vacuum reduction, described on page 2·379, is ideal for this purpose.

An ultrasonic homogenizer can also work; in effect, it shakes the gases out of the liquid. Because most dissolved gas molecules, such as the nitrogen and oxygen molecules in air, are not chemically bound to the water, they are easy to dislodge.



THE PHYSICS OF

Carbonated Drinks

Gas solubility plays a major role in how we experience carbonated water, Champagne, beer, and soft drinks. When a can of soda is filled at the factory, it is generally pressurized with a volume of carbon dioxide that, at normal atmospheric pressure, would occupy a volume three to four times larger than the can. The exact amount of carbonation is considered part of the recipe and varies for each brand of bottled water or soda, but the liquid is usually less than saturated with carbon dioxide. (In some parts of the world, such as India, they prefer more carbonation. Indian soft drinks contain so much CO_2 that, when poured into a glass, they look like they're at a rolling boil.)

The pressure of the gas inside the can varies with the temperature but is typically 3–4 bar / 44–58 psi) at room temperature. The pressure can be much higher if the can gets very hot.

When you open the can, the pressure drops to atmospheric pressure. The liquid is now a supersaturated solution of carbon dioxide, so the excess gas comes out of solution as tiny bubbles. If the soda is served cold, it can still hold a substantial amount of CO_2, which then slowly comes out of solution in steady streams of bubbles as the soda warms.

Caveat emptor: there is a gadget on the market that is claimed to restore the fizz in bottles of flat soda. You use it to pump air into the bottle; when you open it later, it makes a satisfying *pfft!* sound. But that's just the compressed air escaping. You have added no more carbon dioxide (beyond the tiny amount in the air) to either the air space or the liquid, so it is just as flat as before. Trust your tongue, not your ears.

Carbon dioxide is a unique gas for many reasons. If it were less soluble than it is, you couldn't dissolve enough of it in the soda to make it bubble out when the pressure is released. And if its solubility changed more drastically with changing temperatures than it does, it would depart from the soda too quickly as it warms. And, of course, CO_2 gives a pleasant acidic tang to the beverages.

When soda is poured into a glass, the physical agitation causes more carbon dioxide to bubble out of solution. Typically, the glass is warmer than the soda, so nucleation bubbles form on the sides of the glass and feed the turbulence.

As you drink a cold carbonated soda, it comes in contact with your mouth and tongue, which are at about 37 °C / 98.6 °F. These surfaces warm the soda, reducing the solubility of the carbon dioxide and forcing more of it to come out of solution as bubbles in your mouth, thus creating the unique sensation characteristic of carbonated beverages.

For more on carbonation as a cooking technique, see page 2·456.

WATER QUALITY AND PURITY

Pure water is an excellent solvent—indeed, it's sometimes called the universal solvent, because it dissolves more substances than any other liquid, including strong acids. That's due in part to its polarized structure and in part to its hydrogen bonds. Add a little carbon dioxide from the atmosphere, and water becomes an even *better* solvent, as the properties of carbonic acid augment its native abilities.

Because water dissolves things so well, it's often full of minerals collected from its surroundings: particularly calcium and magnesium but also iron, copper, aluminum, manganese, bicarbonates, and sulfates, depending on the geographical location. **Hard water** is the term for water containing large quantities of dissolved minerals.

Most kitchens use tap water for cooking, and recipes that call for water don't specify what kind to use. But the quality and purity of tap water can have a big impact on cooking processes. Hard water is a cooking variable that comes out of your faucet.

Hard water toughens some vegetables cooked in it, for example, as the minerals in the water combine with the pectin in plant cell walls. Hard water can interfere with gelling and thickening processes, too, because the dissolved minerals are in the form of charged **ions** and the hydrocolloids used in these applications are very sensitive to ionic concentration. The minerals in hard water can also leave troublesome deposits on equipment that boils water, such as espresso machines and combi ovens.

In addition to minerals, municipal tap water in most parts of the world contains both a form of chlorine to kill parasites and fluoride to prevent tooth decay. These compounds also can affect cooking processes, as well as the flavors and textures of cooked food.

How can you determine the quality of your water supply? Very hard water has an off-taste and a slippery or slimy feel. If you are on a municipal water system, you can contact your water provider to get a complete analysis of what's in your tap water. If you have a private supply, you can have your water tested or get a testing kit and do it yourself. Some manufacturers of water softeners will even give you a free kit.

Once you know more about the contents of your water, you can pick the right strategy to purify it. There are a number of water-softening and purification methods, varying in cost, capacity, and the kinds of contaminants they remove. The simplest method is an **ion-exchange filter**, which uses special resins to capture the ions of dissolved minerals. Often referred to simply as "water softeners," these filters make **deionized water**, which works best for cooking vegetables and hydrating hydrocolloids.

You may want an even higher level of purity if your water tests high for contaminants. **Distillation** removes impurities by boiling the water and condensing the steam in a separate container. Distilled water makes a fine substitute for deionized water, but it's more expensive.

Reverse osmosis uses pressure to pass water through a membrane that screens out contaminants. It makes extremely pure water and is cheaper than distillation, but it generates a large volume of wastewater and doesn't remove chlorine or other dissolved gases.

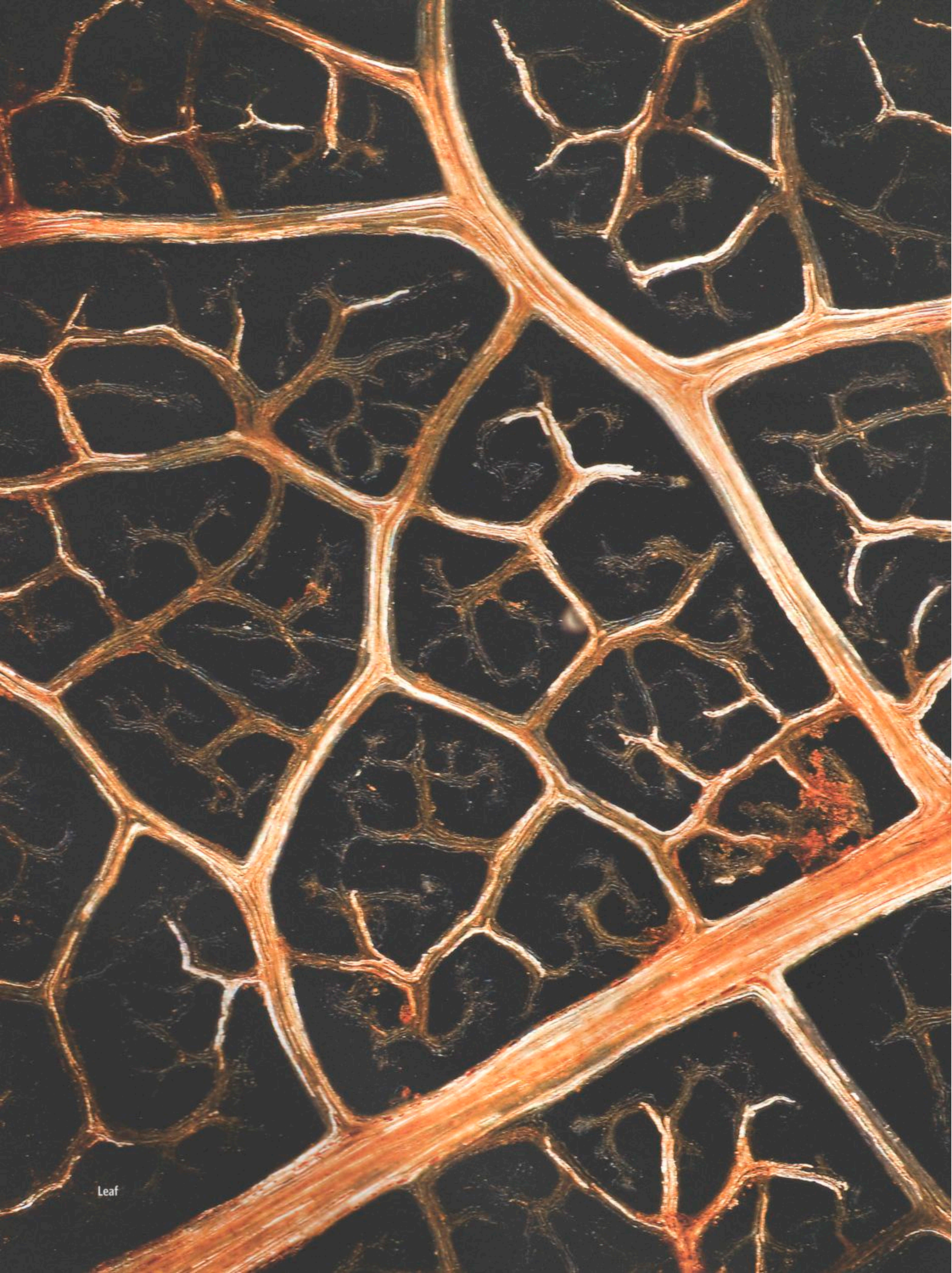
Carbon filtration, on the other hand, is the best way to remove chlorine and the dissolved organic compounds that can be a health issue in some areas. But it won't soften the water, so many household treatment systems utilize more than one approach: pressurized water passes through carbon filters and reverse-osmosis membranes before being irradiated with **ultraviolet light** to kill any lingering microorganisms.

Microporous filtration yields water of the highest purity for use in laboratory experiments. But it's overkill for the kitchen.

If you're overwhelmed by these options or don't want to spring for your own water-purification system, you can always buy bottled water for critical cooking applications: deionized water and distilled water are widely available. A word of caution, however. Although very pure water may be appropriate for combining with food in cooking, it doesn't taste very good. We're used to water flavored by dissolved gases and minerals, and some of these substances contribute essential nutrients as well. Without them, the water tastes flat.

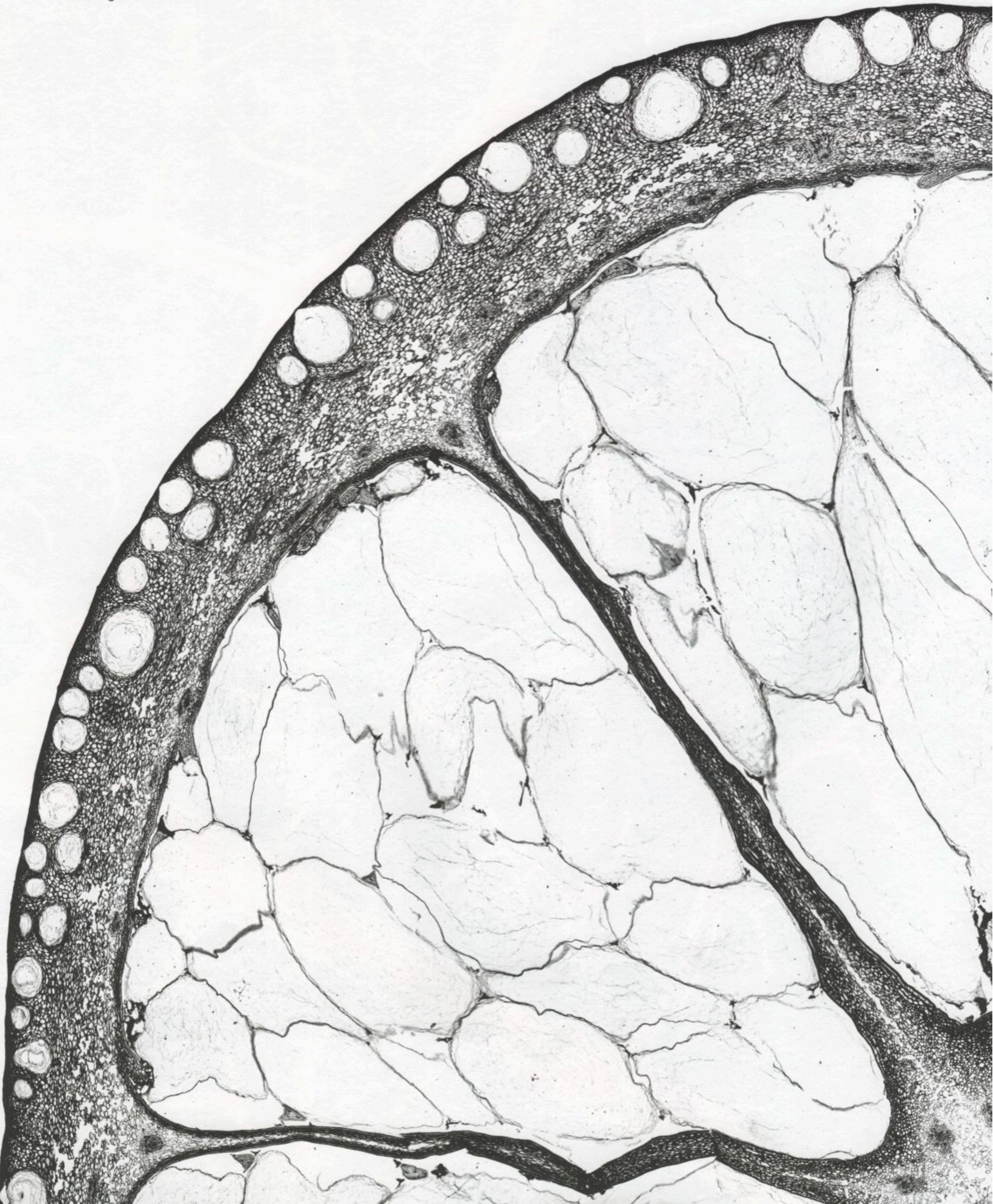
Water softened by an ion exchange filter contains a higher concentration of sodium, which is exchanged for the calcium and magnesium in hard water. For that reason, it may be unsuitable for some cooking uses.

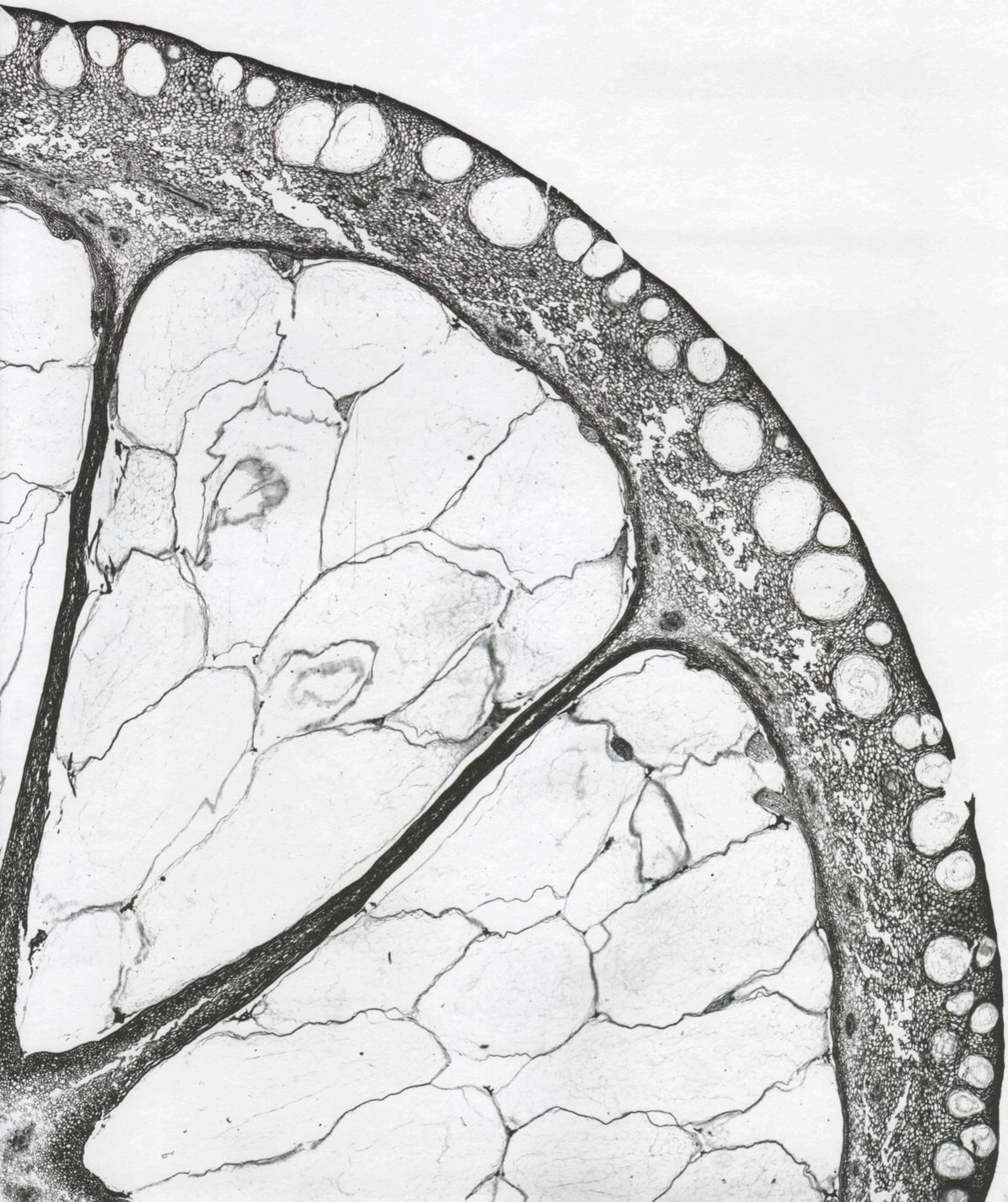
The food industry uses reverse osmosis extensively to concentrate fruit juices, maple syrup, and milk and to isolate whey proteins. It is even used in making wine, including many of the more elite vintages.

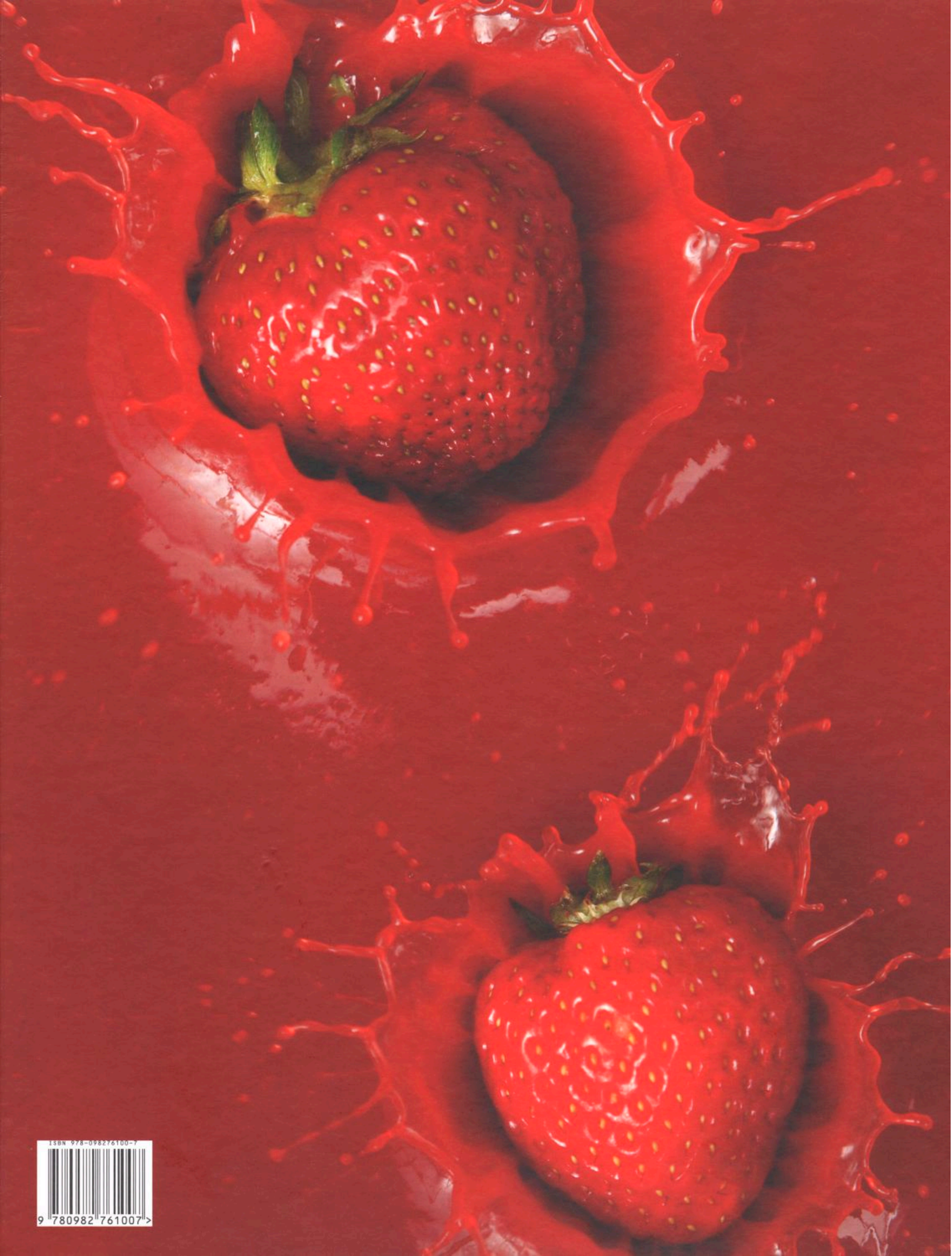


Leaf

Lemon segment







ISBN 978-0982761007-7
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