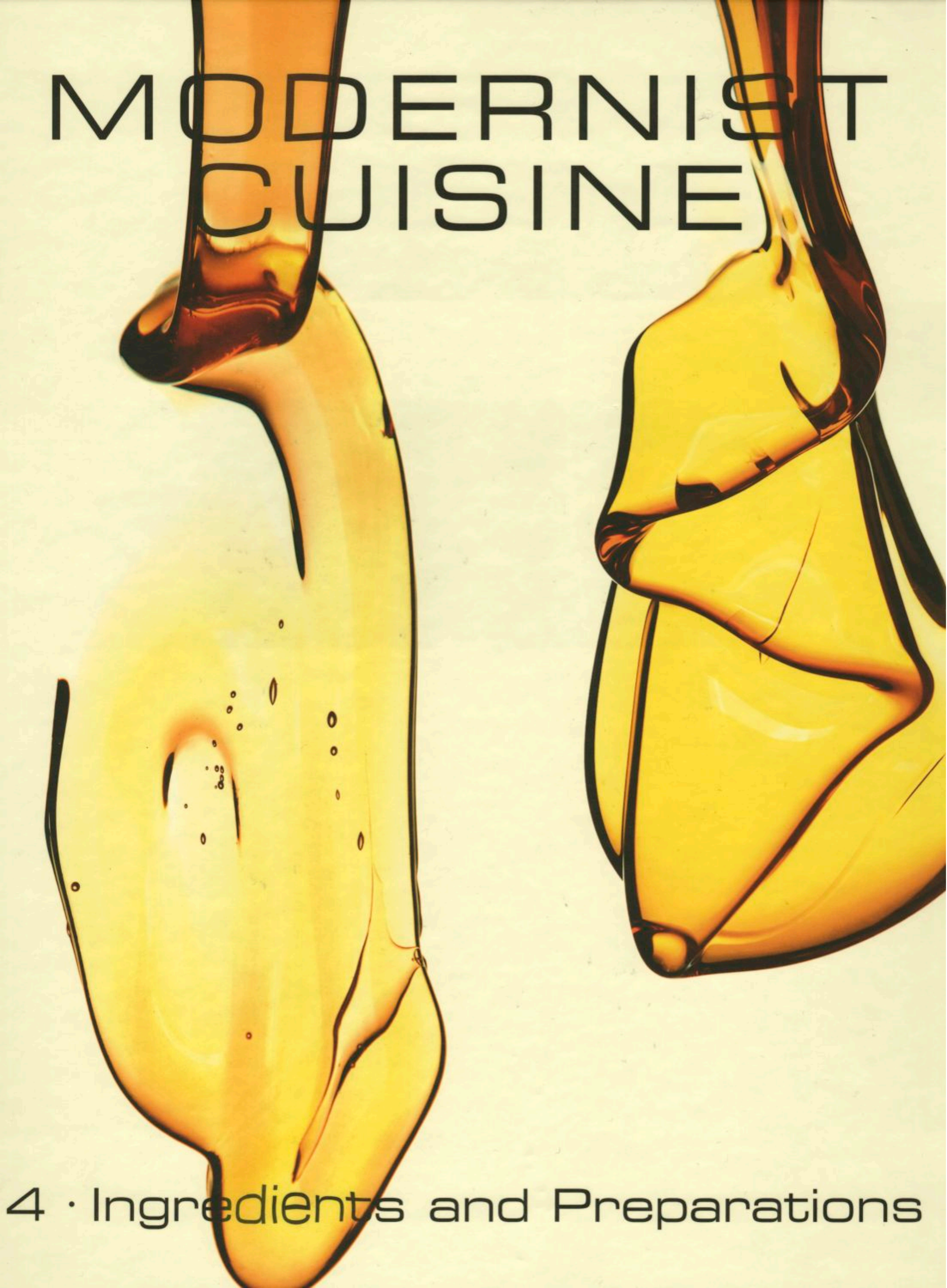
MODERNIST CUISINE

4 · Ingredients and Preparations



Mustard seeds

Tomato

MODERNIST CUISINE

The Art and Science of Cooking

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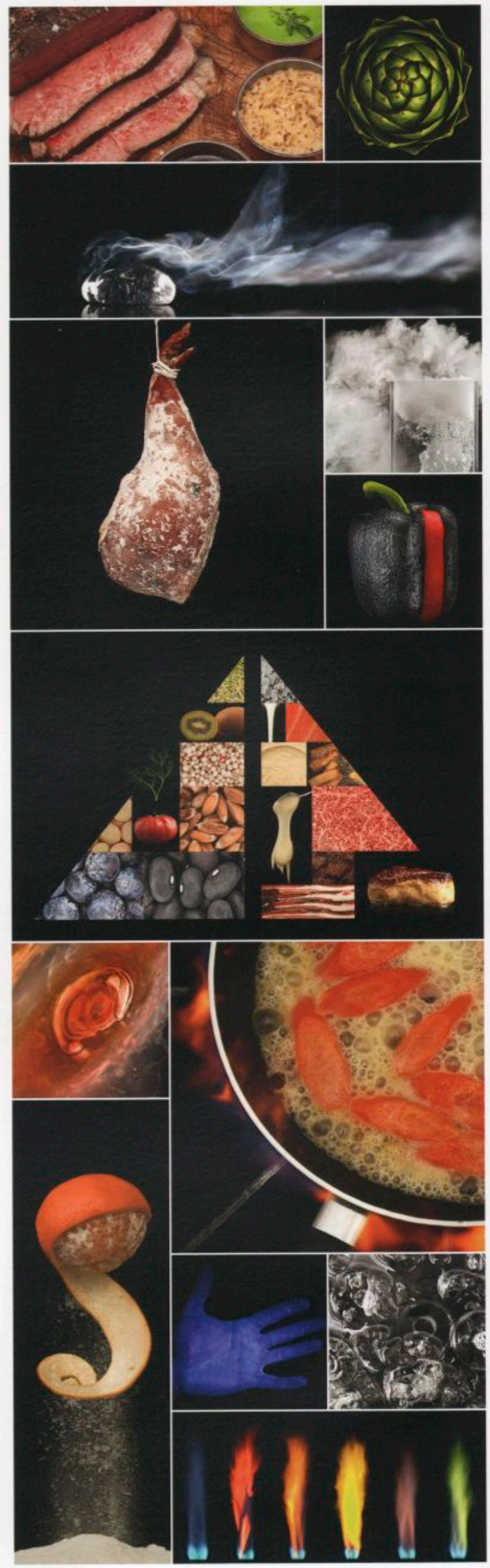

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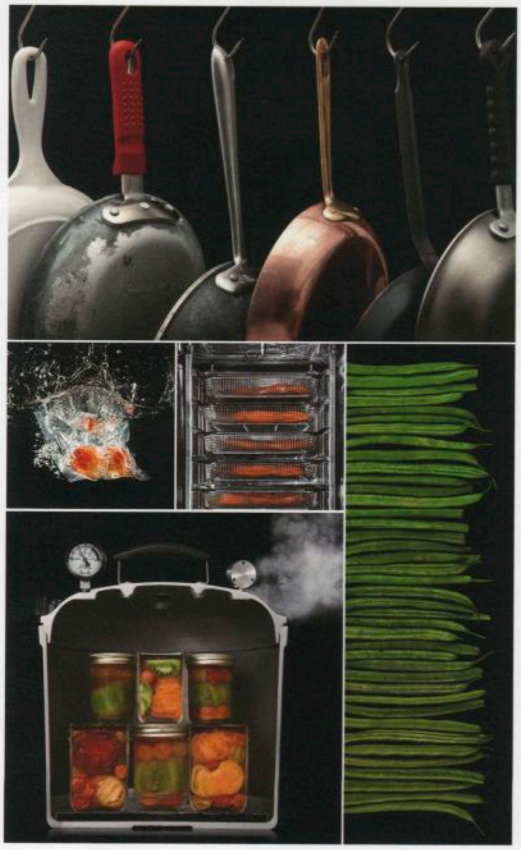

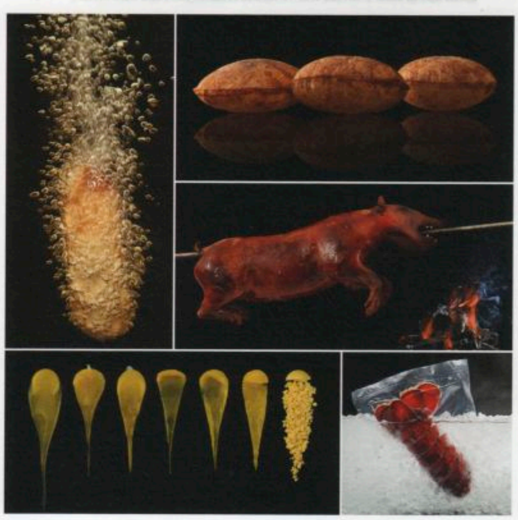

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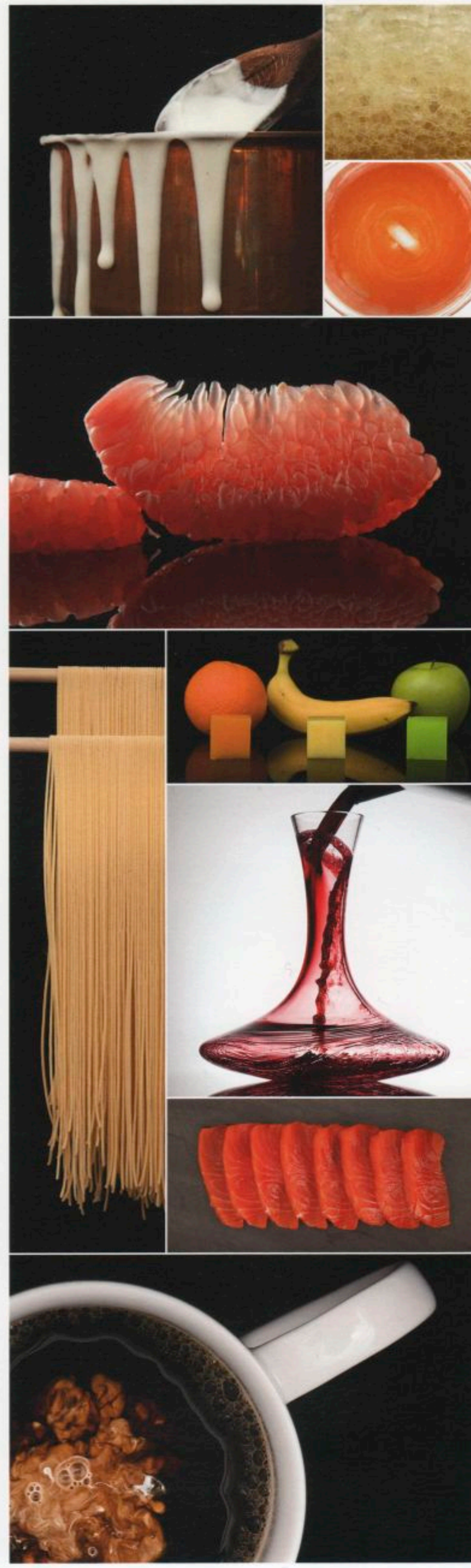
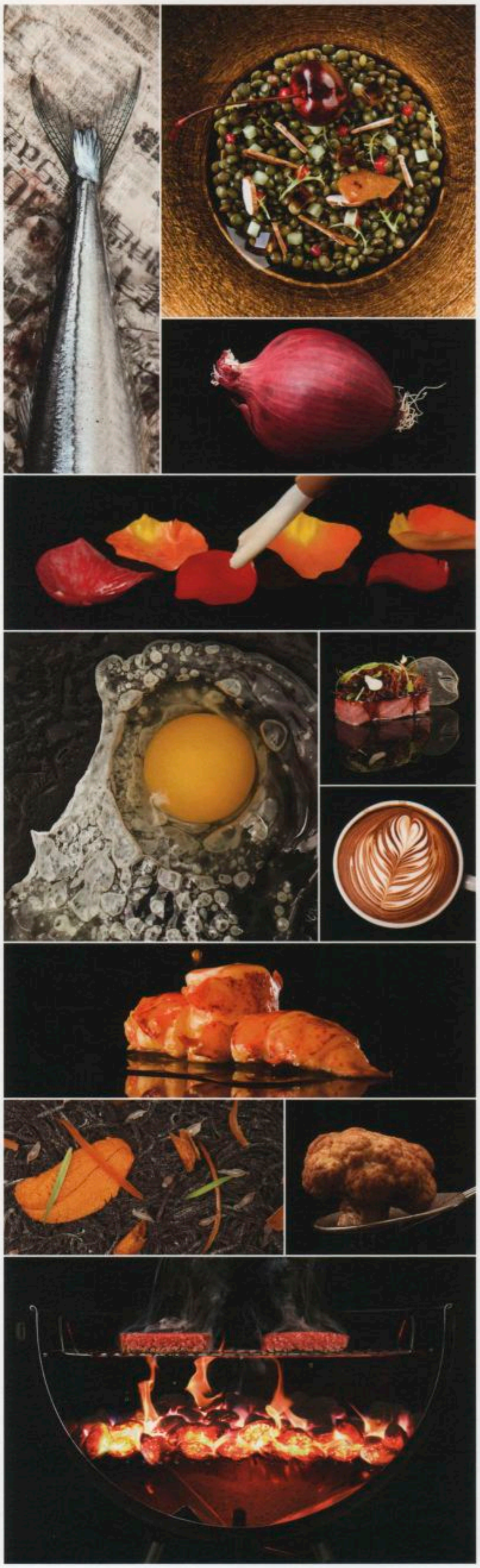
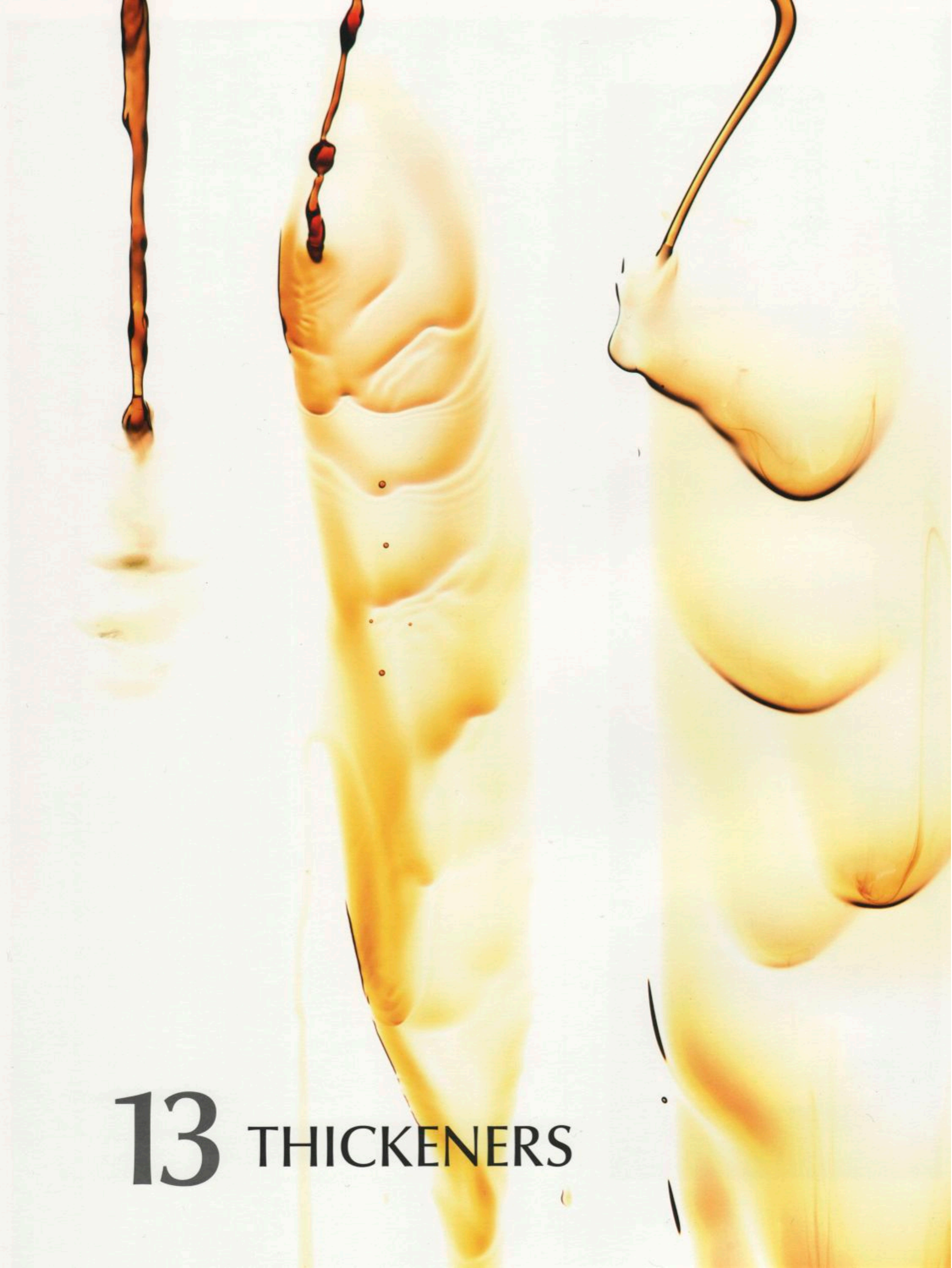






13 THICKENERS

THICKENERS

Making a liquid thicker is one of the most basic tasks in cooking. It is a key part of making sauces, soups, and many beverages. Thickening is included in some of the earliest recorded recipes. The celebrated early Roman cookbook *Apicius* described ways to thicken liquids by reduction and by adding wheat starch, pounded bread, or egg yolks. Since then, cooks have developed many more techniques for giving liquids the thickness and texture they want.

We thicken liquids for several reasons. Thickening a sauce or dressing helps it cling to food as we raise it to our mouths, a functional benefit that improves the eating experience. Imagine the frustration of a water-thin salad dressing or barbecue sauce that runs off before you can eat it. Thickening modifies the mouthfeel of a soup and can add body to a beverage or texture to a pudding or custard. Thickeners also extend the longevity of foams and emulsions. For example, we make a vinaigrette dressing that is thickened by an emulsion, but the emulsion is stabilized with the addition of xanthan gum. The applications of thickening in the world of cooking are manifold.

Traditional cooking offers dozens of ways to thicken (see table on page 7). Most cooks are familiar with the starch-based thickeners—corn starch, tapioca, and roux of flour and fat—used in everything from sauces to fruit pies. Another common thickener is gelatin, which can thicken a liquid moderately or to the point of making it a solid gel. Seaweed-based thickening agents such as alginate, agar, and carrageenan have been used for centuries in traditional Asian cooking and have been applied in new ways in recent years.

Modern thickening agents allow you to adjust the viscosity of liquids across a wide range from runny to barely fluid (opening photo). Traditional thickeners, such as the flour in a béchamel sauce (left), can work well, too, albeit with less precision.

Food science extends the possibilities further still, providing new ingredients that can thicken under conditions that traditional thickeners can't handle. They can thicken with improved flavor release, with the option to reheat, without weeping, and with many other capabilities. The Modernist chef has all of the traditional thickeners to work with plus many more new ones. It's truly the best age ever in which to thicken a liquid.

For more on Apicius, see chapter 1 on History, page 1·10.

Thick and Thin

We know about the relative thickness of liquids at a basic level. Water pours more easily than honey, and honey pours much faster than mashed potatoes. Each can be viewed as a liquid with a vastly different viscosity.

Scientists use the term **viscosity** to describe the resistance that a fluid poses to **shear forces**, forces that push in opposite directions along two distinct parallel lines. In practical terms, viscosity is a measurement of how easily a fluid flows.

Thick liquids move more slowly and thus mix more slowly, as shown by dye in thickened water.

Other units of viscosity, such as the Reyn, exist but are seldom used in food science.

Liquid nitrogen is the lowest-viscosity fluid found in the kitchen, at about 0.2 cP. Swish some around in a container or stir it, and it's easy to see that it is much thinner than water. Most kitchen liquids are far thicker. Milk is 3 cP; corn syrup is 5,000 cP, and sour cream is 100,000 cP, all at 20 °C / 68 °F.

The liquid that shows the lowest known viscosity is liquid helium, which condenses from gaseous helium at -268 °C / -450 °F. Below -270 °C / -454 °F, helium becomes a quantum superfluid that has a viscosity of exactly 0 cP.

Viscosity changes so much with the application of heat or cold that one must always quote viscosity at a particular temperature.

The old saying is true: blood *is* thicker than water. Its viscosity is 3–4 cP at body temperature, compared to about 0.65 cP for water at that temperature. Blood is thicker in part because it is a colloidal suspension of particles—the red and white blood cells and platelets—in watery plasma.

Think of the way your morning coffee behaves as you give it a stir. In response to the shear forces exerted by the moving spoon and friction with the cup, the fluid circles the cup with ease in the same direction of your stirring motion; it has a low viscosity. Take a spoon to your pancake batter, on the other hand, and you've got to work harder to make the batter swirl in its bowl with the same speed; it has a relatively high viscosity. Traditional cooks use subjective measures of thickness, like the way a sauce coats a spoon. Better accuracy can be attained using a **viscometer**, as described in Measuring Viscosity, page 8.

Technically speaking, any fluid has several different types of viscosity. The most useful one for food applications is called absolute viscosity or **dynamic viscosity**, which is measured in units of centipoise (cP) or Pascal seconds (Pa · s, which are just centipoise divided by 1,000). Water is the typical reference fluid for viscosity: it has a viscosity of 1 cP at a temperature of 20 °C / 68 °F.

In nearly all fluids, viscosity is a function of temperature. Except for a few strange cases, higher temperatures result in lower viscosities, meaning that fluids flow more easily. Consider honey and molasses. Both are quite thick at room temperature and even firmer when chilled but much thinner when warm. Hence folk expressions like "slow as molasses in January."

Heat and cold don't affect just molasses; almost all liquids' viscosities change with temperature, even water's. The viscosity of liquid water at 0 °C / 32 °F is 1.8 cP—that's 80% higher than it is at room temperature. At 60 °C / 140 °F, a typical serving temperature for a hot drink or consommé, the viscosity of water drops to 0.5 cP, and at just below the boiling point, it is 0.3 cP. Few people realize that liquid water varies its viscosity by a factor of 6.4 over its full temperature range. This is one of the things to keep in mind when developing the body or mouthfeel for a consommé—its viscosity is going to drop by more than half in going from room temperature to serving temperature.

Most liquids respond to shear forces in a simple manner: the more force you apply, the quicker they flow. They are called Newtonian fluids because they behave just as Newton's laws of motion predict they should. Even some very slow-flowing substances are considered Newtonian liquids. Pitch is a liquid that has an extremely high viscosity (see The "Solid" That Drips, page 9). Window glass can be thought of as the limiting case of an extremely thick, high-viscosity liquid.

A culinary equivalent of glass is the edible film—a thin, sometimes transparent film that can be formed by evaporating a thick liquid on a nonstick surface, such as a silicone rubber sheet. Because such a film is technically a glass—which is to say, an extremely viscous liquid—our recipes for edible glasses appear in this chapter, beginning on page 60, rather than in chapter 14 on Gels.

A set of substances called non-Newtonian fluids have even more interesting properties than slow-moving liquids do because of the complicated ways in which they respond to shear forces. Among the non-Newtonian fluids are **shear-thinning fluids**, which require a certain amount of force to get going but move with more ease once they start flowing.

Shear-thinning is important in many types of cooking. For example, fluid gels act like solids until you stir them, at which point they begin to act like liquids. A classic kitchen example of a shear-thinning liquid is ketchup. If ketchup were a Newtonian fluid, it would flow evenly, in direct proportion to how steeply you tilt the bottle. But that's not what happens. Ketchup stubbornly stays in the bottle and acts solid, even if the bottle is held vertically. If you shake the bottle, the flow starts and then picks up speed as the shear forces reduce the viscosity. Often the result is that too much ketchup dumps on the plate.

The Importance of Mouthfeel

Mouthfeel is the complex set of sensations that you perceive when you eat a food, and it is more complicated than simple viscosity. Liquids that have similar "thickness"—in the sense that they give the same reading on a viscometer (such as maple syrup, olive oil, and creamy bisque)—can feel very different on our palates. That is because our mouths are very sensitive to factors beyond simple viscosity.

The human mouth can sense non-Newtonian flows, the stickiness of sugar, the slippery or creamy aspects of fat, and a host of other factors that together produce a distinctive mouthfeel. So a chef's work is more layered and intricate than

Traditional Thickeners

Thickening liquids is one of the key tasks in cooking; as a result, an enormous range of ingredients and methods are used for thickening. The table below summarizes the most important thickeners and methods used in traditional cuisines. It is important to keep the rich heritage of culinary thickening in mind as we consider Modernist methods. Sometimes, the old ways are best. Other times, their shortcomings alert us to a new possibility.

Method	Ingredient	Application	Note
reduction	high-fat liquid	cream-thickened sauce, alfredo sauce	reduction with cream is used widely in Nouvelle cuisine
	high-protein liquid	demiglace	classically used for demiglace and meat stock glazes; used in Nouvelle cuisine for many dishes
	syrup (sugar solution)	gastrique, Cumberland sauce	
starch	flour (with heat)	roux, beurre manié, béchamel, slurry	gelatinizes without clumping when mixed with butter or oil, and then heated
	pregelatinized flour (such as Wondra brand)	gravy	resists clumping
	cornstarch	pudding, stir-fry sauce	plant starches are common in traditional cooking
	starches from rice, tapioca, arrowroot, potato, kudzu, and other plants	congee, jus de veau lié, ambuyat	
particles	bread crumbs	rouille, panada	suspended particles thicken when dispersed in a sauce
	nut solids	pesto, horchata, romesco, tahini	
	puree	tomato coulis, apple sauce	
	spices	mole, curries	
	protein	bagna càuda (anchovies), vitello tonnato (tuna)	
protein (with heat)	egg yolk	custard sauces, blanquette, crème anglaise, egg-enriched savory sauces	thickens when egg proteins form a gel; for details, see chapter 14 on Gels, page 71
	whole egg	egg fluid gel, avgolemono	
	gelatin	broth, gelatin fluid gel (Sauternes for foie gras)	forms a gel
	milk	condensed milk, evaporated milk	forms a gel when heated
	blood	blood sauce (canard au sang, coq au vin)	
coagulant	soy protein	soy milk, tofu	
	cultured dairy	crème fraîche, yogurt, cheese	cultures thicken by bacterial fermentation; rennet and other enzymes coagulate proteins in milk; acids cause milk to curdle
pectin (with heat)	fruit	jams, jellies, and fruit coulis	
emulsion	oil (dispersed phase)	vinaigrettes, mayonnaise	for details, see chapter 15 on Emulsions, page 196
	butter (dispersed phase)	hollandaise, beurre blanc	
	water (dispersed phase)	butter, margarine	
foam	leavening agents (with heat)	batters and doughs	for details, see chapter 16 on Foams, page 240
	whole egg	sabayon	
	egg white	meringue	
	milk (with heat)	caffè latte foam	
	cream	whipped cream	

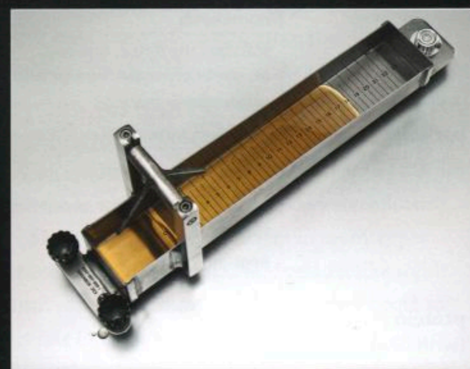
THE TECHNOLOGY OF

Measuring Viscosity

Tools for measuring just how thick a liquid is range from simple to high-tech. Cooks generally prefer the former: tipping over a spoonful and watching how fast the fluid dribbles out (below).

To get a numerical value for viscosity, use a simple ramp-style viscometer (pictured at upper right), which works only for very thick liquids. A fancier, more automated kind of viscometer uses a motor to turn a shaft connected to a rotating disc (bottom right). As the tool spins the disc in the liquid, it measures the force applied—more for molasses, less for water—and calculates the viscosity.

Other types of viscometers, called rheometers, measure the force needed to push a plunger into the liquid, the quality of a drip as it passes through a hole, or the time a sphere takes to fall some distance through the liquid. These are all valid tests of viscosity, but many of them are more precise than we really need for culinary purposes.



Through Thin and Thick: The Viscosity of Common Fluids

Blood really is thicker than water—or milk, for that matter. The higher a liquid's viscosity, measured in centipoise, the slower it flows when poured.

Fluid	Kind	Centipoise (at 20 °C / 68 °F)
liquid nitrogen	Newtonian	0.2 (at −196 °C / −321 °F)
water	Newtonian	1
milk	Newtonian	2
blood	Newtonian	10
cream	Newtonian	20–40
vegetable oil	Newtonian	50–100
corn syrup and honey	Newtonian	2,000–3,000
molasses	Newtonian	5,000–10,000
chocolate syrup	Newtonian	10,000–25,000
yogurt	thixotropic	25,000
ketchup	shear thinning	50,000–70,000
puffed cracker dough	shear thickening	100,000–120,000
tomato paste or peanut butter	plastic	150,000–250,000
lard	plastic	1,000,000–2,000,000

THE EXTREME VISCOSITY OF

The "Solid" That Drips

Pitch is one of the thickest liquids known. Its viscosity—a measure of how resistant it is to being pushed—is approximately 230 billion times that of water. It is such a thick liquid that it appears solid at room temperature and even shatters when struck with a hammer. Yet if you are patient enough, you can also show that pitch flows as a liquid.

Pitch is the star of the world's longest continuously running scientific demonstration, the pitch drop experiment, which is on display in a physics building at the University of Queensland in Australia. In 1927, the university's first physics professor, Thomas Parnell, heated some pitch and poured it into a funnel with no opening. Parnell gave the pitch three years to settle and then cut open the narrow end of the funnel. Since then, the pitch has been dripping out, slowly but surely, at a rate of about one drop every 10 years.

For most of its life, this was not a well-controlled experiment: the pitch was not protected from changes in humidity and temperature, both of which affect how fast it is able to flow. Parnell and his colleagues were nevertheless able to use the apparatus to estimate that the viscosity of pitch is 230 billion cP. Water, by comparison, has a viscosity of 1 cP at 20 °C / 68 °F.

The pitch has dripped only eight times since 1927. Not a single one of the drops had a witness. Curators had aimed a webcam at the pitch before the eighth drop fell in 2000, but the device malfunctioned and failed to capture the event, which occurred while the curator, John Mainstone, was away on a business trip.

As of this writing, there are worries that the ninth drop may be in trouble. The university installed air conditioning in the building while the eighth drop was forming. The cooler air made the pitch thicker, and, consequently, that drop did not completely sever from the funnel; it formed a narrow thread of pitch connecting the funnel to the beaker below. Mainstone says that he has decided to leave Parnell's original experiment setup unperturbed and that he expects that subsequent drops will no longer fall unfettered.

Since the pitch drop experiment was first put on display at the University of Queensland in 1927, just eight drops have fallen out of the funnel full of pitch.

Ham Consommé with Melon Beads, page 48

that of a painter or a cosmetics chemist, who manipulates his ingredients to control functional viscosity, not sensory perception. Despite the title of this chapter, our focus here is really on how cooks can control the texture and mouthfeel of foods made from liquids.

Human mouths can detect solid particles down to 7–10 microns / 3–4 ten-thousandths of an inch. If the granules are below that size, we don't detect them; if they are at or above that size, we perceive them as grittiness. You may have experienced this with hummus, applesauce, or chestnut puree. A viscometer may tell you that a chestnut soup and a carrot soup have the same viscosity, but because chestnuts are very difficult to puree to below the detection limit, they may have a gritty mouthfeel, whereas the carrot puree can feel perfectly smooth.

In addition to sensing suspended particles, people notice whether a thick liquid is sticky (like a sugar syrup), slippery, or slimy (like a concentrated salt brine). Liquids that contain multiple phases, like the separated emulsion found in greasy and stringy melted cheese, have yet a different mouthfeel. Sometimes, this is exactly what you want. The rubbery nature of *pommes aligot* (see page 3·296) or the Turkish ice cream *dondurma* are considered desirable, but would be out of place in other contexts.

When using thickeners, you generally want to increase viscosity first and foremost, but you must also pay attention to the rest of the mouthfeel. There are many ways to thicken a liquid to the same viscosity—choose the one that produces the mouthfeel you want.

Setting Flavors Free

Flavor release is an important consideration when selecting a thickener option. It can help guide your choice between two thickeners or help you adapt recipes to suit the flavor-release profile of the thickener at hand.

Flavor is a very complicated—often highly subjective—concept. But flavor *release* is one of the more objective, scientific pieces of the puzzle. Whether it's the direct flavor sensation on our taste buds or the sense of taste generated when chewing releases aroma vapors, the perception of the flavors of a food can vary substantially with the thickening technique used.

Compared to other thickeners, starch generally produces a duller overall flavor. Although there can be exceptions, the general rule is that starches have poor-to-fair flavor release. In part, this is because starches carry little flavor themselves yet often make up a large fraction of the volume of thickened liquids. Hydrocolloid gums, which thicken at low concentrations (0.1%–0.5%), generally release flavors better, albeit with considerable variations from one to the next.

In the rebellion against flour-thickened sauces that was a hallmark of Nouvelle cuisine (see page 1·24), flavor release was one of the rebels' complaints. A reduced jus has a more vivid flavor than a stock-based sauce thickened with a flour *roux*.

The Nouvelle love of reduction as a thickening method has its drawbacks, however. It is expensive in ingredients, high in fat content (if you're thickening with added cream), and very time-consuming in preparation. It also does not work in all culinary situations. Today, chefs can turn to a wide variety of thickeners, like xanthan gum, that have a neutral impact on flavor release and work in contexts in which reduction would be impractical.

Fat also makes an impression on flavor release, both by imposing its own flavor and by altering the release of other flavors. A lot of research by food ingredient companies has gone into understanding the role of fat in mouthfeel and flavor release, so they can mimic different aspects of it. Egg yolks and cream contribute rich thickening and mouthfeel to high-fat ice creams, but the fat slows down the release of flavor and makes it seem less pronounced. Gelato, which has much less fat, can have a much stronger, more immediate flavor impact—but one that doesn't linger on the palate as long. Neither is necessarily better than the other; they are simply examples of different ways that flavor release affects the eating experience.

Keep in mind that the flavor sensors on the tongue typically can't taste very large molecules. A familiar example here is pure corn syrup. It's quite thick but not very sweet in comparison to other sugars. The syrup contains short, sweet-tasting glucose molecules but is made thick by long, tangled chains of those molecules. Because the chains are so large, we don't perceive their sweetness as much (although they are digested in our stomachs like sugar and still impart their calories). That is why commercial corn syrups are often treated with enzymes that convert some of the glucose chains into the far sweeter fructose.

THE VARIOUS METHODS OF Thickening by Reduction

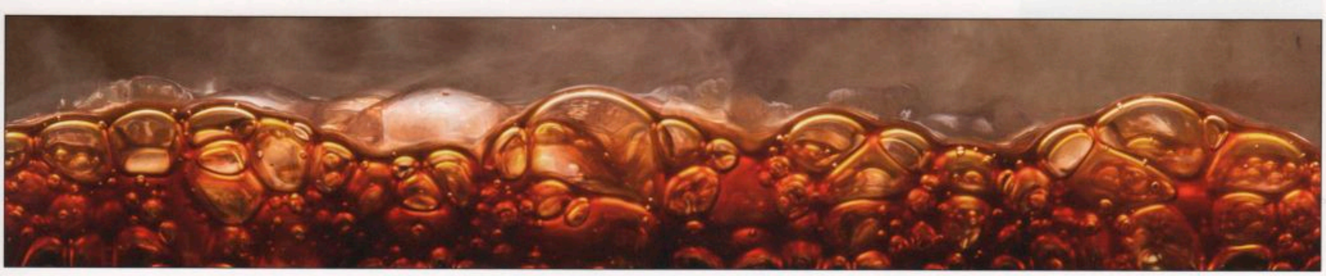
Reduction has always been one of the techniques used for thickening—it's been in every cookbook since *Apicius,* and it took center stage in Nouvelle cuisine. Reductions become thick, however, only if some component in the liquid causes thickening when its concentration increases above a certain threshold.

That phenomenon often occurs when you reduce a colloidal suspension of particles. As you evaporate water from a broccoli soup, for example, the broccoli particles are left behind, which means that the ratio of particles to water gradually changes. There's less water diluting the broccoli pieces, so the liquid appears to thicken. If you boil it long enough, it will ultimately achieve the consistency of a puree or paste (a very high-viscosity liquid).

Reduction is also a process by which you can thicken many emulsions, in which oil or fat droplets play the role of colloidal particles. Evaporation thickens cream by increasing the concentration of butterfat droplets in the water that remains.

And reduction works with solutions that contain lots of dissolved solids. Although the sugar molecules in a sugar syrup—or "simple syrup"—are dissolved rather than floating about as discrete entities like broccoli particles or fat droplets, they can still thicken the liquid at a high enough concentration. A meat stock thickens into demiglace for a similar reason: gelatin molecules and other dissolved solids in the meat stock can't leave the pot as the water evaporates. Reduction removes water, increasing the concentration of both suspended particles and dissolved solids.

Unfortunately, heating any complex liquid mixture can change its flavor, and not always in a desirable way. Vacuum reduction (described more fully on page 2·381) concentrates flavors and thickens liquids without heating them at all.



HOW THICKENING WORKS

Although there are dozens of types of thickening agents, thickening involves only a few basic phenomena. It's important to know them to help you understand which method to apply and why.

For more on how to puree food into fine particles, see page 2·398.

The first method suspends solids or bulking agents within the fluid. The technical name for a liquid that holds solid particles in it is a colloidal suspension, or **colloid.** Many traditional cooking methods employ colloids. A cream of broccoli soup is a colloidal suspension of broccoli particles within broth, for example. The broccoli does not dissolve in the water—chunks of the vegetable are still there. The chunks are simply so small that they yield a smooth mouthfeel.

For an illustration of how thickening works at the molecular level, see the illustration on page 71.

Suspended particles in a colloid rub past, and bump into, each other. These collisions impede their motion and dissipate energy. The higher the concentration of particles, the more collisions occur. Think of the liquid as a subway platform and the particles as people on the platform. When the platform is nearly empty, people can walk around each other easily. There is low viscosity. But at rush hour, when the subway is crowded, people bump into other travelers and have a hard time moving quickly. They dissipate a bunch of energy sliding past each other. If everyone tries to get on a subway train at once, they can't move as quickly. Viewed globally, the flow of people has high "viscosity."

It's easy to walk past a few people, harder to move past a crowd, and nearly impossible to move in a dense crowd. In a similar way, the more that the molecules in a thickened liquid bump into one another, the more viscous it becomes.

Now imagine that groups of people on the platform link arms and start moving around together; the crowd would slow even further. That occurs on a molecular level, too, when small particles in a colloid temporarily tangle or weakly bond with one another to form clusters or chains. Thickening caused by molecules bumping into one another like this is sometimes referred to as **steric hindrance** or **steric resistance**. It is the molecular basis for nearly all of the thickening methods used in cooking.

You can thicken foods by using large, macroscopic particles—like bread crumbs in the rust-colored, garlicky red pepper mayonnaise known as *rouille*—or particles that are tiny but still detectable by your mouth, as in applesauce or hummus. In a smooth puree, the particles are smaller than the threshold of detectability, which is 7–10 microns / 3–4 ten-thousandths of an inch; that is how a very smooth broccoli soup becomes viscous. The suspended particles can even be minuscule molecules, like the dissolved sucrose molecules that make a sugar syrup thick. They are far smaller than even the finest particles in a puree, but their collective effect is quite noticeable.

The degree of thickening you get depends on the nature and concentration of the particles responsible. Some particles tend to stick to each other more, especially long polymer molecules. These act a bit like strands of spaghetti that tangle as you pour them from a pot. The most effective thickeners tend to be long molecules that stick to each other enough that they generate considerable steric hindrance.

There are several ways you can use this effect for thickening. The first and simplest is to make a colloid of suspended particles by mechanically grinding or pureeing a food, as in broccoli soup (see page 2·424). You need a high concentration of suspended solids if you want to achieve much thickness, though, and the more you add, the more likely that some will settle out over time, creating sediment—a sign that your colloid is no longer fully suspended. Moreover, you may not want to use so much of the ingredient—not an issue for broccoli, perhaps, but thickening a truffle soup with nothing but pureed truffle would be an expensive proposition.

A second approach to thickening is to add particles directly. One of oldest means of thickening a colloidal suspension—adding ground bread crumbs to a liquid—was cited in *Apicius*. The delicious *rouille* is thickened with fresh bread. It's not the most sophisticated means for thickening and can't be applied very broadly, but it definitely works.

Adding bread crumbs to a broccoli soup certainly thickens it but also creates a characteristic texture and mouthfeel. Other particle sources lend a different mouthfeel. Microcrystalline cellulose (MCC) is a plant fiber (cellulose), which is ground into crystalline bundles small enough to add some viscosity and make a creamy mouthfeel. MCC and similar products are widely used to make low-fat foods that seem to have creamy fat in them. Adding MCC to the broccoli soup would not only increase its thickness but also give it a mouthfeel of creaminess without introducing any dairy or fat.

The most powerful variation is to add thickening agents that dissolve into long polymer chains that tangle in water to provide lots of resistance to movement—and thus thickening. They are so small that we never taste them as individual particles. Compounds that form this sort of tangle of molecules in water are called **hydrocolloids**. These include starch, which is another of the oldest means of thickening (see page 28), and **gums**, which are chemical cousins of starches.

Technically speaking, anything that forms a colloidal suspension with water is a hydrocolloid, including pureed broccoli and bread crumbs. This broad use of the term "hydrocolloid" isn't very useful because it encompasses almost everything. Most chefs use the term "hydrocolloid" to mean plant gums and gelatin, and we follow that convention. Although starches, proteins other than gelatin, and colloidal suspensions of particles (even broccoli in soup) are also hydrocolloids, most cooks use their specific names when referring to them.

A third approach to thickening works only for liquids that already contain the raw materials needed for forming polymers. In these cases, you don't need to add a polymer—you just activate the molecules already there.

Eggs are a classic example. Proteins found in both the whites and the yolks of eggs coagulate, causing thickening and gelling, when they are heated. Dairy liquids are another classic example. Milk is a complicated emulsion of fat and water in which proteins and minerals are suspended. The proteins in raw milk slide around one another easily, but add an acid, and the milk proteins form clusters that thicken the fluid.

Yogurt and crème fraîche are natural examples of this process: the bacteria that ferment them secrete lactic acid. Instead, one can add an **acidulant**—a chemical that causes acidity directly. Even more powerful than acids are **enzymes** like rennet, which cause the proteins to tangle so much that the milk coagulates into a familiar gel: cheese.

Thickening Oil

Most thickening involves making a water-based **solution** thicker, but sometimes we want to make an oily liquid thick. The physical and chemical properties of oil are very different from those of water, so the details are different. But some of the principles are similar.

One way to "thicken" oil is to **emulsify** it with water or some other substance. An **emulsion** is a mixture in which tiny droplets of one or more liquids are suspended in a different liquid, acting as the undissolved "particles" in it. Emulsions are so important in cooking that we devote chapter 15 to them (see page 196); we mention them here only to sketch their role in thickening.

For more on dairy gels, see page 102.

Strictly speaking, an emulsion isn't just thickened oil—it is something different, but it does result in a product that is much thicker than either the oil or the water that it is made from. Mayonnaise is a classic example.

As with a colloidal suspension, bumping and **friction** among the droplets (and between them and the molecules that surround them) cause the emulsion to thicken. You can increase the viscosity of an emulsion further by adding a gum or other thickener. This works whether the emulsion comprises oil droplets in water or vice versa. Some modern thickeners work directly on oil, bypassing the need to emulsify it first.

N-Zorbit, made from tapioca starch, becomes "wet" with oil (technically speaking, it **adsorbs** the oil). By stirring it in well, and you can turn oil into anything from a thick slurry to a solid mass. Food manufacturers use N-Zorbit to add oil in powder form to boxed cake mixes, for example. You can also thicken oil by mixing it with another oil that has a higher melting point. Although oils do not dissolve in water, they can dissolve in each other.

Thickening is such a wide-ranging topic that we cover some aspects of it more fully in other parts of this book. Thickening with egg or other heat-modified proteins is really thickening with a fluid gel, so we discuss such techniques in detail in chapter 14 on Gels, page 64. We likewise cover thickening with emulsions in chapter 15 on Emulsions.

Olive oil (top) remains liquid well below room temperature, whereas cocoa butter melts just below human body temperature. The viscosities of both increase dramatically near their freezing points. So mixing olive oil with deodorized, flavorless cocoa butter yields an oil that tastes like olive oil yet stays solid at room temperature (bottom). Even at 40 °C / 104 °F, it remains quite thick (see page 51).

STRATEGIES FOR THICKENING

To choose which thickener to use, think about the flavor of the food you'll be thickening and the desired end result. Over the years, industrial food scientists have developed a great many thickening agents, each having properties that make it well suited for a particular set of thickening tasks. For factory-scale use by the ton, the cost of the ingredient matters a great deal. Home and restaurant cooks, on the other hand, can pay more attention to the functional characteristics that make one thickener better than another for the dish at hand.

The table What Matters for Thickening on the next page lists some of the most pertinent factors to keep in mind as you scan your cabinet of thickeners. Will the food you are about to thicken be served hot or at room temperature? Will it be

A rotor-stator homogenizer disperses thickeners without leaving lumps.

What Matters for Thickening

Myriad factors are involved in thickening a liquid. Will the final product be served hot or cold? Should it be clear or opaque? These and the other factors listed in the table below influence the choice of which thickener to use. Each thickening agent has different properties, strengths and weaknesses.

Factor	Range of values	Example
serving temperature	cold (≤5 °C / 41 °F)	chilled
	neutral (~20 °C / 68 °F)	room temperature
	hot (≥50 °C / 120 °F)	hot
clarity	clear/transparent	consommé, coffee
	opaque	milk; white or brown sauces
viscosity	very thin (10–20 cP)	orange juice
	thin (20–75 cP)	cream
	medium (75–200 cP)	olive oil
	thick (200–1,200 cP)	egg yolk
	very thick (1,200–5,000 cP)	honey, yogurt
	paste (5,000–20,000 cP)	mustard, mayonnaise
	nearly solid (50,000–200,000 cP)	peanut butter
pH	alkaline (≥8)	native egg white
	neutral (6–8)	most vegetables and meats
	mildly acidic (3–6)	fruit juices, purees
	very acidic (≤3)	lemon juice, vinegar
flavor release	slow and long-lasting	fat
	fast and short-lived	gelatin
mouthfeel	creamy	cream sauce
	sticky	syrup
	slippery	raw fish
syneresis (weeping)	low	yogurt
	moderate	apple sauce, flan
	high	chawanmushi, gazpacho

thawed and reheated after freezing? Many thickeners work well only in one temperature range.

If you're thinking about freezing your thickened composition, keep in mind the freeze–thaw stability of the thickener you're considering. Some will freeze and later defrost without any issues; others won't. For example, a sauce made without hydrocolloid stabilizers tends to separate when frozen and then defrosted. Including the right thickeners will keep it creamy and smooth.

Once a frozen sauce is thawed, you may want to reheat it. Some thickeners are restored to their original glory when reheated, while others, once cooled and gummy, can never be revived. Natural starch thickeners in particular often respond poorly to reheating. In fact, that is one of the problems that motivated the creation of modified food starches.

Also consider the optical attributes of the thickening agent. Creating a thin consommé of high clarity is relatively straightforward, but say you want a thick liquid that is crystal clear—like a thick syrup without the sugar. That's more of a challenge. Many thickeners have large molecules, or clumps of molecules, that refract light, and turn the liquid cloudy or opaque. Gums, like cellulose gum and guar gum, work in such small amounts that they are unlikely to add opacity to your sauce. Or you can use xanthan gum or other thickeners that have been modified to yield a clear appearance.

For more on the synergistic effects of thickeners used in combination, see Hydrocolloid Interactions, page 44.

For more on fluid gels, see page 176.

Your options for controlling viscosity (the degree of thickening) are very wide. Starches, both natural and modified, are typically best applied to high-viscosity preparations, such as thick, rich sauces. Then there is xanthan gum, which is in many ways the universal food thickener. With the proper technique and at the right concentration, a bit of xanthan can give the gentlest bump in body to a beverage, produce a very thick paste, or form a fluid of nearly any viscosity in between.

At the low-viscosity end of the scale are thickeners that provide only slight changes in viscosity and texture but that are nonetheless very important. You might not think of a soda such as Mountain Dew as having much viscosity or body, but in fact it contains gum arabic, which serves as an emulsifier (see page 239) that keeps the flavor oils in suspension.

If no one thickening agent can achieve the viscosity you want because of temperature or other limitations, you may be able to combine two or more different thickeners and exploit a phenomenon called **synergy**. Pair xanthan gum with locust bean gum, for example, and you can create a distinct gelling effect even though neither gum can, by itself, cause a liquid to gel. Guar gum shares this limitation in solo use but shows synergistic thickening when combined with xanthan.

Many thickeners create a liquid that is (to some degree at least) non-Newtonian, meaning its viscosity depends, in part, on the forces applied to the liquid. The simplest examples are shear-thinning liquids, which have a lower apparent viscosity (flow more easily) when stirred or poured. Sometimes this property is desirable, and sometimes it is a side effect of using a particular thickener.

Fluid gels are extreme versions of shear-thinning liquids. A fluid gel sets to a solid but can be disrupted to form something that, due to shear thinning, flows like a liquid when shearing force is applied. Fluid gels are very good for suspending small particles in a liquid: they have a high viscosity at rest, with just the force of gravity acting on the suspended particles, but then flow like a low-viscosity liquid when stirred, poured, or consumed. Fluid gels provide unique shear-thinning, textural, and mouthfeel properties.

An interesting variety of fluid gel is quite traditional: eggs used to thicken sauces. When you heat egg to a particular temperature, the protein molecules reorganize and link to one another. That's what makes eggs set. If you heat an egg-containing sauce gently while you beat it, you're making a fluid gel by promoting links between protein molecules, which are larger than sugar molecules but smaller than hydrocolloid molecules.

Fluid gels are important to keep in mind as you consider your thickening options. Because they are so closely related to normal semisolid gels and involve many of the same gelling agents, we treat the details of fluid gels in chapter 14 on Gels.

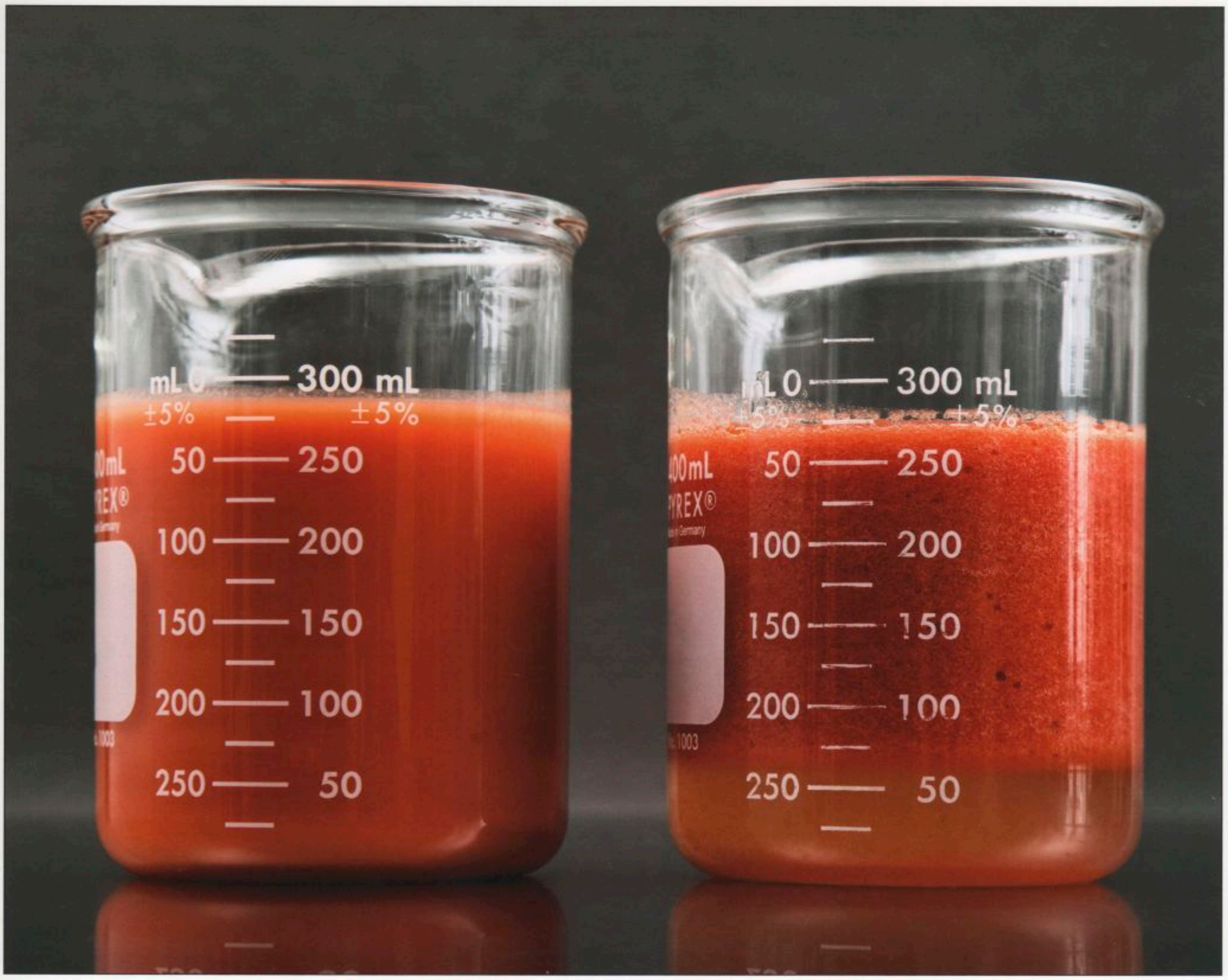
Acidity is another important factor in choosing a thickener. A low pH impairs the performance of some thickeners, so if your liquid includes acidic ingredients, choose your thickener appropriately. Xanthan gum is stable across a range of pH levels, but other hydrocolloids, including alginate, do not do well under acidic conditions. You can sometimes work around this limitation by premixing the thickener with pure water and then heating it gently before adding it to the liquid to be thickened.

Caramelized Coconut Cream, page 50

We discussed flavor release and mouthfeel, both crucial considerations, earlier on page 6. Often, there is no single right choice among the options here. You might ask yourself what your audience is likely to prefer, keeping in mind that individual and cultural preferences vary. Some diners treasure a slippery and lingering mouthfeel, whereas others find it repellent.

A final consideration is **syneresis**, the naturally occurring separation of water from a solid or a thick liquid. If you've ever overcooked an egg custard or an omelet, or let a tub of yogurt sit too long on the counter, you may have noticed water "weeping" from the surface or edges of the food. Egg proteins contract so much when overcooked that they push the water out. In other foods, such as thick applesauce, the water is so loosely bound that it just gradually seeps out of the mixture. If you serve food immediately, syneresis may not be a concern, but it can be critical for food prepared well in advance. Weeping can also be a problem for food served immediately—as it is for applesauce or gazpacho (see photo).

Because many frozen foods and shelf-stable products also suffer from syneresis, commercial food scientists have put a lot of research into helping them resist the phenomenon. They found that the addition of a stabilizer or thickener helps to prevent weeping. Guar gum, locust bean gum, iota carrageenan, and the ubiquitous thickener xanthan gum are often used alone or in combination to reduce syneresis, as are modified starches.



Syneresis, or weeping, occurs when water or other fluid separates from a mixture. It is very common in particle-thickened fluids like applesauce or the Spanish cold soup gazpacho (shown here). We add 0.2% xanthan gum and 0.5% Ultra-Sperse 3 to prevent syneresis (see page 30).

MODERN METHODS OF THICKENING

Texture manipulation is a key technique in the Modernist kitchen. Food texture should never be a mere gimmick but rather an enhancement that intensifies the ultimate enjoyment of a presentation. Achieving that goal demands thickeners that minimally affect the natural flavor of the food.

The contemporary chef's pantry of thickeners can read like a science fiction novel at times because it includes such staples as low-acyl gellan, N-Zorbit, and carboxymethyl cellulose. No doubt these ingredients will be intimidating at first, but the more familiar you get with each one, the more comfortable and approachable you will find them to be.

Many of these agents, like kudzu, carrageenan, agar, and most gums, are rooted in culinary history but have new, modern applications. Modified food starches are primarily classic starches that have been tweaked to save time by the manufacturer, who has done the hydrating and the gelling for you.

A few thickeners—like methylcellulose, which melts at cool temperatures—and some of the scientific, moisture-reduction tools now available to the chef—like the centrifuge and spray dryer—really do seem space-age, but that is part of their appeal. They are part of a new pantry that inspires experimentation and exploration.

Creamed Spinach, thickened with xanthan gum and Ultra-Sperse 3. **For a recipe, see page 55.**

Method	Ingredient	Example application	Note
starch	pregelatinized starch paste	instant velouté or béchamel sauces	simple to use: just pour and stir
	pregelatinized starch	nut butters, puddings, vegetable purees, gravies	many proprietary blends available
	modified starch		
fruit-based hydrocolloid	high-methoxyl pectin	sweet or savory creams, low pH	thickens at very low concentrations
	low-methoxyl pectin	low-sugar jams and jellies, high pH	
plant-based hydrocolloid	tapioca	fillings, gravies, sauces	in common use worldwide for centuries
	konjac flour	puddings, pastes, and spreads	
	aloe vera tissue	yogurts, glazes	
	kudzu, mallow root, violet root	dondurma, sago pudding	
marine-based hydrocolloid	agar	fluid gels, savory puddings	good for fluid gels
	carrageenan (all varieties)	fluid gels, yogurt, cream cheese	creamy mouthfeel; thickens at low concentrations
	sodium alginates	low-fat milks and creams	
	propylene glycol alginates	rich gravies and sauces, mayonnaise	thickens and emulsifies
modern cellulose-based hydrocolloid	methylcellulose	cheese sauce, ice cream	thickens at low concentrations but can add a chemical flavor; methylcellulose is unusual because it thickens when hot and is thin when cold
	carboxymethylcellulose	ice cream, mayonnaise	
	hydroxypropyl cellulose	puddings	
	methyl hydroxypropyl cellulose	ice cream, mayonnaise	
	microcrystalline cellulose	fruit and vegetable purees	
microbial-based hydrocolloid	xanthan gum	vinaigrettes, broths	most versatile thickener
	gellan gums (high- and low-acyl)	fluid gels	can be sheared into fluid gels
seed gum	locust bean gum	low fat creams, yogurts	can usually be dispersed and hydrated cold
	guar gum	salad dressings, ketchup	
	tara gum	ice cream, mayonnaise	
exudate gum	gum arabic	savory syrups	can usually be dispersed and hydrated cold
	gum tragacanth	puddings	
	gum karaya	cheese spreads, sorbet	
traditional fluid gel	egg	egg yolk and whole egg dressings	shearing weak gels creates a fluid gel
	gelatin	coating gels and sauces	
hydrocolloid fluid gel	carrageenan (kappa and iota)	savory puddings, fruit and vegetable juice purees	fluid gels allow you to thicken with a solution that normally forms a solid gel
	agar		
	gellan gums (high- and low-acyl)		
particles	N-Zorbit	oil powders, pastes	suspended particles thicken the sauce when dispersed
	microcrystalline cellulose	nut and legume milks	
	clay	jus and broths	dissolves rather than dispersing
	dextrins	savory ice cream	
	freeze-dried vegetable powders	barbecue sauce, vegetable purees	
	isomalt, mannitol, xylitol, trehalose	savory syrups	
enzyme	transglutaminase	yogurt, cheese spreads	adds an enzyme that cross-links proteins
	quick enzymatic reactions	artichoke, ginger, rennet	
	pH precipitation	crème fraîche, posset, alcohol-coagulated egg sauce	
emulsification	fat and various emulsifiers	beurre blanc, mayonnaise	for more details, see chapter 15 on Emulsions
	water and various emulsifiers	gravies, sauces, soda	
foams and bubbles	assorted techniques	hollandaise, sabayon	for more details, see chapter 16 on Foams
modern reduction	spray-drying	juices, buttermilk, vinegar	can thicken as well as classical reduction but without heat-induced flavor change; for more details, see chapter 12 on The Modernist Kitchen
	vacuum reducing	fruit and vegetable juices, syrups	
	freeze-concentrating	citrus juice	
	freeze-drying	mushroom ketchup	
	centrifuge concentrating	nut pastes	

STARCHES

Starches are an example of a class of molecules known as **polysaccharides**—which means "many sugars"—because they are made up of sugar molecules bonded together in long chains. Plant gums are also polysaccharides, but they have a different molecular structure.

The body digests starches, breaking them down into their component sugars. The body treats many other polysaccharides as fiber, however; they pass through undigested.

Molecules made of repeated units of a set of building block molecules are called polymers. Starch is an example of a polymer; it is made of repeated glucose molecules bonded together. Chemists study a wide range of polymers including many plastics. DNA, the information-bearing compound central to all life, is a very different type of polymer molecule.

Starch is the most familiar example of a substance that thickens liquids with the long, tangled molecules called polymers. Natural starches are composed of two types of polymers, amylose and amylopectin. Amylose is a linear chain of octagonally arranged molecules. Amylopectin has a branched structure a bit like that of a tree limb. Both are large chains of glucose molecules, but amylose is better for forming gels, whereas amylopectin binds up water and thickens better. Although they are composed of glucose (a sugar), they do not taste sweet because they do not bind to the receptors in our tongues that detect sweetness.

Natural starches contain amylose and amylopectin in various ratios. Corn and wheat starch are about 25% amylose and 75% amylopectin; tapioca starch is about 18% amylose and 82% amylopectin. A few plants have much higher concentrations of one or the other. Many are commercially bred to exaggerate the desired type, but waxy corn, discovered in China in the early 1900s, is an example of a natural variety that is almost all amylopectin. Since the 1960s, hybrids of waxy corn have been grown to create starches for commercial food production or for Modernist cooking because it produces a pure cornstarch that, when cooked, is both transparent and stable.

Natural starch occurs in plant cells in granules, typically having a nested structure of concentric layers, like the layers of an onion. Different plants produce starches with different-sized granules, which is important in choosing a starch to meet your goals. Corn and rice starch granules are very small, producing a smoother appearance when cooked. Potato starch granules are very large, turning out sauces with grainy, mottled textures.

In order to thicken with a natural starch, we first need to soak the granules in water. The granules absorb large quantities of water, causing them to swell. As the granules swell they become, in essence, gooey balloons filled with water.

The problem is that wet granules can stick to each other, so the starch forms lumps immediately. This tends to prevent water from reaching granules in the center and leads to a lumpy sauce or other liquid. That is why we first must uniformly distribute the starch granules, a process called **dispersion**, and then make sure that they absorb water in a controlled way, known as **hydration**. Hydration without dispersion leads to lumps, also called "**fish eyes**."

Modified starches are modern inventions that use starch molecules as their building blocks but take them to places that natural starches cannot go. The term "modified" means that the starches are processed in various ways—usually reacted with acid or alkaline solutions or with enzymes. They may be heated, cooled, washed, dried, and subjected to other steps. Each modified starch has a somewhat different recipe, but the goals are similar: to create starches with properties that improve on those found in natural starches. Almost every weakness or problem of natural starches can be addressed (at least in part) by using an appropriate modified starch.

Dispersion

One approach to dispersal is simply to whisk the starch into cold water to make a slurry; this is typically done with starches like cornstarch or arrowroot. A blender or homogenizer can do the whisking more thoroughly than we can by hand, but the principle is the same. We use cold water because it soaks in more slowly, giving us time to break up any lumps before the granules get sticky.

Wheat flour doesn't tend to work well as part of a slurry. It forms lumps too easily, even in cold water. In addition, it tends to have a raw flour taste that many people don't like. This issue gave rise to the classic technique of cooking the flour with fat (oil or butter) to make a roux. In a roux, the starch granules are coated with fat to help prevent them from sticking to each other. You don't have to cook

Tapioca starch creates an extremely thick, viscous fluid when fully gelatinized. It can be diluted to yield a wide range of different textures and thicknesses (see page 28).

For recipes that use modified starches, see page 28.

There are two key steps to using natural starches. First, you must disperse them, uniformly distributing them in a liquid. Second, you must hydrate them, letting them absorb water in a controlled way. Modified starches can make either or both of these steps easier or unnecessary.

Despite the sound of the name, gelatinization has nothing directly to do with gelatin or with the process of gelling. It is a necessary step for either thickening or forming a gel, but it does not mean you have formed a gel.

the roux to hydrate it, but the cooking removes the raw flour taste. A lightly cooked, or "blond," roux is heated just enough to remove the taste. A medium or dark roux is cooked longer to develop color and taste from browning reactions. Cooking the roux also makes it less likely to cause your sauce to congeal, but the primary point of cooking a roux is to govern flavor, not thickness. Hydration of the starch in a roux occurs only after the roux is mixed with a water-based liquid and heated.

Although most Modernist thickening methods make use of hydrocolloids rather than flour, you can use technology to update the classic roux. A pressure cooker or autoclave will brown the flour to a precise level quite quickly. Indeed, you can also use a roux-like technique with starches that don't have a raw taste, such as cornstarch: just disperse them in fat before adding them to liquid. You can also disperse starch in another dry ingredient, such as sugar, to achieve a similar effect. In all cases, dispersion keeps the granules away from each other while they absorb water during the hydration step.

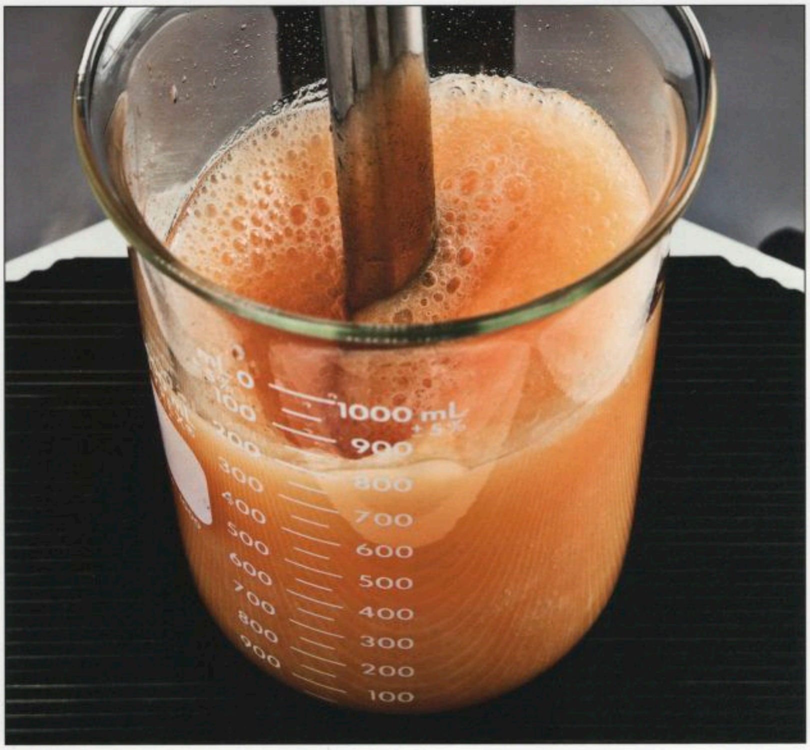
Natural, unmodified starches require heat to thicken, while many modified starches can thicken without heat (because the modification steps have prepared them). Once starch has been dispersed in water, either directly or via the intermediate step of first dispersing it in fat, we must heat the starch so that it undergoes **gelatinization.** This is a technical term for what happens to the molecules of natural starches in the presence of heat and water; the bonds between the molecules in a crystallized starch are broken, thus allowing water to penetrate. The starch changes from an ordered crystalline state to one that is disordered and amorphous—and the liquid medium thickens. The gelatinization step is necessary for a starch to either gel or thicken.

Gelatinization typically occurs across a narrow range of temperatures, which differs for each type of starch. As an example, potatoes typically start gelatinizing at 58 °C / 136 °F, and the process continues up to 65 °C / 149 °F.

Gelatinization is a property of the starch itself, not of the solution or mixture it is in. In fact, a gelatinized starch doesn't have to be in solution at all; it can be turned into a dry powder. That is exactly what happens with many modified starches: the manufacturer has already performed the gelatinization step, along with other modifications. These "instant" starches don't need to be cooked further when added to a liquid; they thicken right away.

A common supermarket example is "instant flour," such as the Wondra brand, which is a low-protein, high-starch flour that has been agglomerated to prevent lumping. Technically speaking, it has not been pregelatinized, so it still needs to be cooked to thicken. The dispersion step is simplified, however, because instant flour can be directly added to hot liquids without first making a slurry or roux, with little danger of forming lumps. Modified starches such as Ultra-Sperse 3 and Ultra-Tex 8 are made from natural sources, such as tapioca, but have been modified to be stable and pregelatinized. They thicken directly, without any heat being added.

Another approach is to start with a natural starch and make your own pregelatinized starch paste that can be stored in the refrigerator and used as needed—see page 29 for a recipe.



A rotor-stator homogenizer is a great tool for dispersion.

HOW TO Measure Thickeners

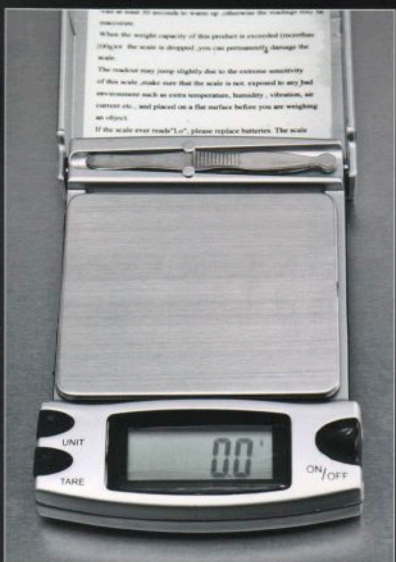
When using thickening agents such as starches or hydrocolloids, accurate and precise measuring is vital. Traditional cookbooks use volume-based measurements, but a measuring spoon or a pinch is never accurate enough when it comes to such powerful compounds. So always weigh your thickening agents. A fraction of a gram can make the difference between a sauce that is velvety and moist and one that is slimy or rubbery. Recipes with hydrocolloids require a good scale.

Standard digital kitchen scales, accurate to 1 g / 0.04 oz, may not be accurate enough for this task. Digital pocket scales, accurate to 0.1–1 g / 0.004–0.04 oz, are widely available and sufficient for most applications.

Better yet is a laboratory-quality scale, which is typically accurate to 0.0001–0.01 g / 0.000004–0.0004 oz. You can buy these excellent, well-calibrated tools through lab supply web sites and, more and more often, from good kitchen supply sources. For extreme precision, super-precise analytical scales will measure every granule. These are marvelous tools, but they're not very practical in a busy kitchen environment.

Whatever kind of scale you use, keep it clean, calibrate it regularly, and move it as little as possible.

We always measure our hydrocolloids on waxed weighing paper or a special plastic tray (called a weighing boat). These are available from lab supply web sites.



Digital pocket scale
Accurate to 0.1–1 g / 0.004–0.04 oz

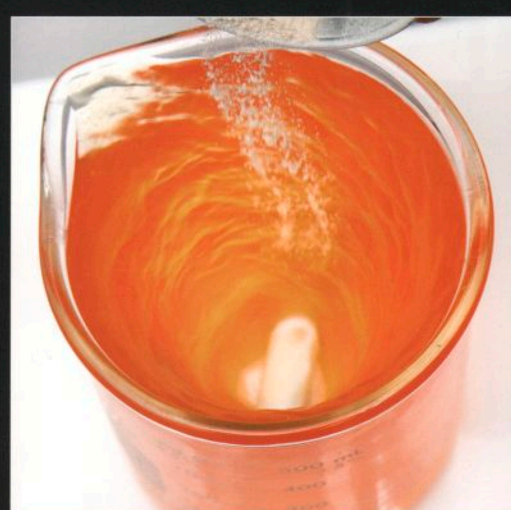
Laboratory scale
Accurate to 0.01 g / 0.0004 oz—the best choice for measuring small quantities of hydrocolloids

Analytical scale
Accurate to 0.1–1 mg / 0.000004–0.00004 oz (higher than needed for culinary applications)

1. **Place waxed weighing paper or a plastic weighing boat on a scale.** Set the scale to zero with the tare button.

2. **Sprinkle the powder onto the paper or tray until the required weight is reached.** If using multiple dry hydrocolloids, mix them together while they are on the scale.

3. **Sprinkle the weighed powder directly into the liquid.** Do not repeatedly transfer the powder from one container to another because some of the powder will stick to the sides and reduce the weight. For more on dispersing the powder, see instructions on the next page.



HOW TO Disperse a Thickener

A starch, hydrocolloid, or other thickening agent will work properly only if you distribute it very evenly throughout the liquid. Just mixing dry powder into a liquid is not good enough, as you may have discovered if you have ever added dry cornstarch to a gravy and ended up with powdery lumps. Properly dispersing, as the process is called, is not always as easy as it sounds. You don't get reliable visual cues when blending in the agent, so take extra care.

Thickeners usually disperse most evenly in cold liquid. The notable exceptions to the rule are cellulose gums such as methylcellulose, which may disperse best in hot water.

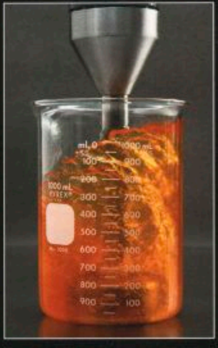
Whenever you need to use more than one thickener, mix all of the agents dry before you disperse them together into the liquid; dispersing each one separately can lead to less than even distribution. If you are going to mix in a liquid fat or oil, then you can first disperse the agents into it and then disperse the mixture into the water-based liquid. This is what occurs in a traditional roux.

Many cooks simply whisk or stir thickeners into the liquid. That works fine for most starches, but many hydrocolloids are more finicky. A handheld immersion blender or commercial blender does a fine job. A **magnetic stirrer bar**, handheld whipping wand, or rotor-stator homogenizer all work well, too. When using power tools, take care not to blend for too long because they can overmix, which may undermine the performance of the thickener.

1 **Bring the liquid to the correct temperature.** Most—but not all—thickeners disperse best in cold liquids.

2 **Sprinkle the powder evenly over the surface of the liquid (2a).** If using more than one powder, mix them dry before sprinkling. If using a blender, you can add the powder while it runs (2b).

3 **Blend for at least one full minute to distribute evenly.** Don't blend for more than a few minutes, as this may overmix the thickener. If you are using a blending tool, like a Thermomix, that can heat as well as blend the fluid, you can proceed directly to the hydration step (see page 26) without pouring the liquid into another container.



Handheld immersion blender

Commercial blender

Rotor-stator homogenizer

Magnetic stirrer bar

Thermomix

VARIATION: Dispersing with a Magnetic Stirrer

A **magnetic stirrer bar** can create a less violent vortex than a blender, which makes it well suited for dispersing thickeners. Allow a vortex to form before you sprinkle in the powder, and then continue mixing for 2 min. Mixing for 1 min in a conventional blender is usually sufficient.

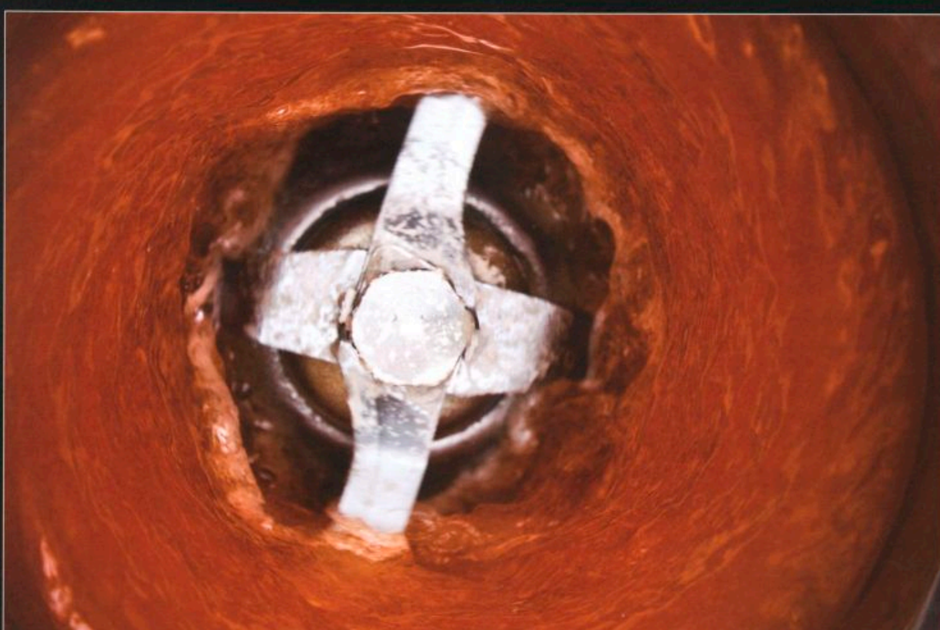
The dispersion techniques shown here apply to direct dispersion into water. Dispersion into oil, as with a roux, is also possible and can be done as a first stage, before dispersing the oil-thickener mixture into the water-based fluid.

Most laboratory magnetic stirrers also include a hot plate that can be used for hydration (see next page).

VARIATION: Dispersing with a Thermomix

Thermomix-brand blenders have built-in heaters that make them convenient for working with thickening and gelling agents because they can disperse and hydrate in the same container (see next page).

The power setting 3 on the Thermomix creates a vortex fast enough to disperse the powder fully in 1 min.



HOW TO Hydrate a Thickener

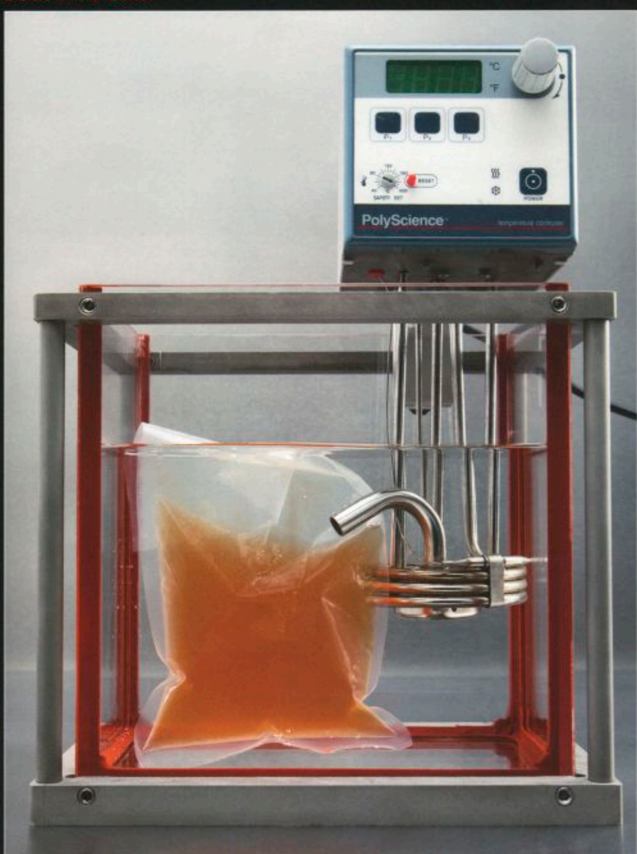
The goal when hydrating a starch or hydrocolloid is to surround the dispersed particles of the thickener with water so that they swell to full size. Some hydrocolloids, including many gums, hydrate and begin to thicken almost immediately when they are dispersed in a liquid. Some thickeners, including natural starches, must be heated or allowed to sit in the liquid for some time to hydrate fully. See the Hydrocolloid Properties and Uses table on page 42 for specifics on ingredients.

The simplest and most common approach is to warm the dispersed solution on the stove to the hydration temperature. For best results, use a thermometer to reach the correct temperature, and then hold the solution at that temperature for 2–3 min. Too much time or too high a temperature can be problematic, as can too little heat or hurrying the hydration step.

We prefer to hydrate sous vide in a water bath for several reasons. Vacuum sealing the solution eliminates the risk that evaporation may alter the concentration of the thickener and thus the texture and viscosity of the result. A water bath also offers precise control over the hydration temperature, which is very difficult to achieve on a stove top.

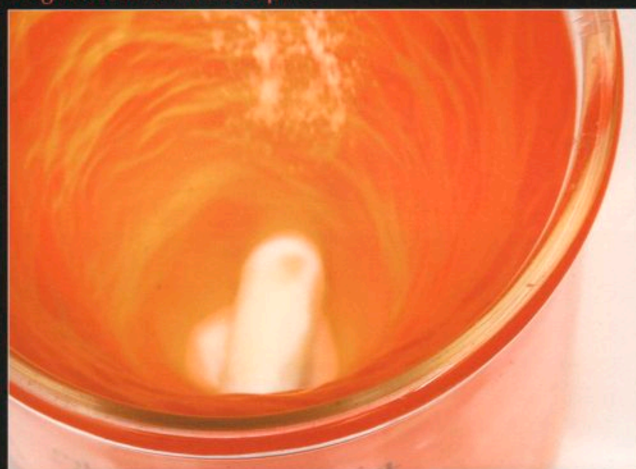
Some cooks like the convenience of a Thermomix blender, which allows you to heat the mixture in the same container you blended it in. A heated magnetic stirrer plate can also be a precise hydration tool.

Sous vide bath



Stove top

Magnetic stirrer with hot plate

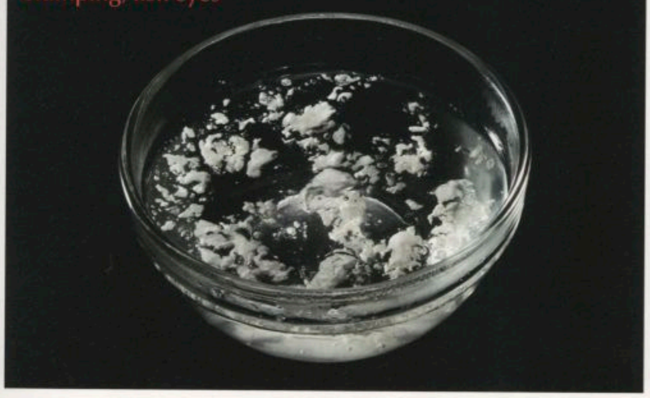


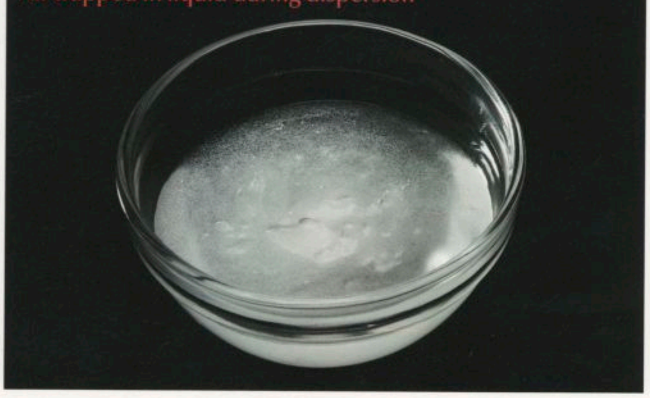
Thermomix

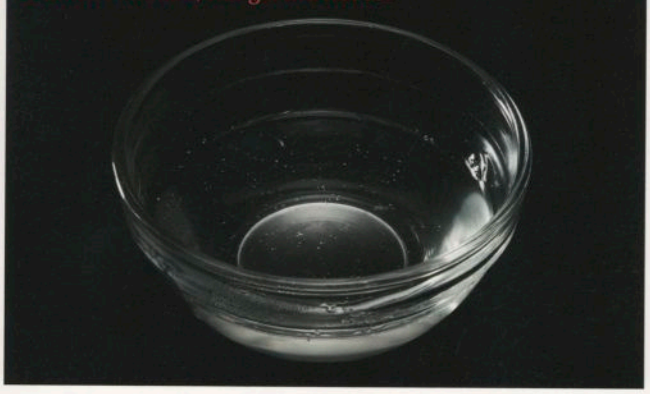
Common Problems when Thickening and Gelling

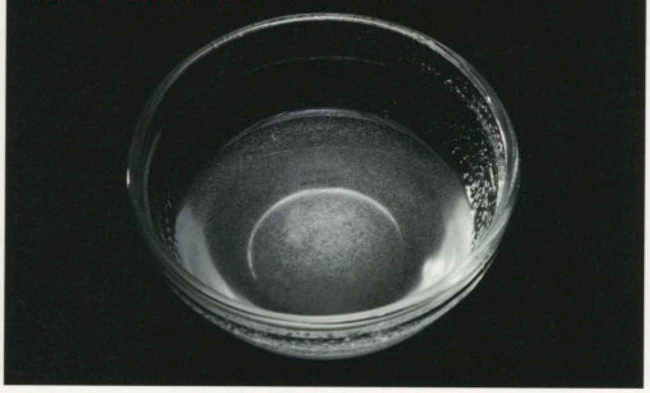
Problem	Possible cause	Solution
"Fish eyes" or clear lumps appeared during dispersion.	The thickening or gelling agent dispersed unevenly.	Use a dry bulking agent, or disperse in oil or another nonaqueous liquid.
	Steam caused the agent to aggregate.	Avoid steam or boiling of the liquid, or add starches or hydrocolloids in a continuous flow.
Granules failed to dissolve during hydration.	The pH was outside the operating range of the thickening or gelling agent.	Hydrate first at a pH within the agent's tolerances, and then adjust the acidity of the hydrated solution.
	The solution was overprocessed, which hindered hydration.	Avoid shearing at very high speeds for more than 1 min.
	The salt concentration was outside the operating range of the agent.	Hydrate first at a salinity within the agent's tolerances, and then adjust the salinity of the hydrated solution.
	The alcohol concentration was too high.	Use an alcohol-tolerant hydrocolloid.
Thickening or gelling did not occur.	The salt concentration was outside the operating range of the thickening or gelling agent.	Adjust the salinity of the hydrated solution.
	The temperature was outside the operating range of the agent.	Adjust the temperature, or choose a different starch or hydrocolloid.
	Agitation of the gel while setting disturbed the cross-linking process.	Allow the gel to rest undisturbed until it sets.
	Hydration was not completed properly.	Verify that the hydration procedure was followed correctly.

For more on how to treat and buffer your water source, see the Sequestrants table on page 129 and the Hydrocolloid Interactions table on page 44.


Clumping/fish eyes


Air trapped in liquid during dispersion


Granules swelled, but gel did not set


Granules did not swell

PARAMETRIC RECIPE

TRADITIONAL STARCH THICKENERS

Classic starches are perfectly good thickeners. They are easy to use, inexpensive, and have pleasant, predictable results. Traditional starches maintain good sauce yields and improve the body and texture of many recipes.

Cooks sometimes overuse starches, however, deploying them to cut corners or "bulk up" foods without substance. If you've had cherry pie that is all gooey red juice without much fruit, or lo mein glazed in murky, garlic-scented glue, you've experienced starch abuse firsthand. The Nouvelle cuisine movement eliminated stodgy, starch-heavy sauces from the kitchen altogether. The thickening of sauces was instead exclusively achieved by using reduction and fat (see page 1·24).

We find starches useful in many dishes. Tapioca and arrowroot thicken gently and do not interfere with the flavor of the food. Cornstarch and wheat flour have a more pronounced taste, but that can be welcome in many recipes, such as corn pudding and gumbo.

THICKENING WITH A TRADITIONAL STARCH

1 **Disperse by mixing the starch with whatever liquid you want to thicken until a slurry forms.**

2 **Heat to at least 80 °C / 176 °F to hydrate.** Use a water bath if available; if heating on a stove top, stir the mixture constantly. The starch solution will change from milky to clear when it is fully hydrated.

Best Bets for Thickening with Natural Starch

Starch	Texture	Translucency	Flavor	Application	(scaling)*	Heat-sensitive	Stable when thawed
arrowroot	creamy	clear	neutral	broths	1%	no	unstable
				jus, gravies	2%		
corn	creamy	opaque	strong	broths	1.50%	yes	unstable
				velouté, cream sauce	2.0%–2.5%		
				gravies	3%–4%		
				puddings	5.0%–6.5%		
				set gels	9%		
kudzu	gelatinous	clear	neutral	broths	2%	no	unstable
				glazes	5%–7%		
				dense puddings, tofu	12%		
potato	sticky	clear	subtle	broths	1%	yes	unstable
				jus, gravies	2%		
				stir-fry sauces	2.5%		
rice	sticky	opaque	subtle	glazes	3.0%–3.5%	yes	unstable
				soups	4%–5%		
				puddings, purees	7%–8%		
tapioca	sticky	clear	neutral	broths	1.5%–2.0%	somewhat	stable
				jus, gravies	2.5%–3.0%		
				fruit fillings	4%–5%		
waxy corn	creamy	opaque	subtle	broths	1%	no	stable
				low-fat salad dressings	2.50%		
				gravies	4%		
wheat	creamy	opaque	strong	velouté, cream sauce	2.5%	yes	stable
				gravies	3.0%–3.5%		
				béchamel	4%–5%		

**(set weight of liquid to be thickened to 100%)*

EXAMPLE RECIPE

PREGELATINIZED STARCH PASTE

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	50 g	12.5%	① Whisk starch into water until fully dispersed.
Tapioca starch	50 g	12.5%	② Vacuum seal mixture.
			③ Cook sous vide in **80** °C / **176** °F bath for 2 h.
Water, hot	400 g	100%	④ Blend in hot water until fully incorporated while the paste is still warm.
			⑤ Strain, cool, and store vacuum-sealed at room temperature.

(2010)

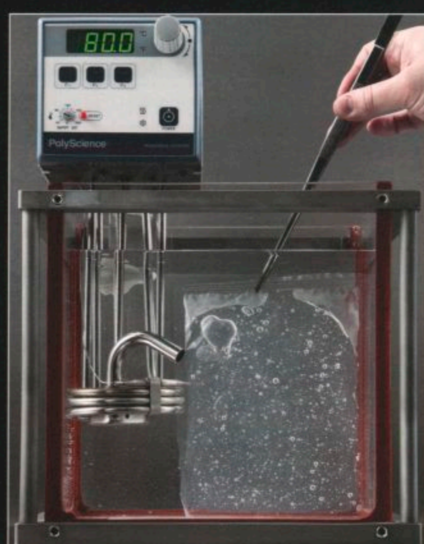
1a

1b

The thickening product Micri, invented by Spanish chef and neurologist Dr. Miguel Sanchez Romera, is a tapioca starch gel. Since Micri is no longer available commercially, one can adapt recipes calling for it by using this pregelatinized starch paste.

Blend the paste in cold liquids until the desired thickness is achieved. The liquid can then be heated as required.

3a



3b

4

PARAMETRIC RECIPE

MODERN STARCH THICKENERS

Prehydrated starches are available with the same range of properties as traditional raw starches, and they can serve the same purposes. But the modern varieties are much more convenient to use. National Starch, Grain Processing Corporation (GPC), and other manufacturers take care of all the fussy steps: precise measuring, hydrating, heating, and gelling the starch molecules. Some of their products also combine thickeners in handy proportions to yield one thickening agent that can do the job of several.

The end results are instant, "pour-and-stir" thickeners such as Wondra, a prehydrated flour from General Mills. Anyone who has experienced the misery of eating lumpy Thanksgiving Day gravy can appreciate the one-step simplicity offered by modern starches.

Modified starches are most often used in industry and manufacturing, but increasingly they are also finding a niche market in the modern kitchen. We recommend experimenting with them to explore the boundless range of textures you can create with these ingredients, from velvety smooth syrups to fluffy, oily powders.

A pressure cooker browns roux evenly in a way that is easy to repeat.

THICKENING WITH A MODERN STARCH

1. **Select a thickening agent from the table below.** Note that starches marked as unstable below may break down upon heating or upon thawing from a frozen state.

2. **Whisk the starch into the liquid to be thickened by hand.** Do not use a blender, which can make the mixture gluey or stringy.

3. **Heat to hydrate if necessary.** Bring Pure Cote B790 and Wondra to a simmer to hydrate fully; heat Novation PRIMA 600 to **75** °C / **167** °F.

Best Bets for Thickening with Modified Starch

Product	Brand	Source	Scaling range*	Translucency	Texture	Stable when Heated	Stable when Thawed	Example use	(scaling)*	See page
N-Zorbit M	National Starch	tapioca	20%–100%	nearly opaque	swelled granules	unstable	unstable	oil powders	30%–40%	35
								oil pastes	85%–100%	34
								bulking gels, sauces	5%–20%	96
Ultra-Sperse 3	National Starch	tapioca	0.2%–8%	nearly to fully opaque	smooth	stable	stable	meat gravies, jus	3%–4%	33, 5·122
								puddings	6%–8%	
Flojel 60	National Starch	corn	1%–10%	opaque	smooth, stringy	stable	unstable	cream sauce	4%	
								puddings	7%	
Novation Prima 600	National Starch	corn	1%–7%	opaque	smooth	stable	stable	broths	2.0%–2.5%	
								purees	4%	
Ultra-Tex 8	National Starch	tapioca	1%–10%	nearly opaque	creamy	stable	unstable	cream sauce	3.0%–3.5%	
								meat gravies, jus	4%	
								purees	6%	
								puddings	8%	
Pure-Cote B790	GPC	corn	0.5%–20%	clear	smooth	stable	unstable	films	12%	60
								thickened juices	15%	
Maltrin	GPC	corn	1%–30%	clear	smooth	stable	stable	thin sauces	10%	
								purees	20%	
Wondra	General Mills	barley malt, wheat	1%–15%	opaque	smooth	stable	unstable	gravies, velouté	6%–7%	
								béchamel	8%–9%	

*(*set weight of liquid to be thickened to 100%*)

EXAMPLE RECIPE

MODERNIST BÉCHAMEL

Yields 215 g

INSPIRED BY AKI KAMOZAWA AND H. ALEXANDER TALBOT

INGREDIENT	QUANTITY	SCALING	PROCEDURE
All-purpose bleached flour	250 g	125%	① Combine, and divide mixture among three 500 ml / 1 pt mason jars.
Unsalted butter, melted	250 g	125%	② Seal jars, and place them upright in pressure cooker. ③ Fill pressure cooker with water to middle of jars. ④ Pressure-cook fat at gauge pressure of 1 bar / 15 psi for 2 h. ⑤ Cool resulting roux at room temperature; measure 15 g for recipe, and refrigerate remainder for later use.
Whole milk, warmed to 45 °C / 113 °F	200 g	100%	⑥ Whisk together with reserved roux until smooth to form béchamel. ⑦ Warm béchamel to desired temperature.
Pressure-cooked roux, from above	15 g	7.5%	
Ultra-Sperse 3 (National Starch brand)	7 g	3.5%	
Lambda carrageenan (Texturas brand)	0.2 g	0.1%	
Nutmeg, freshly grated	to taste		⑧ Season.
Salt	to taste		

(original 2010, adapted 2010)

The béchamel can also be made by using 1.25% (2.5 g) lambda carrageenan rather than the amount indicated above and substituting 1% (2 g) pregelatinized starch paste for the Ultra-Sperse 3. For more details, see page 29.

If pressure-cooked in a canning jar, the roux can be stored without refrigeration. It has effectively been canned (see page 2·88). Once opened, it must be refrigerated.

EXAMPLE RECIPE

JERUSALEM ARTICHOKE PUDDING

Yields 160 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Jerusalem artichokes, thinly sliced	200 g	200%	① Combine in nonstick pan. ② Cook artichoke slices over medium heat until golden brown and very tender, about 20 min.
Neutral oil	20 g	20%	
Whole milk	400 g	400%	③ Puree milk with cooked artichokes until smooth. ④ Pass puree through fine sieve; reserve 100 g of artichoke puree for recipe.
Jerusalem artichoke puree, from above	100 g	100%	⑤ Blend with reserved puree to form pudding. ⑥ Divide pudding equally among four small bowls. ⑦ Cover and refrigerate bowls of pudding.
Ultra-Sperse 3 (National Starch brand)	3 g	3%	
Xanthan gum	0.2 g	0.2%	
Lambda carrageenan (Texturas brand)	0.1 g	0.1%	
Jerusalem artichokes, thinly sliced	25 g	25%	⑧ Heat oil to 190 °C / 375 °F. ⑨ Add artichokes, and fry until golden brown, approximately 2 min. ⑩ Transfer artichokes to tray lined with paper towels, and cool.
Grapeseed oil	as needed		
Roasted-hazelnut oil	8 g	8%	⑪ Drizzle oil evenly over each bowl of pudding.
Roasted hazelnuts, quartered	10 g	10%	⑫ Garnish puddings.
Pickled Jerusalem artichoke, fine julienne see page 3·348	6 g	6%	
Parmigiano-Reggiano, grated	5 g	5%	
Flaky salt	to taste		⑬ Season puddings. ⑭ Top with fried artichokes.

(2010)

STEAMED COD WITH COD ROE VELOUTÉ

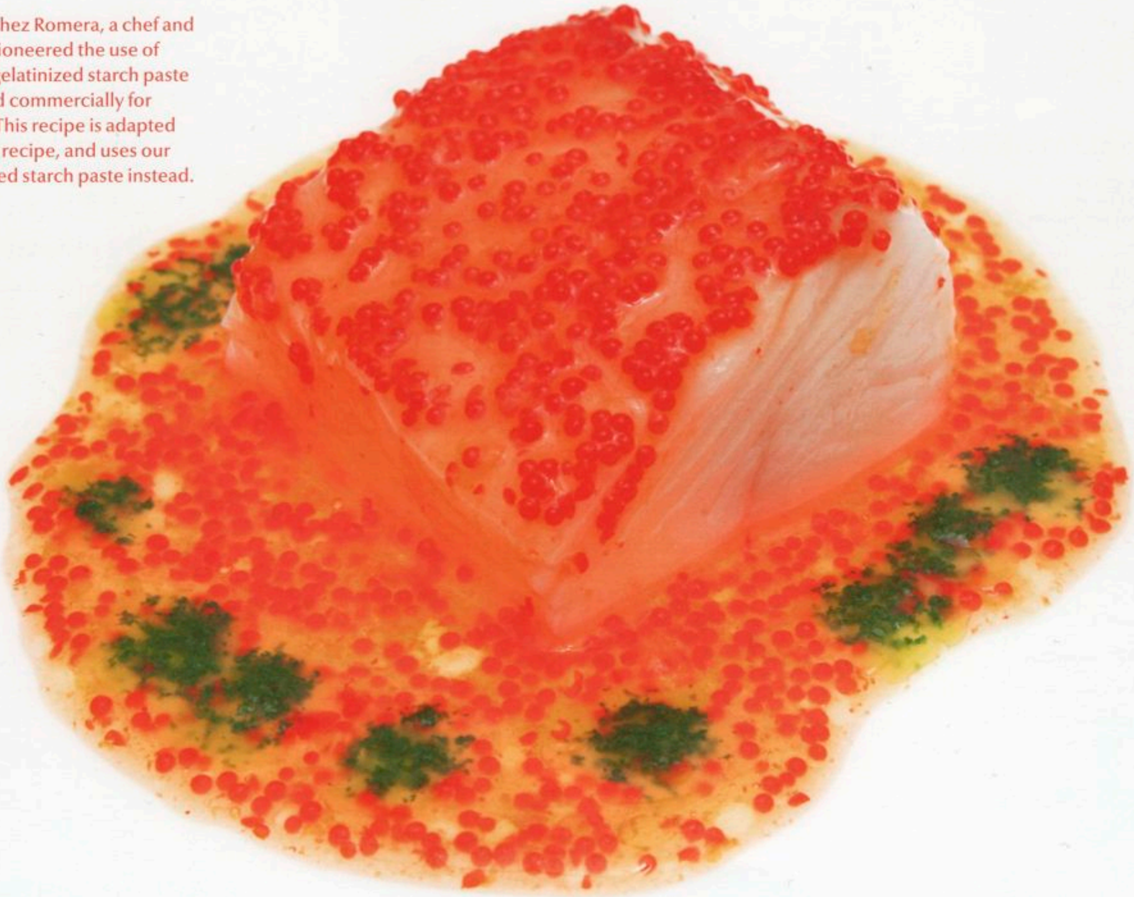
ADAPTED FROM MIGUEL SANCHEZ ROMERA

Yields four portions

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White fish stock see page 2·296	50 g	100%	① Blend together.
Pregelatinized starch paste see page 29	20 g	50%	
Water	25 g	50%	② Combine warm, and stir until dissolved to make syrup.
Sugar	10 g	20%	③ Cool completely.
Lemon juice	10 g	20%	④ Add juice and zest to syrup.
Lemon zest	2.5 g	5%	⑤ Blend syrup with fish stock mixture to make velouté.
Cod fillet	300 g	600%	⑥ Cut loin into four portions of 75 g each.
			⑦ Vacuum seal portions individually.
			⑧ Cook sous vide in 43 °C / 109 °F bath to core temperature of 42 °C / 108 °F, about 25 min.
Salted cod roe (or tobiko)	30 g	60%	⑨ Warm velouté.
			⑩ Whisk in rœ.
Salt	to taste		⑪ Season roe velouté.
Garlic oil see page 2·328	50 g	100%	⑫ Place one cooked loin portion in center of each of four bowls.
			⑬ Spoon roe velouté over loins.
			⑭ Drizzle oil on top.

(published 2006, adapted 2010)

Miguel Sánchez Romera, a chef and physician, pioneered the use of micri, a pregelatinized starch paste that was sold commercially for some time. This recipe is adapted from a micri recipe, and uses our pregelatinized starch paste instead.



EXAMPLE RECIPE

TURKEY WING

Yields 450 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Turkey wings, ends cut off	300 g	100%	① Mix salt and sugar and rub evenly onto wings.
Salt	9 g	3%	② Vacuum seal.
Sugar	3 g	1%	③ Refrigerate to cure for 24 h.
			④ Remove cured wings from bags; rinse off cure.
Clarified butter	15 g	5%	⑤ Vacuum seal wings with butter.
			⑥ Cook sous vide in 58 °C / 136 °F bath for 12 h.
			⑦ Remove wings from bag while still hot; carefully debone without rupturing meat.
			⑧ Refrigerate.
Potato starch	25 g	8.3%	⑨ Coat wings with starch.
Frying oil	as needed		⑩ Pour thin film of oil in nonstick pan.
Sage, leaves	as needed		⑪ Fry coated wings for 2 min on each side.
			⑫ Transfer to serving plates, and garnish with gravy and whole sage leaves.

(2010)

In November 2003, Jones Soda Company in Seattle introduced a Turkey & Gravy seasonal flavor in honor of Thanksgiving. Demand was so overwhelming that Jones sold out within two hours.

EXAMPLE RECIPE

THANKSGIVING TURKEY GRAVY

Yields 245 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Brown chicken or turkey stock see page 2·296	600 g	300%	① Reduce to 200 g, and reserve.
Reduced chicken or turkey stock, from above	200 g	100%	② Blend reduced stock and garlic confit together to make gravy.
			③ Whisk in Ultra-Sperse 3.
Garlic confit, pureed see page 3·354	25 g	12.5%	④ Warm gravy to 70 °C / 160 °F
Ultra-Sperse 3	8 g	4%	
Dried cranberries, finely minced	10 g	5%	⑤ Whisk into warm gravy.
Sage, finely minced	2 g	1%	
Black peppercorns, coarsely ground	0.15 g	0.075%	
Salt	to taste		⑥ Season gravy.

(2010)

N-ZORBIT

Ever wonder how Betty Crocker gets the oil into those cake-in-a-box mixes? The answer is N-Zorbit, a remarkable modified starch. Food chemists took a natural starch and figured out how to make its surface fuzzy so that minuscule droplets of oil could stick to the fuzz. Whisk some oil into the powder, and it seems to vanish—heat the powder, and the oil reappears. The recipes below use N-Zorbit M to make oils from olives, Parmesan cheese, and bacon into tasty solids—and even to create a delicious food that looks amazingly like soil.

EXAMPLE RECIPE

MALT VINEGAR POWDER

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Spray-dried malt vinegar	200 g	100%	① Grind together, and sift through fine sieve.
Acetic acid	40 g	20%	② Season with salt to taste.
Salt	36 g	18%	③ Store in an airtight container in dark, cool place.
Sugar	12 g	6%	
N-Zorbit M (National Starch brand)	8 g	4%	

(2010)

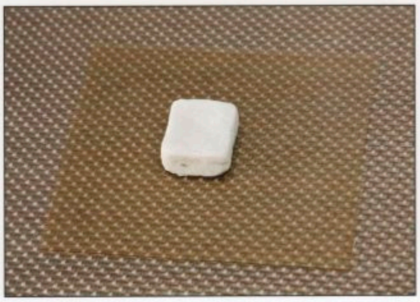
EXAMPLE RECIPE

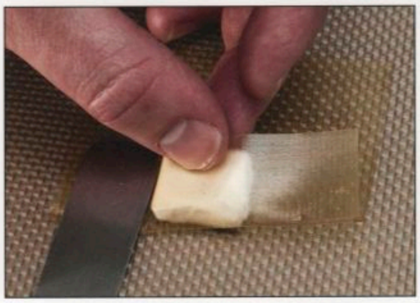
BACON POWDER SQUARES ADAPTED FROM GRANT ACHATZ

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Smoked bacon fat, rendered see page 3·145	100 g	100%	① Warm bacon fat just enough to liquefy it.
N-Zorbit M (National Starch brand)	80 g	80%	② Whisk bacon fat into N-Zorbit M a little at a time until fully incorporated with powder.
Salt	to taste		③ Season powder.
Black pepper, fine powder	to taste		④ Form powder into squares 13 mm / ½ in wide, and set aside.
Pineapple glass see page 3·370	70 g	70%	⑤ Cut glass into squares 5 cm / 2 in wide.
			⑥ Place one single bacon powder square in center of each glass square.
			⑦ Fold glass squares over bacon powder squares to form small packets.
			⑧ Serve immediately, or store packets in cool, dry environment.

(original 2005)





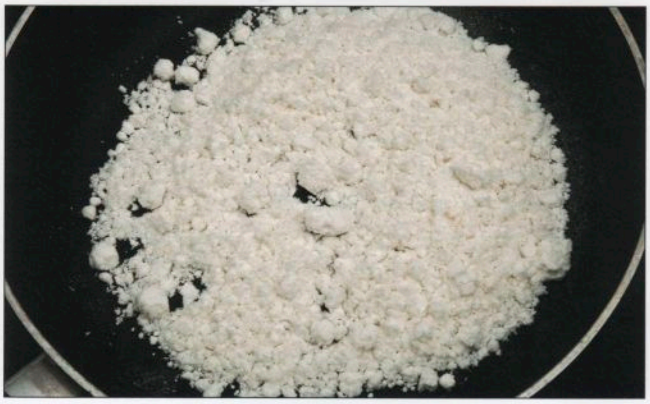
EXAMPLE RECIPE

PARMESAN NUGGETS INSPIRED BY FERRAN ADRIÀ

Yields 35 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Parmesan, grated	100 g	100%	① Microwave until oil separates from solids. ② Strain; reserve 10 g of oil for recipe.
N-Zorbit M (National Starch brand)	25 g	25%	③ Whisk oil into N-Zorbit M a little at a time, until fully incorporated. Resulting powder may be used as seasoning. ④ Spoon thin layer of resulting powder into nonstick pan. ⑤ Sauté powder over low heat; swirl constantly until small spheres form and begin to dry. ⑥ Serve at room temperature, or refrigerate.

(original 2006, adapted 2010)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EXAMPLE RECIPE

VANILLA OLIVE OIL POWDER ADAPTED FROM GRANT ACHATZ

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Confectioner's sugar	80 g	80%	① Dry blend.
N-Zorbit M (National Starch brand)	160 g	160%	
Vanilla pulp and seeds	14 g (from four beans)	14%	
Salt	4 g	4%	
Olive oil	100 g	100%	② Whisk into powder until fully incorporated. ③ Press through fine tamis to remove clumps. ④ Store in airtight container in cool, dry place.

(original 2005, adapted 2008)


2a


2b


2c

EXAMPLE RECIPE

ALMOND POLENTA ADAPTED FROM WYLIE DUFRESNE

Yields 575 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Marcona almonds, toasted and finely grated	250 g	100%	① Whisk together. ② Set dry mixture aside.
N-Zorbit M (National Starch brand)	30 g	12% *(5%)**	
Ultra-Sperse M (National Starch brand)	5 g	2% *(0.9%)**	
Xanthan gum	0.4 g	0.16%	
White chicken stock see page 2·301	250 g	100%	③ Pour stock into pot. ④ Whisk in dry mixture from above. ⑤ Cook over medium heat; stir until just thickened, about 3 min.
Sweet almond oil	40 g	16%	⑥ Whisk in.
Salt	to taste		⑦ Season.

(original 2008, adapted 2010)

(% of total weight of all ingredients*)

EXAMPLE RECIPE

CORN PEBBLES ADAPTED FROM WYLIE DUFRESNE

Yields 95 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Corn, freeze-dried and ground into powder see page 3·372 (or store-bought)	30 g	100%	① Dry blend.
N-Zorbit M (National Starch brand)	15 g	50%	
Spray-dried buttermilk see page 2·443 (or store-bought)	15 g	50%	
Smoked-grapeseed oil (store-bought)	6 g	20%	② Combine oils. ③ Whisk into powder mixture until fully incorporated.
Grapeseed oil	30 g	100%	
Salt	to taste		④ Season resulting corn pebble base. ⑤ Form into 1 cm / ⅜ in diameter balls; wearing latex gloves will help. ⑥ Bake in 135 °C / 275 °F oven until balls become lightly golden and begin to firm, about 6 min. ⑦ Serve immediately, or store in airtight container in cool, dry place.

(original 2006)


5a


5b


5c

EXAMPLE RECIPE

EDIBLE EARTH INSPIRED BY RENÉ REDZEPI AND WYLIE DUFRESNE

Yields 475 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Almond flour, toasted	200 g	100%	① Blend in food processor until resembles soil.
Black bread, thinly sliced and dehydrated at 135 °C / 275 °F	150 g	75%	
N-Zorbit M (National Starch brand)	20 g	10%	
Barley malt powder	18.5 g	9.25%	
Dried chicory root, coarsely ground	17 g	8.5%	
Dried porcini powder	15 g	7.5%	
Freeze-dried shiitake powder see page 3·372	14 g	7%	
Grapeseed oil	31 g	15.5%	② Drizzle into dry mixture while continuing to blend with food processor until oil is fully incorporated.
Toasted-pumpkin seed oil	9 g	4.5%	
Caramel color powder	as needed		③ Adjust color if necessary.
Salt	to taste		④ Season.
			⑤ Transfer to airtight container and store in cool, dry place.

(2009)

This is our homage to the edible landscapes of Michel Bras (Le Gargouillou de Jeunes Légumes), David Kinch (Into the Vegetable Garden), and the many modern chefs who have simulated the aesthetics of nature in their dishes, including Quique Dacosta, Ferran and Albert Adrià, Andoni Luis Aduriz, Yoshiaki Takazawa, and Sam Mason, among others.

1

2

3

HYDROCOLLOIDS

The word "hydrocolloid" may sound scary to some people, but these products are no more or less natural than gelatin, tapioca, cornstarch, flour, or other more common ingredients. Indeed, all of those are hydrocolloids.

For more on the health and safety aspects of hydrocolloids, see page 1·250.

Like starches, hydrocolloids need to be dispersed and hydrated before use. Technically speaking, a hydrocolloid does not undergo gelatinization in the same way that a starch does, but from a chef's point of view, the process is much the same. You must first disperse it without lumps, and then hydrate the hydrocolloid. Complete hydration for many hydrocolloids requires heating to a certain temperature. A few, like the miracle thickener xanthan gum, don't require heat for hydration. As with starches, our main enemies are lumps and fish eyes.

The most common technique is to disperse the hydrocolloid in cold water, and then to increase the heat slowly to promote hydration; hydrocolloids dissolve poorly in cold water. It may seem counterintuitive, but dispersion is easiest if the rate of dissolving is slow because it gives us the chance to break up lumps before they form.

A hand blender is often the most convenient way to disperse a hydrocolloid, but anything that vigorously mixes or shears the fluid will work. Some hydrocolloids can be dispersed easily, but others need substantial mixing at high shearing rates to do the job. Hydrocolloids can also be dispersed in oil or fat, like flour in a roux. Unlike flour, hydrocolloids do not need to be cooked to remove a raw taste. Once mixed with water, they may need to be heated in order to hydrate.

Gelatin is a protein and thus chemically different from other hydrocolloids, but you use it in much the same way. First hydrate the gelatin sheets or powder in cold water, a process known as blooming, and then add the gelatin to a hot liquid or otherwise heat it to a specific temperature.

Modern hydrocolloids like xanthan gum can thicken liquids at extremely low concentrations. As little as 0.1% by weight can yield a thick liquid, and 0.5% can make a thick paste. Traditional thickeners like flour typically require far larger amounts to do a similar job. The quantity matters because the more thickener you have as a fraction of the total mixture, the more likely it is to impose an undesirable texture or to inhibit flavor release.

Before you use a hydrocolloid to thicken a mixture, you first have to measure out the material, which will typically be in very small amounts. You'll need a scale accurate to a tenth or a hundredth of a gram. Inexpensive digital scales of this type are widely available; there's just no excuse not to use an accurate scale.

There are two common ways to measure on a scale of this nature. For larger volumes, use the tare method (press a button to reset the scale to zero). Start by putting the bowl on the scale and tare to zero. Then add the appropriate measure of liquid and again tare to zero. Finally, weigh out the needed amount of thickener. Some very precise scales have capacities of up to 1 kg / 2 lb or more, with a resolution of 0.01 g / 0.0004 oz or less, so they can be quite versatile when used in tare mode.

For scales of a smaller capacity, you'll likely need to weigh the hydrocolloid alone. In laboratories, the common method is to use a small, disposable plastic container called a weighing boat or a small slip of wax paper called a weighing slip. You put the boat or slip on the scale, tare it, and measure out the powder. You then add the measured material to another container holding the liquid.

You must disperse the hydrocolloid evenly to avoid any lumps or clumps. Several techniques are typically used for this task: simple dispersion in water, dispersion in oil, and premixing with a bulking powder.

In the first approach, the hydrocolloid—typically in the form of a fine white powder—is stirred vigorously in cold water with a magnetic stirrer bar, a blender, a hand blender, or a rotor-stator homogenizer. While blending, you gently raise the temperature of the liquid to hydrate the hydrocolloid.

Hydrocolloids have joined spices as part of the repertoire of a Modernist chef.


GLYCERIN
FENUGREEK
JUNIPER
CALCIUM LACTATE
NUTMEG
SZECHUAN
LAVENDER
METHOCEL A15C
CORIANDER
WHEY PROTEIN
TURMERIC
FREEZE DRIED TOMATO
HEATHER
STAR ANISE
AGAR
GUM ARABIC
FENNEL
HIBISCUS
CHILI
CHAMOMILE
PINK PEPPER
CARDAMOM
CINNAMON
CARRAGEENAN
NIGELLA

Many hydrocolloid suppliers have been around for decades (and sometimes longer). Interesting stories lie behind the names of some of them.

The Kelp Company formed in San Diego in 1929 to extract alginate and other hydrocolloids from seaweed. In 1934, Copenhagen Pectin was formed in Denmark as part of a jam-making business. The two companies merged in the year 2000 to form CP Kelco.

The Tragancanth Importing Company was formed in 1909 to import gum tragancanth and other plant gums. It now operates as TIC Gums.

In 1895, a 25-year-old named Alexander Alexander took over National Gum and Mica Company in New York City, primarily to make starch wallpaper paste. Today, the company is called National Starch.

How Hydration Works

During hydration, particles in the powdered hydrocolloid break down and allow water to soak in to swell and dissolve them, thus forming a uniform solution. For the hydrocolloid to thicken or gel, these molecules need to be both separated and wet. If you do this properly, the hydrocolloid will mix evenly with the water so that each hydrocolloid molecule is surrounded by water molecules, forming a colloidal suspension.

Each type of hydrocolloid becomes fully hydrated at a characteristic temperature. Some compounds, like xanthan gum, guar gum, gum arabic, and some carrageenans, can be hydrated without adding heat; others must be brought to 85 °C / 185 °F or higher. A few hydrocolloids have a hydration temperature that depends on the **ion** content of the liquid with which they are hydrated. These are important for gels and are covered in chapter 14, page 129.

In some instances, you might use the second technique and start by dispersing the hydrocolloid in oil, rather than water. This is essentially an uncooked version of a roux in which the oil coats the particles and helps to keep them from sticking to each other in lumps. Xanthan gum, for example, is often dispersed in oil and then emulsified to make bottled salad dressing, such as a shelf-stable vinaigrette. As a rule of thumb, good dispersion occurs when you mix oil with xanthan at a ratio of at least 3:1. Since generally much less xanthan is used than oil, it's easy to achieve these ratios.

The third method is to mix the hydrocolloid with a dry powdered material, or bulking solid, before dispersing it. The two should be processed in a blender or food processor to be sure the hydrocolloid is very well incorporated with the solid, which can then be added to a liquid for hydration. Some examples of bulking solids are maltodextrin, other sugars, and starches. For example, we often blend the gelling agent pectin with sugar before dispersing and hydrating it in a liquid solution. In this case, the ratio of sugar to pectin should be at least 5:1.

When choosing a technique to use for dispersion and hydration, consider your recipe. Direct dispersion and hydration in water certainly works and is probably the most common technique. With a vinaigrette, you're going to have a lot of oil anyway, so it is convenient to add a hydrocolloid to the oil; a dessert may call for dispersion in sugar.

THE MYRIAD USES OF

Xanthan Gum

Xanthan gum is one of the best discoveries in food science since yeast. The gum is used as a thickener in a wide variety of foods that we find on grocery store shelves. Many canned or prepared products contain xanthan gum: salad dressings, sauces, soups, and baked goods—particularly those that are gluten-free because xanthan can perform some of the same functions that gluten does.

Xanthan gum is one of the most useful food additives around, effective at a wide range of viscosities, temperatures, and pH levels. First discovered by USDA scientists in the 1950s, it is formed by fermentation by plant-loving bacteria that are characterized by sticky cell walls. It is no less natural than vinegar or yeast. Given the huge demand, xanthan gum is produced in large volumes worldwide. It is used not only in foods but also in toothpaste and cosmetics. It even has many industrial uses: the oil industry uses it to thicken drilling mud, and in underwater construction, the concrete in docks and other structures is thickened with xanthan.

Almost every thickening task can be handled by xanthan, making it one of the most popular Modernist thickeners. It is easy to use, has no taste, and generally works quite well. The only downside is that it sometimes yields an undesirable texture when used to create very thick fluids. But even then it's possible to add something else to get the desired texture.

THE SOURCES OF

Proprietary Thickening Blends

Hydrocolloids and starches are produced from natural sources by a variety of processes, including fermenting, cooking, and purifying natural products to extract the thickening agent. Small changes in how a thickener is produced can cause big changes in the final product and its applicability. Companies like CP Kelco, TIC gums, and National Starch (among many others) have done a tremendous amount of research to create products with specific strengths tailored to particular applications. Each company has its own standards and has created proprietary blends using formulas that are trade secrets. These products work very well, but it is hard to substitute one for another because each functions somewhat differently. Of course, that is also why companies take this approach: they want their customers to rely on their branded product.

This is also true of seemingly generic products. Xanthan gum, as sold by a food ingredient company, comes in various grades, made to specifications that are not standardized across the industry. Any xanthan gum formulation is likely to work to some degree, but if you switch to a different supplier you may need to adjust the recipe to correct for differences between their product and others. It is also possible to buy xanthan gum at the grocery store, but it may not be of the same quality, and it may vary even more from brand to brand.

This is particularly important to keep in mind if you want a specific effect—like leaving a liquid crystal-clear—which requires a special grade made for that purpose.

In some of our recipes, we call for a general thickening agent, such as agar, while in others, we suggest a proprietary product, such as Kelcogel LT 100 gellan gum, Ultra-Tex 8, or N-Zorbit M. Different brands of such products can be substituted in many cases, but such a change may require slight adjustments in the amount used, the temperature, or the dispersal technique. It is important to be aware of the different brands and products on the market today and to what degree substituting one type of thickener for another may or may not work. For a table of hydrocolloid products, see page III near the end of this volume.

Hydrocolloid Properties and Uses

Hydrocolloid thickening and gelling agents are perhaps the most useful edible products of modern chemistry. Although derived from natural sources, they make it easy to transform liquids or purees in ways that are hard or even impossible to accomplish with traditional ingredients. Most hydrocolloids will stabilize an emulsion or foam and will thicken fluids, with mouthfeel effects that vary from one product and concentration to another. Many products will also form a gel when properly hydrated and held within a certain range of concentration, temperature, and pH.

Some products form brittle gels; others make elastic gels. Just how brittle or elastic depends on the amount of gelling agent used, but no single product can make both brittle and elastic gels. The cellulosic gums (MC, HPMC, and CMC).

Product	Used to	Origin	Clarity	Texture as gel	Mouthfeel as thickener	Scaling range*
agar	stabilize emulsion or foam, thicken, gel	various species of red algae	slightly cloudy	very brittle; elastic with LBG or sorbitol	clean	0.05%–0.50%
kappa carrageenan	stabilize emulsion or foam, thicken, gel		slightly opaque	brittle	clean, creamy	0.02%–2.00%
lambda carrageenan	stabilize emulsion or foam, thicken		clear	n/a		0.02%–2.00%
iota carrageenan	stabilize emulsion or foam, thicken, form weak gel		clear	elastic with calcium	creamy, clean to lingering	0.01%–3.00%
gelatin	thicken, gel, emulsify, form foam, form film	hydrolysis of collagen	very clear	elastic	clean to lingering and sticky	0.5%–8.0%
high-acyl gellan	stabilize emulsion or foam, thicken, gel	microbial fermentation	opaque	elastic	clean, creamy	0.05%–3.00%
low-acyl gellan			clear	brittle	very clean	0.05%–3.00%
guar gum	stabilize emulsion or foam, thicken, form film	endosperm of seed	slightly cloudy	n/a	lingering, slick	0.05%–1.00%
gum arabic	stabilize emulsion or foam, emulsify, form film	resin from Acacia tree	cloudy	n/a	lingering, sticky	5%–50%
gum tragacanth	stabilize emulsion or foam, emulsify, thicken	resin from Astragalus shrubs	clear	n/a	clean, creamy	0.4%–4.0%
HM pectin	stabilize emulsion or foam, gel, thicken	citrus peel and apple pomace	clear	elasticity depends on dissolved solids	clean to lingering	0.1%–1.0%
LM pectin	stabilize emulsion or foam, gel, thicken	citrus peel and apple pomace	clear	brittle to very brittle	clean to lingering	0.15%–3.00%
konjac gum	thicken, gel	tubers of konjac plants	clear	elastic with xanthan gum	lingering	0.2%–1.5%
locust bean gum (LBG)	stabilize emulsion or foam, thicken, form film	endosperm of locust bean	cloudy	elastic with xanthan gum	lingering, sticky	0.05%–0.25%
methylcellulose (MC)	stabilize emulsion or foam, gel, form foam, form film	wood, cotton, or other high-cellulose plant	clear	brittle to elastic	clean to lingering and sticky	0.1%–3.0%
hydroxypropyl methylcellulose (HPMC)			clear	brittle to elastic		0.1%–3.0%
carboxyl methylcellulose (CMC)			very clear	brittle to elastic		0.1%–2.0%
microcrystalline cellulose (MCC)	stabilize emulsion or foam, strengthen gel, thicken		opaque	n/a	clean, creamy	0.1%–2.0%
propylene glycol alginate	stabilize emulsion or thicken	multiple species of brown algae	clear	n/a	clean, creamy	0.5%–1.0%
sodium alginate	stabilize emulsion or foam, thicken, gel, form film	multiple species of brown algae	clear	M grade is elastic; G grade is brittle	lingering, sticky	0.5%–1.5%
xanthan gum	stabilize emulsion or foam, thicken	microbial fermentation	clear	elastic with konjac or locust bean gum	lingering and slick to sticky	0.05%–0.8%

* (*set weight of liquid to 100%*)

come closest; each of these is available in many varieties, some of which makes brittle gels, whereas others gel to an elastic texture.

As a general rule, hydrocolloids are best dispersed into cold water, and the thick fluids or gels they produce become thinner (less viscous) at higher temperatures. Konjac and the cellulosic gums are the exceptions: these agents should be dispersed into hot water (see page 171), and they thicken when heated.

Hydrocolloids can perform differently when used in combination than they do when employed by themselves. Some agents, such as xanthan gum, gel only when another agent is added (see page 166). The table on the next page summarizes such interactions.

Hydrates		Gels		Melts		Stable pH	Add Ca^{++}, Mg^{++}, K^{+}, Na^{+} to gel	Note
(°C)	(°F)	(°C)	(°F)	(°C)	(°F)			
95	203	35–45	95–113	85	185	2.5–10	no	tolerates salts, sugars, and alcohol; shows extreme hysteresis
>70	>158	30–60	86–140	40–75	104–167	4–10	K^{+} and Ca^{++}	prone to syneresis; brittle with potassium ions; becomes clear in the presence of sugars
cold		n/a				4–10	no	tolerates alcohol concentration of 12%–15%
>70	>158	40–70	104–158	50–80	122–176	4–10	Ca^{++}	resists syneresis; tolerates salts, which firm the gel and add elasticity
swells in cold water; dissolves at 60 °C / 140 °F		4–35	39–95	37	99	5–9	no	moderate alcohol tolerance; melts at body temperature, which aids in flavor release and mouthfeel
>85	>185	70–80	158–176	71–75	160–167	3–10	no	tolerates up to 50% alcohol; tolerates calcium
75–95	167–203	10–50	50–122	80–140	176–284	3–10	all	resists syneresis; add sugar after hydration
cold and hot; solubility increases with heat		n/a				4–10	no	tolerates salts; high stability and particle suspension; moderate alcohol tolerance
		n/a				3–9	no	viscosity decreases with pH; optimal at pH 4
		n/a				2–7	no	stable at high salt concentration; high shelf-stability
85	185	cool to 70–80 °C / 158–176 °F		70–85	158–185	2–7	no	gels at ph ≤ 3.4 and dissolved solid (usually sugar) concentration of 65% or more
40–85	104–185	40–85	104–185			2–7	Ca^{++}	viscosity increases with concentration of calcium and other cations
cold, high shear, best hydrated for >1 h		cool from 80 °C / 158 °F with xanthan gum		n/a		3–10	no	gels at ph > 9; moderately alcohol-tolerant; viscosity increases when heated or at concentration of 1% or higher; doesn't melt once gelled under alkaline conditions
>90	>194	n/a				4–10	all	rarely used alone; tolerates salt; inhibits ice crystals; moderate alcohol tolerance
cold		50–90	122–194	15–50	59–122	2–13	no	highly prone to syneresis; tolerant to alcohol levels up to 100%; precipitates reversibly at 50–75 °C / 122–167 °F
cold		25–90	77–194	35–50	95–122	3–10	no	highly tolerant to alcohol and salts; precipitates reversibly at 60–90 °C / 140–194 °F
any		n/a				5–9	no	resists syneresis; tolerates 50%–60% alcohol; use dispersant or high agitation; thixotropic
cold, high shear		n/a		n/a		4–10	no	viscosity decreases at alcohol levels above 20%; inhibits ice crystals
any		n/a				3–10	no	resists syneresis
any		any		n/a		4–10	all	moderate alcohol tolerance; forms stronger gel with high sugar concentration
any		n/a				1–13	no	tolerates salts; shearing decreases viscosity; tolerates 50%–60% alcohol; requires another hydrocolloid to gel

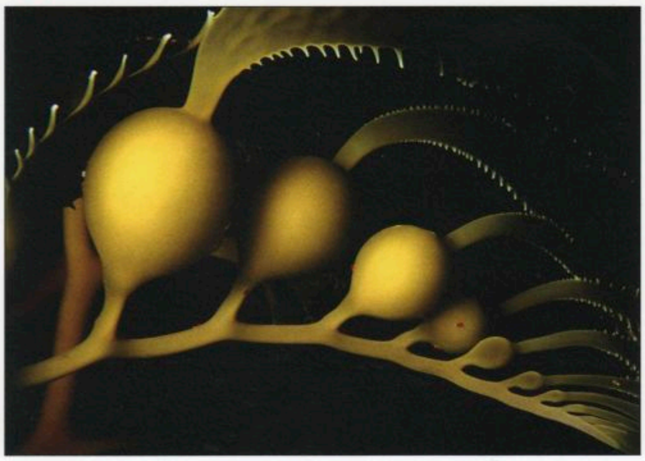
Hydrocolloid Interactions

The performance of some hydrocolloids changes when other thickening agents are present. Pair xanthan gum with another hydrocolloid, for example, and you can get a fluid of higher viscosity than either agent yields by itself. Agar similarly produces an extra strong gel when it interacts with certain other ingredients. These interactions are called synergies. The properties can also be affected by other conditions: high levels of salt, acid, or other ingredients.

Hydrocolloid	Higher viscosity when used with	Stronger gel when used with
agar		locust bean gum, guar gum, konjac gum, CMC, MC, HPMC
carboxymethyl cellulose (CMC)	locust bean gum, guar gum, konjac gum, gum tragacanth, agar, MC, PGA, xanthan gum	agar
iota carrageenan		starch
kappa carrageenan		locust bean gum, konjac gum
lambda carrageenan	xanthan gum	
gelatin		gum arabic (hard, compact), agar, pectin (short, brittle), transglutaminase
guar gum	locust bean gum, gum tragacanth, sodium alginate, PGA, xanthan gum, CMC, MC, HPMC	agar
gum arabic		low- and high-acyl gellans
gum tragacanth	konjac gum, guar gum, locust bean gum, sodium alginate, PGA, xanthan gum, CMC, MC, HPMC	
HM pectin		
konjac gum	CMC, locust bean gum	agar, kappa carrageenan, xanthan gum
LM pectin		sodium alginate
locust bean gum	guar gum, gum tragacanth, sodium alginate, PGA, CMC, MC, HPMC	agar, kappa carrageenan, xanthan gum
low-acyl gellan		gum arabic
methylcellulose (MC) and hydroxypropyl cellulose (HPMC)	locust bean gum, guar gum, konjac gum, gum tragacanth, PGA, xanthan gum, CMC	agar
microcrystalline cellulose (MCC)	xanthan gum	
propylene glycol alginate (PGA)		
sodium alginate	locust bean gum, guar gum, gum tragacanth	
xanthan gum	guar gum, gum tragacanth, carrageenan, CMC, MC, MCC, HPMC	locust bean gum, konjac gum

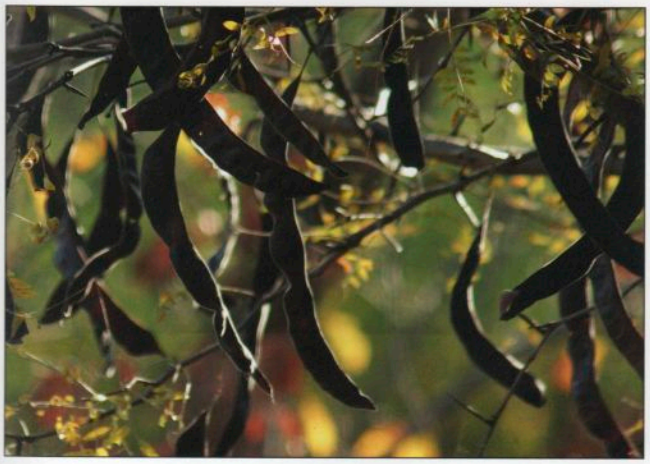
Gum arabic

Alginate



Lower viscosity when used with	Weaker gel when used with	Melts at lower temperature when used with
	sodium alginate, PGA, tannic acid at pH 5.5–5.8	
salt; must hydrate before exposure to high salt or pH		
		starch
		konjac gum, locust bean gum, dairy proteins
	protease enzymes such as papain (papaya) and bromelain (pineapple); modified starches decrease elasticity	salt
acid		
gum arabic	other water-binding solutes	
acidic solution		
high sugar, acid	high sugar concentrations	
	other water-binding solutes	
	sodium or calcium salts	
		salt (which also lowers gel-setting temperature)
salt, acid	agar	
	agar, high ionic concentrations	

Locust bean gum



Guar gum

PARAMETRIC RECIPE

THICKENED HOT AND COLD LIQUIDS

Thanks to modern thickeners, chefs can now change the viscosity of a liquid without altering its flavor. Thickeners these days transform fruit and vegetable juices into sauces without boiling away their freshness. Milks become creams and spreads. Sauces shine and cling without becoming gluey or rubbery. Thickeners open up a world of possibilities.

Once chefs become familiar with the properties of various thickeners, they use them as confidently as they do herbs and spices. These ingredients solve tricky problems, such as when the flavor of a sauce is just right, but the texture needs a slight adjustment. Modern thickeners can also prevent separation, or syneresis, of an unstable preparation like fresh tomato sauce.

There are literally millions of ways to thicken liquid. We chose our personal favorites for the tables of Best Bets below based on their very clean textures and imperceptible flavor impact. Unless specified otherwise, always whisk thickeners into cold liquids, and then warm the mixture. For names of the specific products we used in formulating these tables, see the example recipes that follow.

THICKENING HOT AND COLD LIQUIDS

1 **Choose the amount of thickening desired and a corresponding formula.** We recommend those listed in the tables that follow. Proportions are given relative to the weight of liquid used. For example, add 0.5 g of guar gum and 0.35 g of xanthan gum to every 100 g of carrot juice to make a thick, hot carrot sauce.

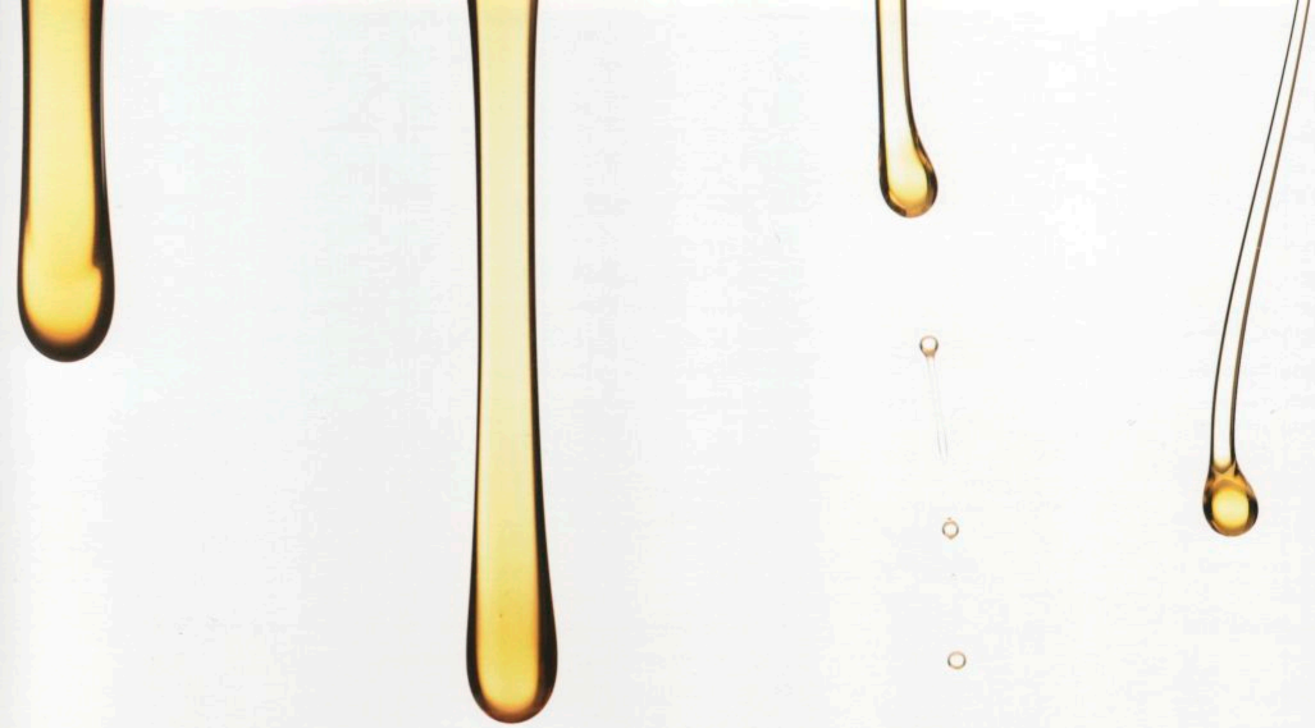
2 **Disperse the thickeners.** Thickening agents listed as cold-soluble can be stirred directly into cold liquids; those listed as hot-soluble can be stirred into hot liquids. Otherwise, stir the agent into a small amount of cold liquid to dissolve it, and then add it to the remaining liquid, and finally whisk to disperse it.

3 **Hydrate fully.** Heat as directed in the hydration column of the tables. Temperatures indicated are the minimum required for proper hydration.

Best Bets for Thickening Cold Liquids

Amount of thickening	Thickeners	(scaling)*	Hydrate (°C)	Hydrate (°F)	Hydrate (min)	Note	Example use
very little	guar gum	0.35%		hot or cold		opaque, not suited for clear liquids	flavored milk
	xanthan gum	0.15%		hot or cold			cold consommés
little	lambda carrageenan	0.15%		cold			broths, light soups
	xanthan gum	0.10%					
	xanthan gum	0.25%		hot or cold			broths, light soups
moderate	guar gum	0.25%		cold			cold cream sauces
	cellulose gum LV	0.50%					
	lambda carrageenan	0.25%		cold			light fruit and vegetable purees, soups
	xanthan gum	0.15%					
	xanthan gum	0.4%		hot or cold			light fruit and vegetable purees, soups
great	konjac gum	0.3%	82	180	3	shear for 5 min after dispersing to ensure that konjac hydrates fully	gazpachos and other cold soups
	locust bean gum	0.1%					
	cellulose gum LV	1.0%		cold		opaque, not suited for clear liquids	coating sauces
	lambda carrageenan	0.5%					
very great	gum tragacanth	0.5%		cold		best texture when fat concentration is above 12%	pastes, thick purees
	xanthan gum	0.2%					
	cellulose gum LV	2.25%	82	180	3	best texture when solids ratio is high	
	propylene glycol alginate	0.50%					

*(*set weight of liquid to be thickened to 100%*)



Best Bets for Thickening Hot Liquids

Amount of thickening	Thickeners	(scaling)*	Hydrate (°C)	Hydrate (°F)	Hydrate (min)	Heat stability	Note	Example use
very little	xanthan gum	0.2%	hot or cold			thins at high temp		light consommés and broths, flavored milks
	lambda carrageenan	0.1%	cold			yes	best used in dairy applications	
little	gum arabic	10%	60	140	5	yes	slightly opaque, not suited to clear liquids	constructed broths, light soups
	160 Bloom gelatin	3%						
	lambda carrageenan	0.25%	cold			yes	best used in dairy applications	
	xanthan gum	0.35%	hot or cold			thins at high temp		
moderate	propylene glycol alginate	0.65%	82	180	3			cream sauces, veloutés, soups
	microcrystalline cellulose	1.5%	cold			yes		
	gum tragacanth	0.35%						
	lambda carrageenan	0.4%	82	180	3	thickens at high temp	high-calcium solutions may become too thick	
	locust bean gum	0.2%						
great	guar gum	0.5%	hot or cold			thins at high temp	good for liquids with a high ratio of suspended solids, slightly opaque	soups and coating sauces, veloutés
	xanthan gum	0.35%						
	160 Bloom gelatin	9%	60	140	5	yes	sucrose, fructose or another, less sweet sugar solid may be substituted	meat glazes, constructed jus (see page 2·344)
	glucose syrup DE40	4%						
	cellulose gum LV	0.5%						
	lambda carrageenan	0.8%	cold			yes	best used in dairy applications	light puddings
very great	xanthan gum	0.3%	cold			yes		purees and spreads, thick glazes, savory puddings
	lambda carrageenan	0.7%						
	cellulose gum LV	1.2%	room temperature		30	thickens at high temp	shear for 5 min after dispersing to ensure konjac fully hydrates; best texture when fat concentration is above 12%	
	konjac gum	0.15%						
	xanthan gum	0.15%						

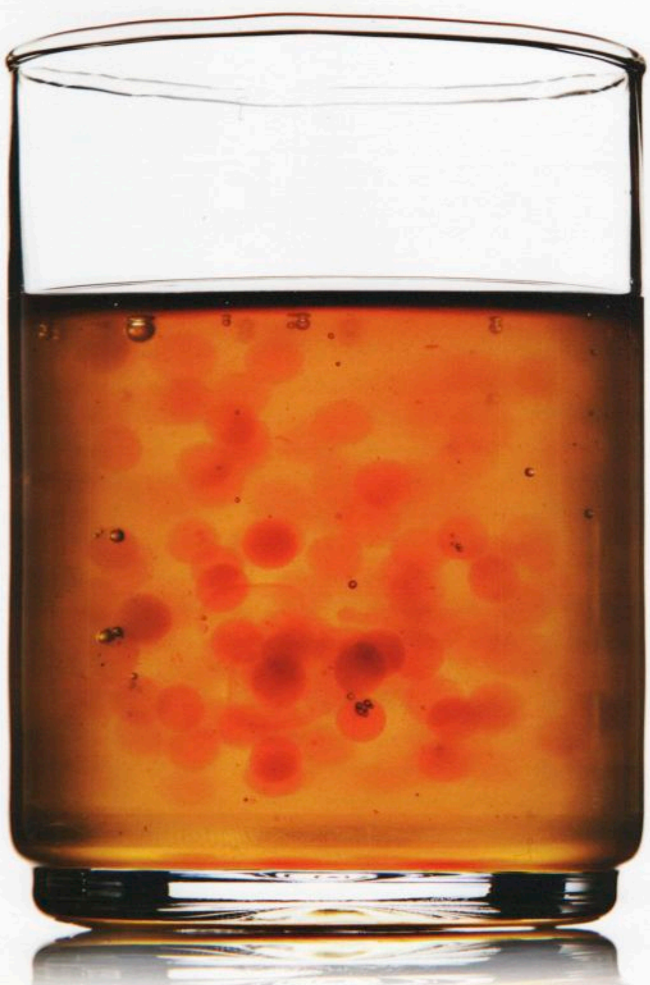
*(*set weight of liquid to be thickened to 100%*)

HAM CONSOMMÉ WITH MELON BEADS ADAPTED FROM FERRAN ADRIÀ

Yields 600 g (10 servings)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water, cold	500 g	200%	① Combine, and simmer for 15 min.
Ibérico ham, excess fat removed, thinly sliced	250 g	100%	② Cool completely, and remove congealed fat from surface of broth. ③ Pass broth through fine sieve, and reserve 250 g of consommé.
Ibérico ham consommé	250 g	100%	④ Blend thoroughly with consommé.
Xanthan gum (Texturas brand)	0.6 g	0.24%	⑤ Refrigerate for later use.
Melon juice see page 2·336	500 g (from about 800 g of melon)	200%	⑥ Blend with juice until dissolved. ⑦ Vacuum seal to remove any trapped air. ⑧ Transfer to Texturas-style syringe.
Sodium alginate (Algin, Texturas brand)	2 g	0.8% *(0.4%)**	
Water	500 g	200%	⑨ Blend together until fully dissolved.
Calcium chloride	2.5 g	1%	⑩ Expel juice from syringe, one droplet at a time, into calcium chloride bath. ⑪ Remove resulting beads from bath after 3 min. ⑫ Rinse beads in clean water bath. ⑬ Serve, or store beads in clean water. ⑭ To serve, fill 10 champagne flutes with 50 g each of cold ham consommé. ⑮ Spoon 10 g of melon juice beads into each flute; beads will remain suspended.
Black peppercorns, finely ground	to taste		⑯ Garnish.

(original 2005) *(% of weight of melon juice)*



Melon juice beads are an example of **spherification**. For more on spherification techniques and methods, see page 184.

EXAMPLE RECIPE

TOMATO WHEY BROTH

Yields 230 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tomato water see page 2·366	100 g	100%	① Whisk together.
Whey, from goat milk ricotta making see page 104	100 g	100%	
Lambda carrageenan (Texturas brand)	0.20 g	0.2% *(0.1%)**	② Dry blend together. ③ Blend into tomato-whey mixture until fully hydrated.
Xanthan gum (Keltrol T, CP Kelco brand)	0.20 g	0.2% *(0.1%)**	④ Refrigerate.
Salt	to taste		⑤ Season just before serving, or whey will curdle.
Tomato vinegar see page 5·65 or lemon juice (optional)	to taste		⑥ Serve cold with fresh mozzarella or on tomato salad.

(2010)

(% of total weight of tomato water and whey*)

By using freeze clarification, you can clarify the whey to make a tomato whey consommé. First, add 1.5% gelatin to the whey, cast the mixture into a mold, and freeze completely. Then thaw, refrigerated, over a drip pan to collect the clarified whey. Make the recipe above using the clarified whey in step 1. For a step-by-step procedure, see page 2·370.

EXAMPLE RECIPE

HOUSE BARBECUE SAUCE

Yields 120 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Malt vinegar	50 g	50%	① Combine in pot.
White beef stock see page 2·296	50 g	50%	② Cook mixture over low heat until reduced to about 100 g.
Maple syrup	25 g	25%	③ Puree until smooth.
Yellow onion, finely diced	15 g	15%	④ Pass sauce base through fine sieve.
Bourbon	13.5 g	13.5%	⑤ Cool.
Rendered bacon fat	12 g	12%	
Sherry vinegar	5 g	5%	
Smoked Hungarian paprika pepper (or other dried, smoked pepper), ground	5 g	5%	
Cayenne pepper, dried and ground	0.5 g	0.5%	
Yellow mustard powder	0.5 g	0.5%	
Liquid hickory smoke (Lazy Kettle brand)	0.1 g	0.1%	
Barbecue sauce, from above	100 g	100%	⑥ Shear into cold sauce base until evenly distributed and smooth.
Tomato powder, freeze-dried see page 3·372 (or store-bought)	20 g	40%	
Microcrystalline cellulose (Avicel CG 200, FMC BioPolymer brand)	1 g	2%	
Salt	to taste		⑦ Season sauce.
Red wine vinegar	to taste		

(2009)

To make thicker sauce, add 0.1%–0.2% xanthan gum at step 5.

For more on barbecue sauces, including multiple recipes and a guide to the regional variations across the southern United States, see pages 5·66 and 3·218.

EXAMPLE RECIPE

CARAMELIZED COCONUT CREAM

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Coconut milk	350 g	350%	① Combine.
Palm sugar	50 g	50%	② Pressure-cook mixture at gauge pressure of 1 bar / 15 psi for 1¼ h.
Baking soda	1.5 g	1.5%	③ Cool completely; liquid may curdle as it cools, which is normal.
Coconut water (canned or fresh)	100 g	100%	④ Blend until sodium alginate is completely dissolved. ⑤ Combine with coconut milk mixture.
Propylene glycol alginate (Protanal Ester BV, FMC BioPolymer brand)	1.75 g	1.75% *(0.35%)**	
Young coconut meat (frozen or fresh)	50 g	50%	⑥ Add to coconut milk mixture, and blend until smooth. ⑦ Strain through fine sieve. ⑧ Refrigerate.
(2010)		*(% of total weight of all ingredients)	

For a photo of the coconut cream, see page 16.

EXAMPLE RECIPE

PRESSURE-COOKED POLENTA WITH STRAWBERRY MARINARA

Yields 800 g (12 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the strawberry marinara:			
Strawberries, thinly sliced	220 g	88%	① Combine all ingredients in pot, and simmer, until reduced and thickened, about 90 min
Heirloom tomato, peeled	190 g	76%	
Strawberry juice, clarified	185 g	74%	
Sweet onion, finely minced	100 g	40%	
White wine (dry)	100 g	40%	
Garlic, thinly sliced and blanched	3 g	1.2%	
Basil leaves, torn	2 g	0.8%	
Tarragon leaves, crushed	2 g	0.8%	
Strawberry marinara, from above	250 g	100%	② Whisk gum into marinara base until fully dispersed.
Xanthan gum (Keltrol T, CP Kelco brand)	0.6 g	0.24%	
Salt	to taste		③ Season marinara, and reserve.
Lime juice	to taste		
For the corn husk consommé:			
Water	1 kg	400%	④ Line baking sheet with corn husks, and toast in 205 °C / 400 °F oven for 10 min.
Corn husks, fresh	125 g	50%	⑤ Flip husks, and toast for another 5 min until deep golden brown. ⑥ Combine husks with water, and simmer for 30 min to infuse. Strain and reserve.
Cellulose gum (Cekol LVD, CP Kelco brand)	2 g	0.8% *(0.2%)**	⑦ Blend gum into consommé base, and season.
Fructose	to taste	4%	
Salt	to taste		
For the polenta:			
Clarified butter	15 g	6%	⑧ Sauté polenta in butter until golden, 3–4 min.
Stone-ground polenta	100 g	40%	⑨ Cool completely.
Corn juice, clarified	300 g	120%	⑩ Combine with toasted polenta, and vacuum seal. ⑪ Place in pressure cooker, and cover with water. Pressure-cook at gauge pressure of 1 bar / 15 psi for 8 min.
Mascarpone see page 56, (or store-bought)	20 g	8%	⑫ Remove cooked polenta from bag, and whisk in mascarpone and ricotta. ⑬ Season with salt.
Ricotta salata, grated	15 g	6%	⑭ Divide among bowls, and garnish with strawberry marinara.
Salt	to taste		⑮ Pour some consommé over polenta at table.
(2010)		*(% of total weight of corn husk consommé)	

EXAMPLE RECIPE

OLIVE OIL SPREAD

Yields 325 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Deodorized cocoa butter	100 g	44%	① Heat to 40 °C / 104 °F to melt.
Olive oil	225 g	100%	② Blend with melted butter.
			③ Allow mixture to harden at room temperature.
			④ Blend again to silky consistency.
Black pepper, ground	1 g	0.4%	⑤ Whisk into spread.
Thyme essential oil (optional)	0.2 g	0.09%	
Rosemary essential oil (optional)	0.1 g	0.04%	
Fleur de sel	to taste		⑥ Season, and warm at room temperature for 20 min before serving.

(2010)

1a

1b

2

4a

4b

This recipe creates a spread with the texture of soft butter but the distinctive flavor of olive oil. Any other nut or seed oil can be substituted.

EXAMPLE RECIPE

WHITE GRAPE SYRUP

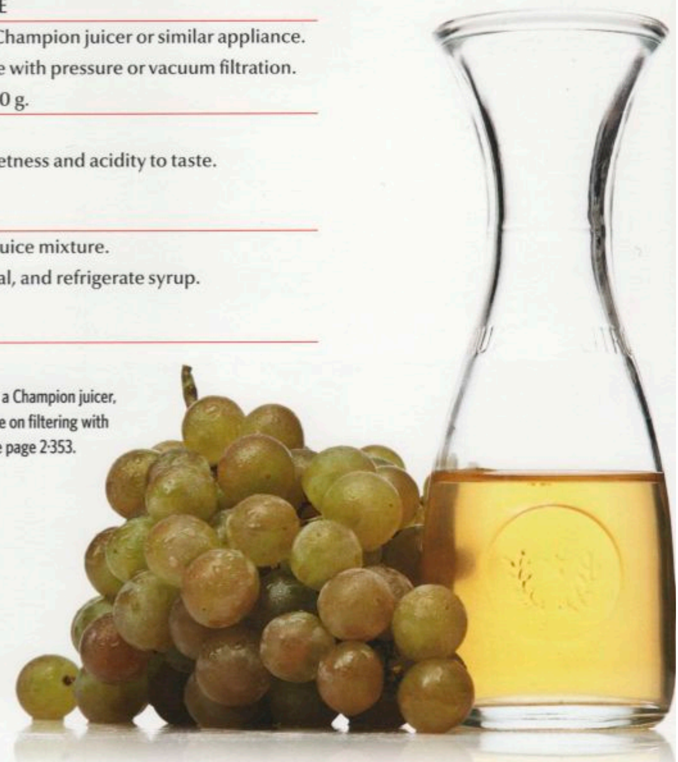
Yields 430 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Muscat grapes (or other white grapes)	2 kg	500%	① Juice with Champion juicer or similar appliance. ② Clarify juice with pressure or vacuum filtration. ③ Reserve 400 g.
Clarified grape juice, from above	400 g	100%	④ Blend. ⑤ Adjust sweetness and acidity to taste.
Fructose	20 g	5%	
Malic acid	4.5 g	1.3%	
Cellulose gum (Cekol LVD, CP Kelco brand)	4 g	1%	⑥ Shear into juice mixture. ⑦ Vacuum seal, and refrigerate syrup.
Xanthan gum (Keltrol T, CP Kelco brand)	1.2 g	0.3%	

(2010)

Most syrups are thick because they contain lots of dissolved sugars. By using thickeners, you can give any liquid, such as a tart fresh grape juice, a syrupy consistency.

For more on how to use a Champion juicer, see page 2·332. For more on filtering with vacuum or pressure, see page 2·353.



EXAMPLE RECIPE

XO SAUCE

Yields 275 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Brown pork stock see page 2·296	250 g	125%	① Combine, and vacuum seal. ② Cook sous vide in 90 °C / 194 °F bath for 1 h. ③ Strain, and press solids to remove as much liquid as possible. ④ Measure 200 g of infused stock, and cool.
Cured ham, finely minced	60 g	30%	
Ginger, peeled and thinly sliced	40 g	20%	
Agave nectar (or honey)	10 g	5%	
Infused pork stock, from above	200 g	100%	⑤ Shear into reserved stock to hydrate.
Cellulose gum (Cekol LV, CP Kelco brand)	2 g	1%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.5 g	0.25%	
Salted dried shrimp, minced	14 g	7%	⑥ Fry together until tender, about 2 min. ⑦ Blot excess oil with paper towels. ⑧ Fold mixture into thickened stock base. ⑨ Serve with Deep-Fried Custard (page 120), or cool and refrigerate.
Ginger, minced	12 g	6%	
Dried scallop, minced	7 g	3.5%	
Fermented black beans, minced	7 g	3.5%	
Garlic, minced	7 g	3.5%	
Dried red chilies, seeded and minced	3 g	1.5%	
Frying oil	5 g	2.5%	

(2010)

Traditional Chinese sauces are often thickened with cornstarch, potato starch, water chestnut flour, or mung bean flour. These thickeners can hinder flavor release and create a characteristic texture. We prefer the approach shown here.

EXAMPLE RECIPE

TRUFFLE JUS INSPIRED BY MARC VEYRAT

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Shallots, finely minced	30 g	30%	① Cook together over low heat until tender, about 5 min.
Clarified butter	15 g	15%	
Black peppercorns, ground	0.5 g	0.5%	
Red port (dry)	40 g	40%	② Add to pan of cooked shallots.
Red wine (dry)	40 g	40%	③ Simmer together for 2 min to cook off alcohol flavor.
			④ Keep port base hot for later use.
Mushroom jus, cold see page 2·348	100 g	100%	⑤ Disperse gum into cold mushroom jus. ⑥ Whisk mushroom jus into hot port base.
Konjac gum (Ticagel Konjac HV, TIC Gums brand)	0.54 g	0.54% *(0.3%)**	⑦ Bring to simmer, and blend continuously for 5 min to ensure konjac is fully dispersed.
Black truffles, vacuum-packed, frozen, thawed, then minced	35 g	35%	⑧ Whisk into warm mushroom jus and wine mixture.
Black truffle oil	7 g	7%	
Dark cocoa powder	4 g	4%	
Thyme essential oil	0.05 g	0.05%	
Salt	to taste		⑨ Remove jus from heat.
Sherry vinegar	to taste		⑩ Season.

(published 2003, adapted 2010)

(% of total weight of red port wine and mushroom jus*)

EXAMPLE RECIPE

WARM POTATO AND PISTACHIO PESTO SALAD

Yields 2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Italian basil leaves	80 g	80%	① Blanch in boiling water individually until tender, about 2 min each.
Cilantro leaves	70 g	70%	② Cool in ice water and squeeze to remove excess moisture.
Chives	70 g	70%	③ Reserve refrigerated.
Scallion greens	70 g	70%	
Garlic cloves, peeled	16 g	16%	④ Blanc in boiling water for 2 min. Drain and reserve.
Extra virgin olive oil	190 g	190%	⑤ Puree together with cooked herbs and blanched garlic until smooth.
Parmiggiano Reggiano, finely grated	100 g	100%	⑥ Measure 900 g of pistachio pesto.
Pistachios, peeled and toasted	100 g	100%	
Roasted-pistachio oil	40 g	40%	
Spinach puree see page 2·424	30 g	30%	
Lemon juice	20 g	20%	
Pistachio pesto, from above	900 g	900%	⑦ Season.
Salt	to taste		
Microcrystalline cellulose (Avicel CG 200, FMC BioPolymer brand)	9 g	9% *(1%)**	⑧ Blend into pistachio pesto to fully hydrate. ⑨ Vacuum seal, and refrigerate for at least 1 h to macerate.
Xanthan gum (Keltrol T, CP Kelco brand)	1.8 g	1.8% *(0.2%)**	
Fingerling potatoes, skin on	1 kg	1000%	⑩ Vacuum seal, and cook sous vide in 90 °C / 194 °F bath until tender, about 45 min.
Olive oil	100 g	100%	⑪ Remove from bag while still warm. ⑫ Slice thinly. ⑬ Toss with pesto as desired.

(2010)

(% of weight of pistachio pesto*)

EXAMPLE RECIPE

BEEF TENDERLOIN WITH JUS DE ROTI

Yields 500 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef tenderloin	400 g	400%	① Vacuum seal together.
Rendered beef marrow or suet	40 g	40%	② Cook sous vide in 53 °C / 127 °F bath to core temperature of 52 °C / 126 °F.
Brown beef stock see page 2·301	100 g	100%	③ Combine. ④ Bring jus to low simmer to dissolve solids.
160 Bloom gelatin	9 g	9%	
Fructose	2.5 g	2.5%	
D-Ribose Powder (Solgar brand)	1.75 g	1.75%	
Cellulose gum (Cekol LVD, CP Kelco brand)	0.5 g	0.5%	
Koji-Aji (Ajinomoto brand)	0.4 g	0.4%	
Caramel coloring	0.2 g	0.2%	
Malic acid	to taste		⑤ Season jus, and serve with sliced beef tenderloin.
Salt	to taste		

(2010)

The recipe above allows a chef to make jus from any stock without having to reduce it to a syrup. The benefits are appealing: because no time is invested in reduction, the yield is equal to the starting weight, and the flavor is pure. Season the jus to taste with fortified wines, herbs, and spices to suit your application.

EXAMPLE RECIPE

CREAMED SPINACH

Yields 125 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Baby spinach, cleaned	150 g	100%	① Sauté until wilted, about 1 min.
Olive oil	5 g	3.3%	② Season, and cool completely.
Salt	to taste		③ Transfer to colander, and press to remove excess liquid.
			④ Chop finely.
Garlic confit, mashed see page 3·354	6 g	4%	⑤ Sauté until shallots are translucent.
			⑥ Add spinach.
Olive oil	5 g	3.3%	⑦ Stir together, and cook for 3 min.
Shallots, finely minced	5 g	3.3%	⑧ Remove spinach from heat.
Mascarpone see next page (or store-bought)	27 g	18%	⑨ Stir into spinach until completely incorporated.
			⑩ Set spinach mixture aside.
Low-fat milk	20 g	13.3%	⑪ Dry blend Ultra-Sperse 3 and xanthan gum.
Ultra-Sperse 3 (National Starch brand)	0.5 g	0.3%	⑫ Whisk dry mixture into cold milk until fully hydrated.
			⑬ Mix thickened milk into creamed spinach.
Xanthan gum (Keltrol T, CP Kelco brand)	0.1 g	0.06%	
Comté cheese, finely grated	10 g	6.7%	⑭ To serve, fold Comté cheese into creamed spinach, and scatter some on top.
Lemon zest, finely grated	0.5 g	0.3%	⑮ Season with lemon zest and black pepper.
Black peppercorns, ground	0.2 g	0.1%	⑯ Serve warm or cold.

(2009)

Instead of sautéing the spinach, you could steam it until just tender. Drain by pressing it against the sides and bottom of a colander.

MILKS AND CREAMS

For centuries, people have enjoyed nondairy "milks." The first depictions of Asian chefs making soy milk are 2,000 years old. Chufa, with nutlike tubers of the same name, is today used to make the popular drink horchata, but long ago, it was was one of the first plants humans chose to cultivate. One can think of these various "milks" as thickeners from the ground soy, chufa, or other foods that turn water into a faux milk.

Rice, soy, and nut milks are refreshing beverages and good options for people who are dairy-sensitive, vegan, or monitoring their cholesterol. In most cases, making nondairy milk is as simple as mixing, resting, and straining. Making soy milk is a little more complicated; for detailed instructions, see page 58.

In addition to making milks from nondairy foods, we can also modify the properties of dairy milk. The addition of thickeners transforms low-fat milk into a rich cream. Real dairy cream almost instantly becomes crème fraîche or cream cheese. Homemade clotted cream, yogurt, and skyr are easy to make and yield foods that are much fresher and tastier than the store-bought versions.

MAKING MILKS AND CREAMS

1 **Select a recipe.** Some of our favorites appear in the table below. Proportions are relative to the main liquid. For example, use 80 g of tigernuts for every 100 g of water to make chufa milk.

2 **Blend liquids with thickeners.** Dissolve acidifiers or rennet in a small amount of water, milk, or cream before adding them to the liquid.

3 **Hydrate the thickeners.** Soak or heat as indicated in the Procedure column of the table.

4 **Sieve if needed to remove lumps.** Nut and legume milks should be sieved after steeping.

Best Bets for Making Milks and Creams

Recipe	Liquid	(scaling)	Thickeners	(scaling)	Procedure
almond milk	water	100%	almonds, finely ground	60%	soak 24 h, and sieve
	sweet almond oil	2%	sugar	1%	
clotted cream	whole milk*	100%	n/a		combine liquids, and pour in open container; steam or cook in 80 °C / 176 °F bath for 1 h undisturbed; refrigerate 24 h; skim clotted cream from surface
	heavy cream	50%			
chufa milk	water	100%	chufas (tigernuts)	80%	soak 12 h, and sieve
buttermilk	butter whey see page 286	100%	lactic acid	0.4%	season with salt to taste, and allow to rest overnight; adjust amount of heavy cream to taste
	heavy cream	20%	lambda carrageenan	0.2%	
skyr	low-fat milk	100%	live culture (Yogotherm brand)	1.0%	heat milk to 82 °C / 180 °F, and cool to 42 °C / 108 °F; add culture and acid, pour into sanitized containers, and incubate at 45 °C / 113 °F for 5 h; drain for 2 h
			lactic acid	0.2%	
yogurt	whole milk	100%	live culture (Yogotherm brand)	1%	heat milk to 82 °C / 180 °F, and cool to 42 °C / 108 °F; add culture, pour into sanitized containers, and incubate at 45 °C / 113 °F for 8 h; drain 12 h for thick, Greek-style texture; for firmer yogurt, scald milk at 85 °C / 125 °F for 25 min, and cool before adding culture
mascarpone	heavy cream	100%	ascorbic acid (or glucono delta-lactone)	0.2%	combine, heat cream to 90 °C / 190 °F, cool for 30 min, wrap in cheesecloth, and hang, refrigerated, for 12 h

(whole milk used in clotted cream should be unhomogenized for best results)

EXAMPLE RECIPE

LOW-FAT "CREAM"

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sweet whey powder	5 g	2.5%	① Dry blend.
Cellulose gum (Cekol LV, CP Kelco brand)	0.7 g	0.35%	
Lambda carrageenan (Texturas brand)	0.2 g	0.1%	
Skim milk	200 g	100%	② Shear powder mixture into milk until fully hydrated. ③ Refrigerate.

(2009)

This recipe makes a liquid that has the viscosity of cream but none of the fat.

EXAMPLE RECIPE

INSTANT CRÈME FRAÎCHE

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Heavy cream (free of stabilizers or thickeners)	400 g	100%	① Heat heavy cream to 40 °C / 104 °F. ② Blend in carrageenan to fully hydrate, and remove from heat.
Lambda carrageenan	1.6 g	0.4%	
Lactic acid	1.6 g	0.4%	③ Dissolve lactic acid in water.
Water	8 g	2%	④ Stir lactic acid solution into warm cream, and refrigerate for 10 min before using. ⑤ Pass through fine sieve, and refrigerate until needed.

(2010)

Traditional crème fraîche is cultured like yogurt. This recipe uses lactic acid directly as the acidulant.

EXAMPLE RECIPE

HERBED CHEESE SPREAD

Yields 125 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Heavy cream (free of stabilizers or thickeners)	75 g	100%	① Dry blend locust bean gum and carrageenan. ② Disperse into cold milk and cream.
Whole milk	25 g	33%	③ Bring mixture to boil while blending to hydrate.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	1 g	1.3% *(1%)**	④ Remove from heat. ⑤ Strain and cool.
Lambda carrageenan (Texturas brand)	0.2 g	0.27% *(0.2%)**	
Fresh goat cheese	30 g	40%	⑥ Add to heavy cream mixture. ⑦ Blend together until homogenized to make spread base.
Garlic confit, pureed see page 3·354	10 g	7.5%	⑧ Fold into cheese spread.
Chives, minced	3 g	4%	
Parsley, minced	2 g	2.7%	
Tarragon, thinly sliced	1 g	1.3%	
Lemon juice	to taste		⑨ Season, and refrigerate until use.
Black pepper, cracked	to taste		
Salt	to taste		

(2010)

(% of total weight of first two ingredients*)

Locust bean gum and lambda carrageenan are often combined to create commercial cream cheese in the United States.

EXAMPLE RECIPE

SOY MILK

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Dried organic soy beans	250 g	100%	① Vacuum seal together.
Water	250 g	100%	② Soak, refrigerated, until beans absorb all water, about 14 h.
			③ Remove from bag.
Water, cold	750 g	300%	④ Puree soaked soybeans in food processor.
			⑤ Add cold water.
			⑥ Blend for 10 min until texture is creamy and grainy.
Water, boiling	425 g	170%	⑦ Pour into saucepan, and bring mixture to simmer.
			⑧ Add boiling water to soybeans; surface should start to foam.
			⑨ Stir until foam subsides, about 20 min.
			⑩ Strain mixture through fine sieve lined with cheesecloth, and collect soy milk.
			⑪ Wrap mixture in cheesecloth.
			⑫ Wring cloth tightly to extract all remaining soy milk.
			⑬ Vacuum seal soy milk, and refrigerate.

(2010)

4a

4b

7

8a

8b

This fresh soy milk is ideal for making tofu (see page 112). This recipe produces milk with a soluble solids concentration of about 8.5 °Brix. It makes an ideal substitute for dairy milk. When making tofu, the soy milk should register 10–14 °Brix on a refractometer or density meter. Reduce the soy milk over low heat as needed to increase the density. The higher the Brix reading, the richer and creamier the milk.

10

12

EXAMPLE RECIPE

TOASTED RICE MILK

Yields 1.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Arborio rice	50 g	33%	① Arrange dry rice in thin, even layer on baking sheet. ② Toast in 175 °C / 350 °F oven until evenly golden, about 45 min. ③ Remove from oven.
Water	1.5 kg	1,000%	④ Combine all rice and 1 kg of water in pot.
Long grain rice	150 g	100%	⑤ Soak rice for 3 h at room temperature.
Fresh pandan leaves (optional)	30 g	20%	⑥ Add to rice and water, if using. ⑦ Simmer mixture for 30 min. ⑧ Remove from heat. ⑨ Add reserved 500 g of water, and puree coarsely to release starch. ⑩ Strain through cheesecloth-lined fine sieve to extract 1.5 kg, about 1 h. To avoid unwanted solids, do not press.
Sugar	60 g	40%	⑪ Whisk into rice milk until dissolved, and cool.

(2010)

EXAMPLE RECIPE

TOASTED ALMOND MILK

Yields 650 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	750 g	250%	① Blend into coarse puree.
Marcona almonds, toasted (or regular almonds, skinless)	300 g	100%	② Refrigerate for 24 h. ③ Blend chilled puree until smooth.
Sugar	15 g	5%	④ Strain through fine sieve to extract almond milk.
Sweet almond oil	15 g	5%	
Salt	9 g	3%	
Almond extract (optional)	to taste		⑤ Add sparingly to milk. ⑥ Vacuum seal almond milk, and refrigerate until needed.

(2009)

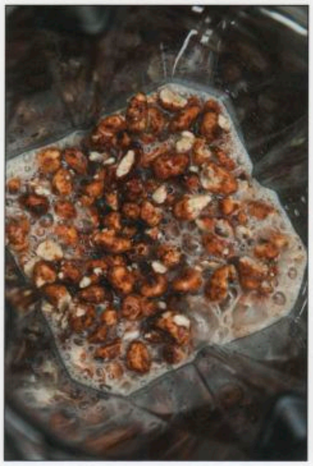
EXAMPLE RECIPE

HORCHATA (CHUFA MILK)

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chufas (tigernuts)	450 g	100%	① Cover nuts with fresh water.
Water	as needed		② Soak nuts in refrigerator for 12 h. ③ Drain nuts, and discard water.
Water	250 g	56%	④ Combine with softened nuts.
Sugar	20 g	4.4%	⑤ Blend to fine, smooth texture.
Whey protein isolate (optional)	1.4 g	0.3%	⑥ Pass milk through fine sieve. ⑦ Vacuum seal milk, and refrigerate until needed.

(2010)



Horchata is a classic beverage of Valencia, Spain, and the surrounding region, where it is served cold, particularly in summer. The chufa, or tigernut (right), is the tuber of the wetland sedge grass *Cyperus esculentus*. It was cultivated extensively in ancient Egypt and is thought to have been introduced to Spain by Arabs. Horchata drinks are common in Latin America but are often thickened with rice or the seeds of the *jicaro*, or Mexican calabash tree.

PARAMETRIC RECIPE

EDIBLE FILMS

Chefs make edible films because they're fun. They are whimsical and add an unexpected textural element and drama to presentations. Most of all, edible films can be very tasty; they can have bold, clean, and often surprising flavors.

The clear paper clinging to Botan Rice Candy is one familiar film. More surprising is watching ramen dissolve and disappear into soup before your very eyes (see page 5·247 for the recipe). At The Fat Duck, Heston Blumenthal has wrapped savory "lollies" and assorted sweets with clear film. Homaro Cantu made quite a stir when he served edible menus at his Chicago restaurant moto.

To make a film you can eat, simply pour a thin layer of the right solution onto a silicone mat, and then dehydrate it. Commercial film applicators, although expensive, offer precise control of thickness. Petri dishes can serve as molds for evenly measured, very thin films; they are inexpensive and come in convenient standard sizes. Store dehydrated films between pieces of parchment in a dark, airtight container; otherwise, ambient moisture will quickly ruin them.

MAKING FILMS OF FOOD

1 **Select a texture and a corresponding film formula.** The Best Bets for Edible Films table below lists several good options that range from tender to brittle.

2 **Mix thickeners into cold liquid to create a slurry.** Quantities in the table are given relative to the weight of the liquid. For example, if you are making a clear, brittle tomato water film, use 10 g of Pure-Cote B790 for every 100 g of tomato water.

3 **Hydrate fully.** Times and temperatures are indicated in the table below. For step-by-step instructions, see page 26.

4 **Cast into a film onto a flat, level surface.** Keep the liquid cold, so that it is more viscous and coats the surface more easily. Films are typically cast in a layer 0.5–1 mm / 1/64–1/32 in thick; crisps and tuiles are usually thicker, 1.5–2 mm / 1/16–3/32 in. For more on making films, see the photos and example recipes on the next two pages.

5 **Dehydrate at the lowest humidity and temperature feasible.** Dehydrating at 30 °C / 86 °F is ideal. Slow, low-temperatures drying produces films that have an even texture; films often crack when dried to quickly and warp when exposed to humidity. The greater the degree of dehydration, the less flexible and more brittle the film becomes. For more information on dehydrating techniques, see page 2·428.

Best Bets for Edible Films

Texture	Clarity	Formula	(scaling)*	Hydrate (°C)	(°F)	(min)	Example use
tender	clear	Methocel SGA 150**	0.75%	refrigerated		8 h	edible wrappers, paper coating films
		160 Bloom gelatin	0.75%	60	140	5	
		sugar	15%	95	203	3	
		HM pectin	2%				
	opaque	agar	1.0%	95	203	3	
		glycerin	1.2%				
		xanthan gum	0.2%				
crisp	clear	low-acyl gellan	0.5%	95	203	3	flavored crisps, delicate tuiles
		propylene glycol alginate	0.5%	60	140	5	
		160 Bloom gelatin	0.3%				
		maltodextrin DE 8	15%		cold		
		sugar or isomalt	10%				
	opaque	Methocel E4M**	1.25%	refrigerated		8 h	crispy cream cheese (see page 63)
brittle	clear	Pure Cote B790	10%	100	212	15	Grant Achatz's pineapple glass wrapper for bacon powder (see page 3·370)
	opaque	N-Zorbit M	20%		cold		seasoned glasses, fruit and vegetable glasses
		glucose powder	15.0%	95	203	3	
		LM pectin	1.5%				
		agar	0.6%				

**(set weight of liquid to 100%); **(for dispersal instructions, see page 24)*

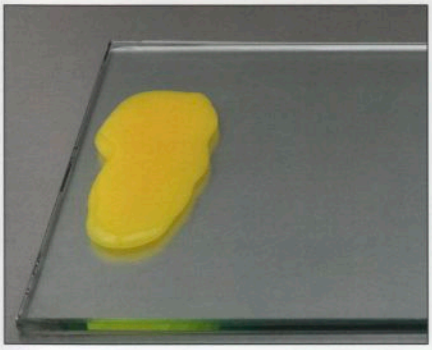
EXAMPLE RECIPE

LEMON STRIPS ADAPTED FROM HESTON BLUMENTHAL

Yields 50 g (50 strips)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Glycerin	3.75 g	1.67%	① Blend together to make lemon water, and reserve.
Lemon essential oil	2.55 g	1.13%	
Deionized water	225 g	100%	
Maltodextrin DE8	7.95 g	3.53%	② Dry blend.
Algin 400F (TIC Gums brand)	8.58 g	3.81%	③ Whisk slowly into lemon water until completely incorporated.
Viscarin TP 389 (FMC BioPolymer brand)	3.18 g	1.41%	④ Vacuum seal or refrigerate for 8 h to remove trapped air bubbles.
Aspartame	0.12 g	0.05%	⑤ Spread mixture onto acetate sheet using film applicator or improvised dowel with a spacer (see photo) to form very thin and even coating.
			⑥ Dry at room temperature for about 24 h.
			⑦ Slice hardened film into 2 cm by 3 cm / ¾ in by 1¼ in strips.
			⑧ Peel off strips from sheet.
			⑨ Store in airtight container.

(original 2002, adapted 2010)



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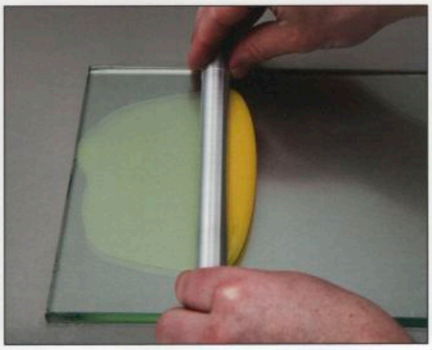

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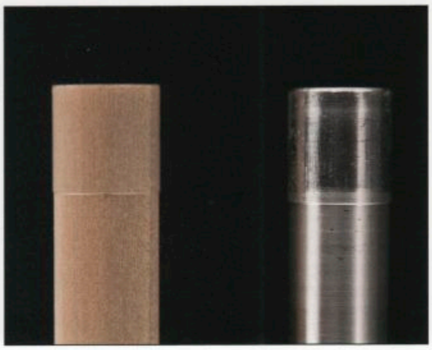
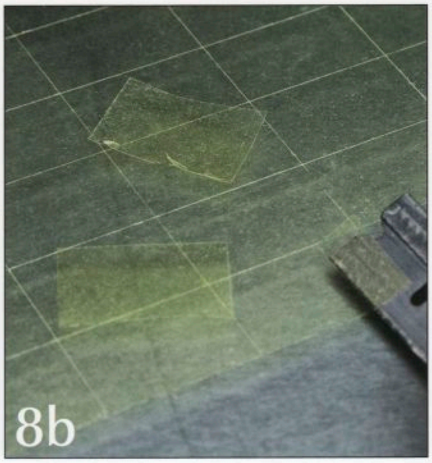


To get a precise thickness for the film, you need a spacer. The best approach is to have a machine shop make an aluminum rod with the end portions larger by 0.2 mm / 0.008 in (above). A simpler approach is to apply a couple of layers of cellophane tape to the ends of a wooden dowel.

8a



8b

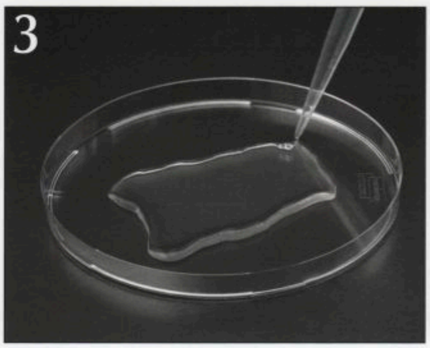
EXAMPLE RECIPE

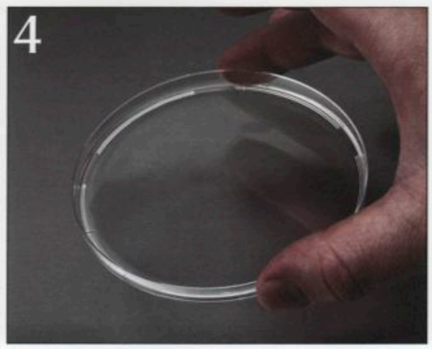
EDIBLE WRAPPERS ADAPTED FROM HESTON BLUMENTHAL

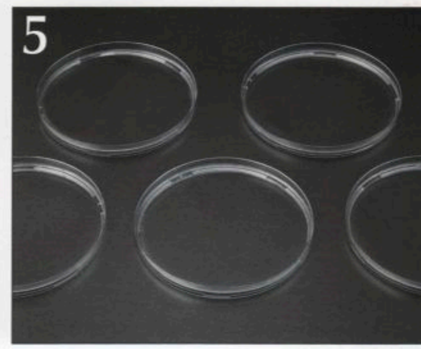
Yields 130 g (65 wrappers)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	400 g	100%	① Combine to bloom gelatin.
200 Bloom gelatin	6 g	1.5%	② Heat solution; whisk constantly to dissolve gelatin.
Glycerin	0.2 g	0.05%	③ Transfer 6 g of solution to 9 cm / 3½ in diameter petri dish with pipette.
			④ Swirl solution to coat dish bottom evenly and eliminate air bubbles.
			⑤ Repeat with remaining solution in individual petri dishes, one for each wrapper.
			⑥ Rest in warm place until resulting films are completely dry, 20–24 h.
			⑦ Peel off wrappers, and store in airtight container.

(original 2006)







If the film turns out to be too brittle, add more glycerin.

EXAMPLE RECIPE

BBQ CARAMELS

Yields 750 g

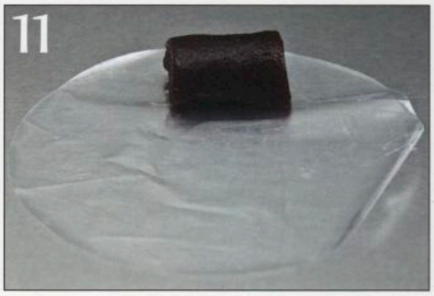
INGREDIENT	QUANTITY	SCALING	PROCEDURE
KC Masterpiece honey barbecue sauce	500 g	286%	① Reduce sauce over low heat to 250 g.
			② Reserve.
Sugar	175 g	100%	③ Blend.
Salt	10 g	5.7%	
HM pectin (Brown Ribbon HV, Obipektin brand)	4.7 g	2.7% *(0.53%)**	
Glucose syrup DE40	175 g	100%	④ Combine with sugar mixture in pot.
Water	175 g	100%	⑤ Heat to 145 °C / 293 °F.
Unsalted butter, cubed	110 g	63%	⑥ Stir into reduced barbecue sauce to form caramel base.
			⑦ Heat to 135 °C / 275 °F, and remove from heat.
Liquid hickory smoke (Lazy Kettle brand)	5 g	3%	⑧ Stir into caramel base quickly while base is still hot.
			⑨ Pour into mold 1.5 cm / ⅝ in thick.
			⑩ Refrigerate until solidified.
			⑪ Cut caramel sheet with scissors into desired shapes.
Edible wrappers, from above	as needed		⑫ Wrap caramels individually.
			⑬ Store in cool, dry place.

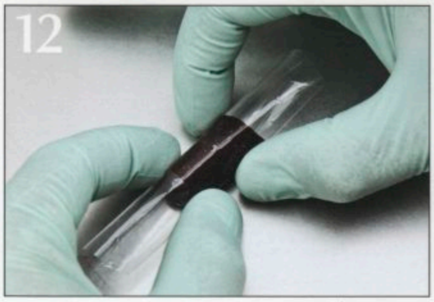
(2010)

(% of total weight of reduced honey barbecue sauce, sugar, glucose, water, and unsalted butter)

You can substitute our House Barbecue sauce (see page 49) or one of the regional sauces (see page 5·66).

For the texture of the caramel to be correct, the sugar content should be 88 °Brix as measured on a refractometer. Extend the cooking time as needed to reach the correct Brix level.





13

EXAMPLE RECIPE

CRISPY CREAM CHEESE ADAPTED FROM WYLIE DUFRESNE

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	100 g	50%	① Bring water to boil.
Methylcellulose E4M (Dow brand)	6 g	3% *(2%)**	② Shear in methylcellulose, and simmer until completely dispersed, at least 3 min.
Cream cheese, at room temperature	200 g	100%	③ Pour mixture onto cream cheese.
			④ Add salt, and blend.
Salt	1.5 g	0.75%	⑤ Cool cream cheese mixture to **10** °C / **50** °F.
			⑥ Spread onto silicone mat in layer 2 mm / $\frac{1}{16}$ in thick.
			⑦ Dehydrate at **50** °C / **120** °F until crisp and brittle, 10–12 h.
			⑧ Allow to cool completely before using.

(original 2008)

(% of total weight of water and cream cheese*)

At wd~50, Wylie Dufresne serves the crispy cream cheese as a garnish for his Everything Bagel ice cream, accompanied by Smoked Salmon Threads and Pickled Onions.

Photo courtesy of Takahiko Marumoto

14 GELS

GELS

Making a gel is one of the more magical things you can do in your kitchen: you can transform a liquid into a solid—or, even more amazing, into a chimerical substance with characteristics of a liquid and a solid. The same basic process that forms Jell-O is at work in bread, scrambled eggs, cheese, and tofu. While not everyone recognizes it as such, creating gels is a fundamental technique of both traditional and Modernist cooking.

In forming gels, you take the principles and processes covered in the Thickeners chapter and push them further. Many of the agents that cause liquids to thicken can also create gels. Traditional gelling agents, such as proteins and starches, and their modern counterparts, including **hydrocolloids**, provide many different ways to turn a liquid into a solid. The science of gelling can be pretty elaborate, and the potential applications of gels vary quite a lot. As you develop deeper knowledge of these processes and their interactions, you will gain a new medium in which to work. Modernist gelling techniques expand the realm of what is possible and give enthusiasts new opportunities to express their culinary imaginations. Be aware, however, that real mastery requires experience and experimentation.

Gel properties vary based on the kind of gel, the concentration of gelling agents in it, and other factors. A single gelling agent can yield a spectrum of results ranging from a sauce with enhanced body to a dessert mousse that has a firmer consistency to hard, chewy gummy bears and jelly beans. The brittleness or elasticity of gels varies widely, as does their mouthfeel and flavor release.

Gels can fail when they undergo **syneresis**, or weeping of liquid from the gel. In traditional cooking: an egg custard left sitting at room temperature for a while will weep a watery liquid around its base. Syneresis is usually something to be avoided, and several kinds of gels are constructed specifically for that purpose. In other cases, syneresis can be desirable, as when freeze-filtering.

Some hydrocolloids, like carrageenan, xanthan gum, and locust bean gum are freeze-stable, meaning that they can be frozen and thawed without problems. They are often added to stabilize gels that otherwise tend to break down in the freeze–thaw cycle. Like freezing, time can destabilize a gel—some gelling agents hold their form better than others.

The word "gel" comes from the French verb *geler*, which means "to freeze."

For more on freeze-filtering see page 2·368.

Familiar Gels

The most familiar and widely used culinary gelling agent, gelatin, is manufactured by breaking down **collagen**, the connective tissue in meat, skin, and bones. It can be derived at home by cooking meat. In fact, gelatin is produced incidentally anytime you make a stock or cook a tough meat slowly.

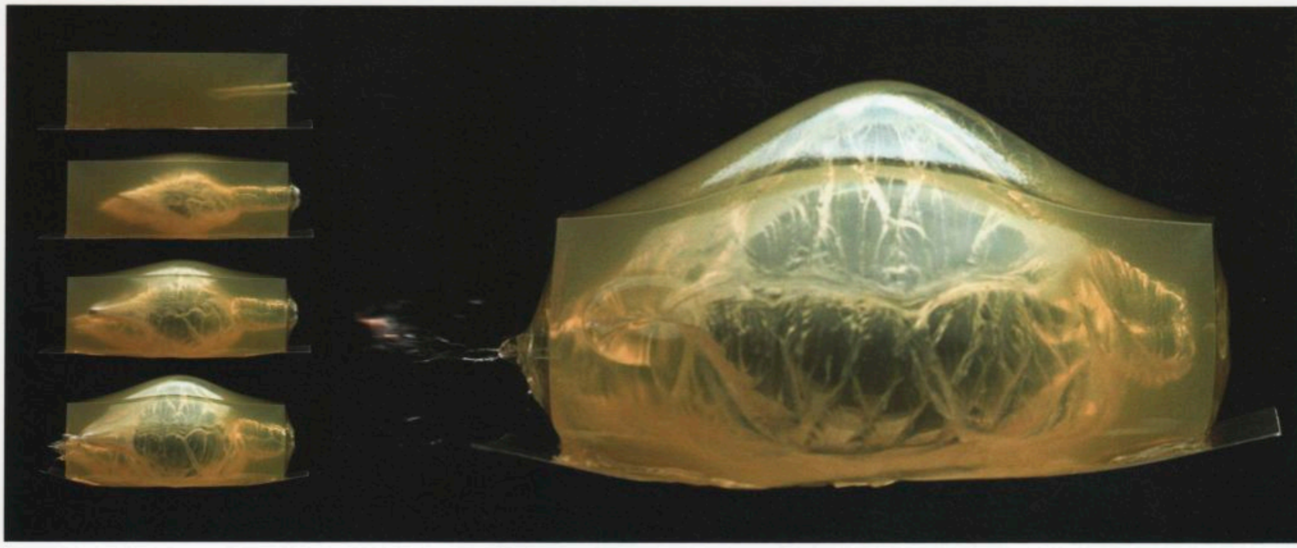
Gelatin is composed of very long **protein** molecules. These molecular strands have an affinity for their own kind, so as they cool, they nest together to form a three-dimensional mesh, trapping water molecules in the process. All gels form in a process essentially similar to this, as illustrated on page 71.

Gelatin melts near the normal body temperature of the living animal in which it formed. In the case of mammalian gelatins, once the temperature

For more on collagen and how it changes to gelatin with cooking, see page 3·80.

Gelatin for aspics and desserts was always prepared at home until Charles Knox saw how time-consuming it was for his wife and, in 1889, invented granulated gelatin for use in the kitchen. Knox is a major gelatin brand in the United States to this day.

With a mastery of gelling techniques, a chef can create eye-catching dishes such as mussels spherified in their own juice (opening photo) and a cluster of grapes suspended in a cylinder of solidified grape juice.



When forensic scientists want to test the effects of bullets or munitions on human flesh, they use ballistic gelatin, which has a similar density and consistency. The recipe is simple: mix a 10% solution of 250 Bloom gelatin with water, and then chill it to 4 °C / 39 °F. At that temperature, the gel mimics the response of flesh to bullet strikes very well. We made a batch and shot it with a .308-caliber bullet.

For more on the **hydration** process that prepares natural starches for use, see page 20.

A **Bloom** is a unit of measure of the rigidity of a gel, named for Oscar Bloom, inventor of a gelatin-measuring device. The higher the Bloom number, the stronger the gelatin's gelling capabilities and, by extension, the higher its quality.

exceeds 37 °C / 99 °F or so, the protein molecules detach and lose their capacity to hold liquid. The gelatins of fish have colder melting points, echoing the lower body temperature of the cold-blooded animals from which they originated.

Aspics are gels that are usually made from the gelatin that naturally occurs in reduced chicken or veal stock. Auguste Escoffier, Antonin Carême, and other classic French chefs embraced the technique of coating cold foods in aspic. Grand buffets of yesteryear featured exquisitely ornate aspic-covered dishes, a flourish that has largely fallen out of favor. New gelling agents let us explore aspics that Escoffier could only dream of, including gels that can be served hot.

Agar is a gelling agent with a high melting temperature that can be served warm (up to 80 °C / 176 °F or a bit higher). Agar is just one of several gelling compounds derived from seaweed. They belong to a class of agents called **hydrocolloids**, meaning they form suspensions of particles in water-based liquids. Whether you regard agar as a traditional gelling agent depends on your heritage: in Asian cuisine, it has been around for centuries, but it is new to most Western chefs (with some exceptions; see page 128). We discuss it, and other hydrocolloids, at length later in this chapter.

Cooks have depended for centuries on starch-based gels. A simple example is the sprinkling of tapioca starch onto fresh fruits before adding them to a pie shell. The liquids that cook out of the fruits set into a gel after baking. Cornmeal that is cooked in liquid until tender and then poured into a pan to cool, as in the initial stage of preparing fried polenta, relies on the formation of a gel produced by the natural starch in the corn granules.

To form a gel, natural starches such as wheat flour or potato starch must be heated to a certain temperature in water in order to become **gelatinized**, a necessary precursor to forming a gel (see page 20). Another prerequisite is having the right ratio of starch to liquid. Under the right conditions, a starch mixture will gel when cooled. Manufacturers have modified some starches to relieve cooks of having to carry out this heating step and to give them more precise control of the gelling process. Modified starches allow you to create gels that would be tricky or impossible to achieve with traditional starches.

Pectin is the gelling agent of choice for jams and jellies and has been for many generations. Apples and the peels of citrus fruits, for example, contain natural pectin and can be used as gelling agents, or you can buy it in processed, powdered form. The original manufactured pectin is known as HM pectin. It requires a certain amount of acid and a high sugar concentration to gel effectively. Various HM pectins are available commercially to provide a range of solidification speeds and setting temperatures. The modified pectin types LM and LMA require less acidity and sugar or other solids to work; like some other gels (see page 129), they require **ions** to coagulate into a gel.

Traditional Gels

Each discovery of a new gelling agent or a new technique for manipulating gels has propelled the preparation of food into new and exciting territory. Questions of texture and structure have always stimulated the serious cook. "What happens if I heat an egg while beating it with a whisk, or if I combine the jellied cooking liquids from meat with fruit or wine?" Gels, in particular, seem to inspire curiosity. Centuries of experimentation with gelling has created sauces, clarifying jellies, rich custards, soufflés, and gateaux—recipes and techniques that are still prized on today's modern menus.

We think of traditional gelling agents as falling into three broad categories: starches, proteins, and gelatins.

Starch molecules swell with water and gel with heat to thicken and bind certain breads and most sauces and creams—items that few people would identify as gels but that meet the technical definition (see page 20).

Coagulated proteins can make very simple gels, like a cooked egg or plain yogurt. Protein also gels into complex and highly seasoned products, such as frankfurters and aged cheese.

Perhaps the first mental image that comes to mind with the word gel is the characteristic wiggle of gelatin. Made from collagen extracted from meat and fish, gelatin is widely used in both sweet and savory dishes.

Class	Gelling agent	Examples
starch	cornstarch	pastry creams, dessert puddings
	flour	baked goods (breads are gels and foamed gels)
	tapioca starch	tapioca pearls, Asian dessert jellies, dessert puddings
protein	bean curd, with calcium chloride or magnesium chloride	soft and firm tofu, yuba
	coagulated protein in meat emulsions	frankfurters and other sausages
	egg white, with heat	soufflées
	egg yolk, with heat	crème brûlée
	whole egg, with heat	hard-boiled eggs, quiches, flans, chawanmushi
	milk, with coagulant (such as rennet)	milk skins, yogurts, junkets, fresh cheeses, mature cheeses, possets
gelatin	gelatin extracted during stockmaking	calf's foot gelée, other cold meat gels
	fish gelatin	salmon mousse, other fish and seafood mousses
	powdered extract of meat, collagen, pork skin, or fish bones	aspics, dessert gelées, mousses, savory and sweet jellies

Cold-smoked eggs

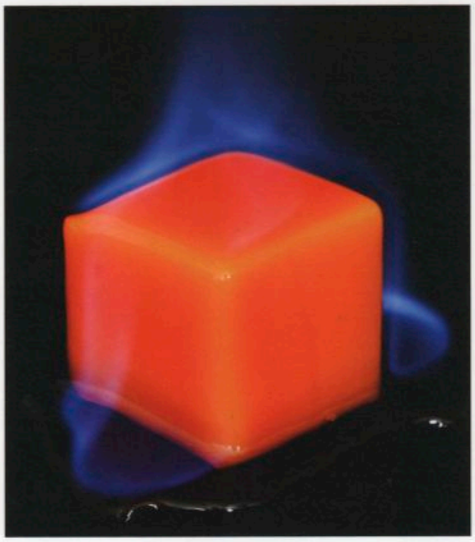
HOW GELLING WORKS

A gel forms when molecules interact with one another to create a three-dimensional network that prevents the movement of liquid. The cage-like assembly traps water molecules, transforming a liquid into a solid gel.

Gels do not always stay solid. In fact, some gels—called fluid gels—actually flow like liquids. At rest, a fluid gel looks like a standard gel, but if the gel is disturbed by blending or stirring, it breaks up and moves like a viscous fluid (see page 176).

As you choose a gelling agent, consider that gels fall into two broad categories that reflect how they respond to a hot–cold cycle: **thermo-reversible** and **thermo-irreversible.** Gelatin is the classic example of the thermo-reversible type: when you heat it above its melting point, it liquefies, but it regains its jelly-like consistency as it cools. Thermo-reversibility does not diminish with use; the gelatin always behaves this way as the temperature moves above or below the melting point.

An egg white, on the other hand, is an example of a thermo-irreversible gel, one that won't return to a liquid form once it was set. An egg sets when it is held for long enough at a certain temperature, as during cooking. Reducing the temperature afterward does not cause the egg whites to revert to a liquid state; once the egg white proteins link into a network, they stay linked.



The Jell-O shot, the notorious refreshment of choice at many college parties, is a gelatin gel that combines alcohol, sugar, and flavors to form a solid cocktail. Contributors to the web site myscienceproject.org have created successful gelatin-based shots with up to 36% alcohol. Sadly, the high-alcohol shots taste terrible, but they do burn rather nicely. Optimum flavor in Jell-O shots seems to max out at around 10% alcohol.

Egg whites require heat to form a gel, but other agents rely on different factors. Without the addition of the appropriate gel-inducer—called a **coagulant**—many gelling agents cannot form a gel (see next page).

Ions of calcium, for example, act as a coagulant that causes several kinds of hydrocolloids to gel. Although calcium is the type of ion most often used because it usually has the strongest effect, ions of magnesium, potassium, hydrogen, and sodium also work with certain hydrocolloids. The presence of these ions helps the molecules in the mix link up to form the gel network. Hydrocolloids and their coagulants allow cooks to achieve some rather amazing feats, including a Modernist hallmark called **spherification.**

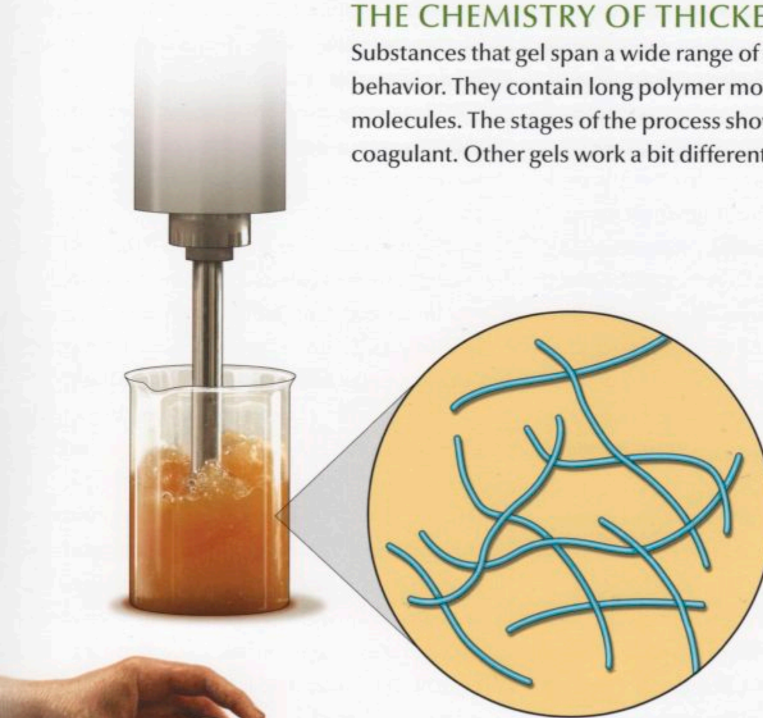
Some proteins, such as those found in egg or in milk (and in a few hydrocolloids), will coagulate into a gel when you add an acid—in other words, the hydrogen ions that cause acidity can also act as a coagulant. Ricotta and a few other fresh cheeses are gelled with acids.

Other coagulants are enzymes; a prominent example is rennet, also called chymosin. You may know it as the agent that causes milk proteins to gel into curds, a key step in cheesemaking. Tofu is a cheese-like gel made by solidifying soy milk to various degrees of firmness by means of a coagulating salt, such as magnesium chloride. In all of these examples, the results are the same even though the underlying chemical reactions are different: a gel forms only when the coagulant is present and other conditions are appropriate.

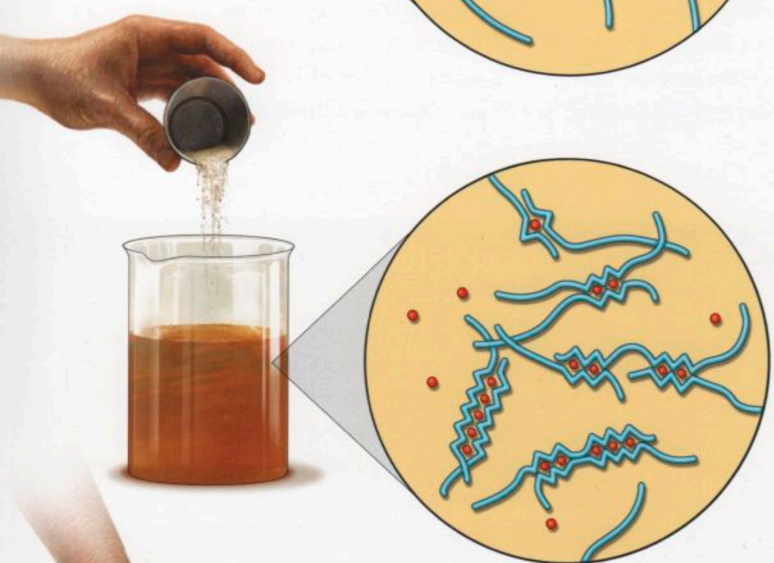
One widely used coagulating enzyme is **transglutaminase**, which encourages the **amino acids** that make up proteins to link together. Food manufacturers often use the compound (the active ingredient in Activa) to make meat stick together (see page 3·250), and as a result, chefs call it "meat glue." Because transglutaminase can link up protein amino acids that are suspended in a liquid, it can also serve as a coagulant to form a protein gel. Added to gelatin, it can help stiffen the resulting gel and raise its melting temperature. Transglutaminase can also increase the stiffness of egg and dairy gels while decreasing syneresis.

THE CHEMISTRY OF THICKENING AND GELLING

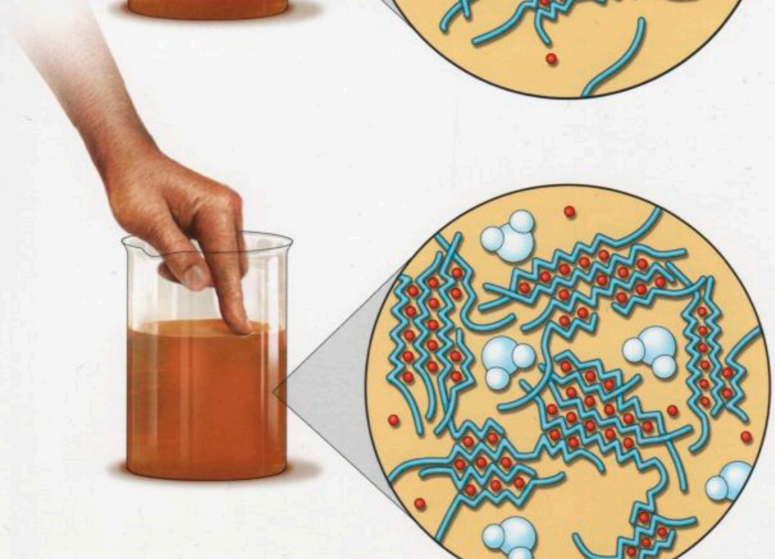
Substances that gel span a wide range of chemical compositions, but they all exhibit similar behavior. They contain long polymer molecules that can link up to create a mesh that traps water molecules. The stages of the process shown below illustrate how alginate gels with a calcium coagulant. Other gels work a bit differently, but always involve interlinking polymer molecules.

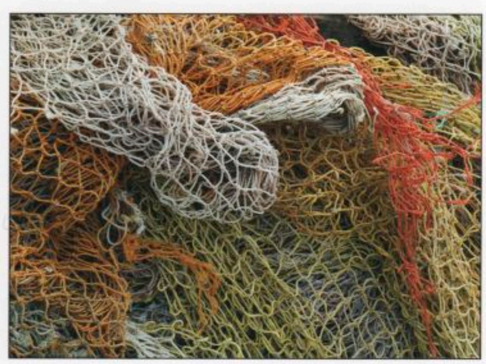


Gelling agents contain long polymer molecules. It takes some effort—heat or stirring, or both—to disperse them and surround them with water molecules, a process called hydration. Prior to gelling, the long molecules typically thicken the liquid as they slide past each other like strands of spaghetti in a pot.



In order to form a gel, the molecules must stick to each other, either directly or through a coagulant such as calcium ions (red spheres). Think of the gel molecules as being like egg boxes, and the coagulant molecules like eggs. Without eggs present, the boxes can't stick to each other; with them, the boxes will connect together to form a gel network. Some gels don't need a coagulant—in that case, the egg carton analogy isn't as apt: the molecules just stick to each other.





The gel sets as water molecules become trapped in the molecular mesh like fish caught in a net. The bonds among the molecules are like the knots that connect strands to make a fishnet.

For more details on Modernist gels, see page 124.

For more on xanthan gum, see page 40.

In some cases, it is important to remove a coagulant in order to prevent premature gelling. This can be achieved by adding a **sequestrant**, a compound that reacts with coagulant molecules and inhibits their ability to promote gelling.

Most gelling agents come in various grades and versions created by food ingredient manufacturers to optimize them for various uses. Generic versions of xanthan gum, agar, or sodium alginate that you might find in the grocery store are quite different from the dozens of carefully graded products available from a food ingredient company. The grades vary by strength, concentration, hydration temperature, or other important factors.

The proprietary ingredients may also include chemical modifications; for example, gellan gum comes in two main forms: low-acyl (LA) and high-acyl (HA) gellan gums, which are produced by different purification steps. They have very distinct properties, and are as different from one another as they are from other kinds of gelling agents. The same is true for HM and LM pectins and for many other gelling agents. Don't assume that agents having similar names also have similar properties—often they don't.

When two or more gelling agents are mixed they can show **synergy**, which means they can act more powerfully together than either does alone, or can even create a distinctly new effect. Some gelling agents react to create tight bonds among their molecules, so using both compounds together makes a much firmer gel than either forms alone. Xanthan gum and locust bean gum exhibit synergy when used together. By itself, xanthan gum can easily thicken fluids, but it will not make a solid gel. Add locust bean gum to the mix, and a gel forms.

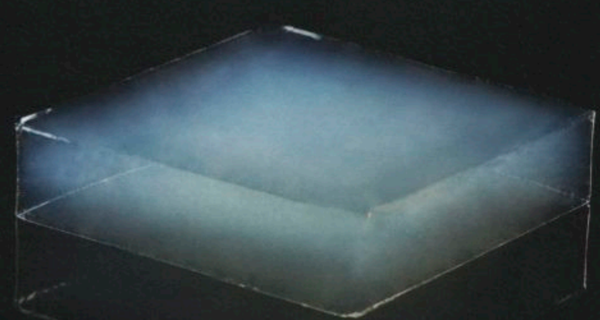
Unfortunately, relatively little theory exists that can help cooks know which gelling agents or coagulants will have synergistic effects. We can recommend several good combinations based on trial and error in our kitchen and others (see Hydrocolloid Interactions, page 44), but more information would be helpful. There are many possibilities out there awaiting discovery.

THE HISTORY OF
Aerogels

In 1931, two chemists at what is now the University of the Pacific in Stockton, California, were competing to remove the water from a gel without causing any shrinkage. Beyond the friendly rivalry, the pair wanted to address an important theoretical question: do the molecules that turn a liquid into a gel form a stable network like a cage? If so, then one might be able to remove the water and leave that cage in place and filling the same volume. But if the molecules did not form a connected structure, dehydration would simply leave a pile of powder.

One of the chemists, Samuel Stephens Kistler, removed the water without affecting the cage-like structure by using a technique called supercritical drying. He exchanged the water for alcohol, and then drove the alcohol to its **critical point**, a condition in which it is neither wholly liquid nor gaseous, so it escaped the gel. Kistler dubbed his new, almost ephemeral material an aerogel. The ghostly stuff has the lowest density of any solid ever created.

An aerogel is incredibly lightweight, but it also displays interesting strength and insulating properties. NASA engineers have used aerogels like a kind of interplanetary catcher's mitt to capture high-speed space dust. The substance also has an unusual bluish hue, like solid cigarette smoke, owing to the very small size of the gel's interlinked molecules. This optical phenomenon is another example of the **Tyndall effect** described on page 203.



What Matters for Gelling

The variety of gelling agents now available to the modern chef is remarkable. The selection may even be overwhelming at first. To choose an appropriate gelling agent, first consider the characteristics of your base. Is it going to be served hot or cold? Is it clear or cloudy? Is it very acidic or creamy?

Answering these questions will narrow your field of choices. Agars and gellans can stand up to heat. Eggs and carrageenans work well in creamy dishes and dairy products. Gelatins are shiny and clear.

Next, choose the gelling characteristics you prefer. Are you making a delicate, chilled wine gelée, so close to liquid that it should quiver and threaten to collapse with a warm breath?

Or perhaps you want dense, chewy cubes of coconut curry to float in hot soup, ribbons of leathery film to tangle into salads, or sticky pâte de fruit cast into whimsical bon bons?

Agar is brittle, starches can be slick and creamy, and gums are exactly as they sound: chewy. As you consider stiffness, pliability, elasticity, and presentation, a few best bets will emerge.

Finally, you can base your choice on taste and flavor release. Gellan gums and pectins have excellent flavor release, while methylcellulose can add a slightly unpleasant taste. Tables throughout this chapter list our recommendations for a wide range of uses.

Factor	Range of values	Example
serving temperature	cold (5 °C / 41 °F and below)	chilled
	neutral (about 20 °C / 68 °F)	room temperature
	hot (50 °C / 122 °F and above)	served hot
opacity	clear/transparent	aspics, dessert jellies
	opaque	custards, mousses
pH	alkaline (≥8)	egg whites
	neutral (6–8)	most vegetables and meats
	mildly acidic (3–6)	fruit juices, purees
	very acidic (≤3)	lemon juice, vinegars
mouthfeel	creamy	cream sauces
	sticky	syrups
	slippery	noodles
setting	thermo-reversible	melts with heat and resets when chilled
	thermo-irreversible	sets with heat and does not melt
	hysteresis	melts and sets at different temperatures
	ions required	some agents require the presence of ions to gel
stiffness	liquid when sheared	fluid gels
	soft gel	gelatin desserts
	stiff gel	pâte de fruit
	very stiff gel	gummy bears
	dried gels	films, tuiles
brittleness/elasticity	soft, rubbery	hard-boiled egg whites, high-acyl gellans
	medium	aspics, gelatins
	stiff, brittle	low-acyl gellans, agar gels
solid suspension	low	low viscosity
	high	highly viscous or thixotropic
flavor release	slow and long-lasting	high-fat gels and starches
	fast and short-lived	gelatins, pectins, gellans

EGG GELS

Egg gels are the basis for many classic dishes. Indeed, eggs are often added to food mixtures precisely because egg proteins act to hold ingredients together. Eggs bind together the constituents of a muffin batter, the flour granules in a pasta dough, and the elements of a sweet dessert custard, a quiche, or a *chawanmushi* (a savory Japanese egg custard). They also bind forcemeats in some sausages or meatloaf.

For more on sausages and how they bind, see Restructuring Meat, page 3·220.

Eggs' versatility as gelling agents is unmatched by other ingredients in conventional cooking. Cook them gently while stirring constantly to make a pourable crème anglaise, or blend and cook without stirring to make a firm egg custard. Standard texts on cooking often fail to discuss in detail why eggs react with other foods in the ways that they do. With an understanding of these processes, you can use eggs to your best advantage.

When egg yolks are frozen and then thawed, they form a raw but quite sliceable gel.

At temperatures below about 55 °C / 130 °F, egg proteins will not join into a gel-forming network—even if they are held under those conditions for hours. You can exploit this phenomenon to **pasteurize** eggs in the shell because salmonella and other egg-borne pathogens die at those temperatures (see page 1·192). Pasteurized eggs look just like raw eggs, with all the physical properties that you'd expect. They can be whipped into a meringue, act as an **emulsifier** in mayonnaise, and perform other "raw" egg roles, but without the risk of causing illness. Millions of people eat raw eggs safely, but occasionally some fall ill. Since it is so easy to do, it is good practice to pasteurize all eggs that would otherwise be eaten raw.

You can turn an egg gel into a fluid gel by shearing it with a hand blender, electric blender, or rotor-stator homogenizer. This trick is rather surprising at first sight: what looks like a completely solid, cooked egg gel instantly turns liquid. This won't work for a fully cooked or hard-boiled egg, of course. It applies only to egg gels that have not been heated enough to set fully.

At temperatures above 55 °C / 130 °F, egg proteins start to form thermo-irreversible gels. It's important to keep in mind that egg whites gel at lower temperatures than egg yolks do. So at any given cooking temperature, the white always sets harder (and seem more fully cooked) than the yolk does, although each has a different texture.

The photos on pages 76 and 77 show the detailed progression of an egg from its raw, pasteurized state to a very firm, brittle, hard-cooked state. As you become familiar with the characteristic solidification temperatures of egg whites and egg yolks, you will be able to deftly tailor egg cooking to suit specific outcomes.

The basic challenge in cooking a whole egg is to strike a balance between the doneness of the white and that of the yolk. Cooking an egg to thermal **equilibrium** (when the temperature is the same throughout) in a water bath, a combi oven, or a water-vapor oven takes about 35 minutes. The cooking time for small quail eggs is shorter (15 min) and longer for large goose eggs (40 min). Because you are cooking until the egg reaches the same temperature as its surroundings, the timing need not be precise.

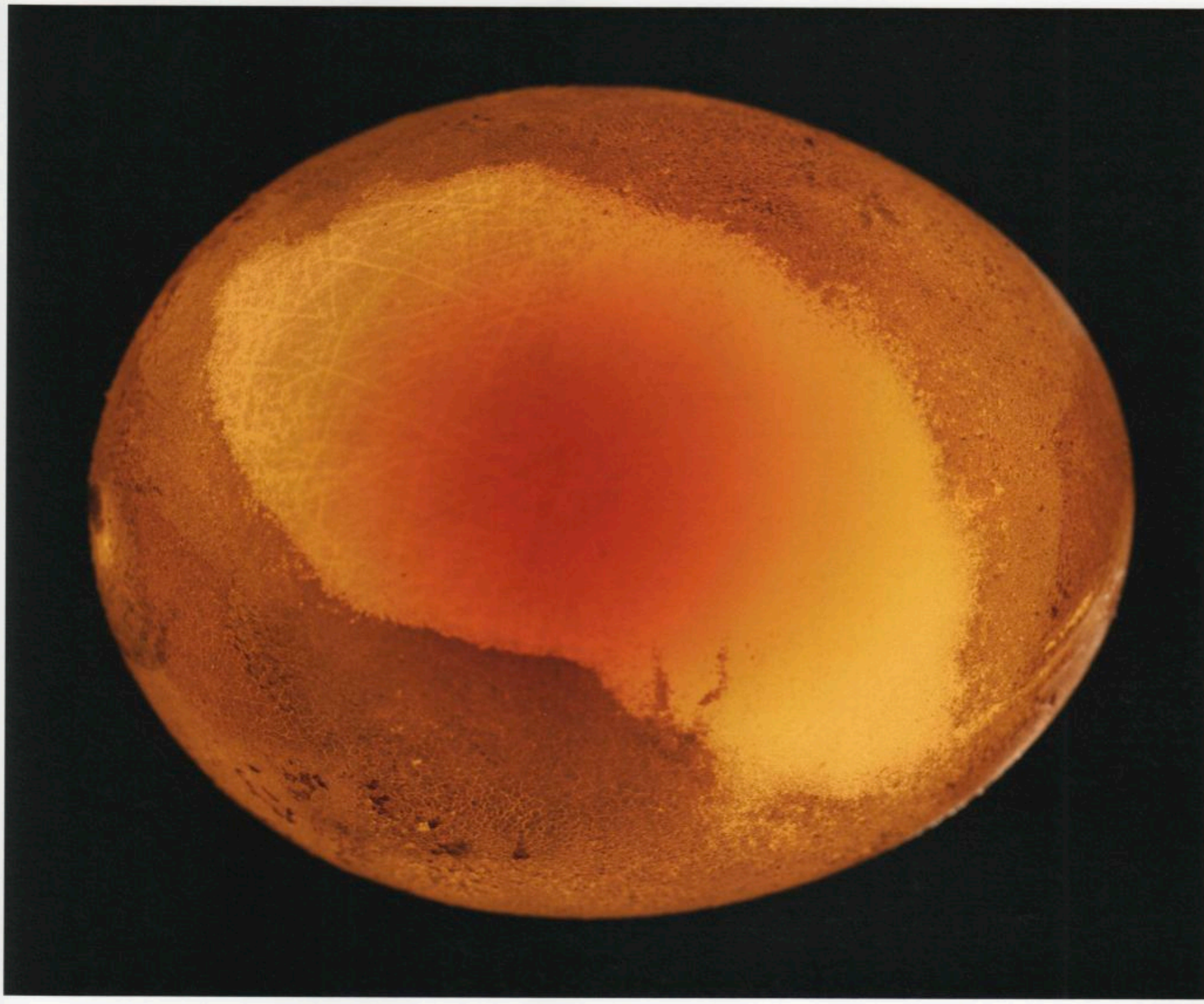
Exacting cooks can make perfect soft-boiled eggs by using a two-step process. First, cook the egg for 35 min at 60 °C / 140 °F for a liquid yolk, or at 64 °C / 147 °F for one that is more set. To ensure food safety, you can pasteurize the eggs by holding them there for an additional 12 min. If necessary for convenience, the eggs can wait at these temperatures for an extended period.

When you're ready to serve the eggs, plunge them into boiling water for 1–2 min if you want to serve them in the shell; boil for 3 min if you want to shell them. This technique creates a thermal gradient in the egg, so the outer layers (the white) are hotter than the interior (the yolk). The brief dip in boiling water should heat the white to nearly an ideal temperature. We find that this two-stage approach is more reliable than the standard "three-minute egg" routine.

It's difficult to achieve a perfect sunny-side up egg in a frying pan because the white and the yolk cook at different temperatures. No approach achieves the right conditions for each of them unless you cook the white and yolk separately.

So that's what we do. We cook the white first inside egg rings on a nonstick pan placed in a steam oven set to 80 °C / 175 °F. We then remove the pan and carefully place a raw egg yolk at the center of each flat round of white. The pan goes back in the steam oven at 60 °C / 140 °F until the yolk is done. This approach yields the ultimate "fried" egg because the yolk and white are cooked at their individual ideal temperatures.

Whole eggs cooked at low temperatures,



Eggs that have been marinated in vinegar for a few weeks lose their shells and acquire a bouncy texture, while remaining translucent.

particularly in the range of 62–65 °C / 144–149 °F, are famous for their unusual, half-congealed texture. In Japan, they have been known as *onsen tamago*, or hot spring eggs, for ages. Their use in Western cuisine has been popularized by Hervé This, Pierre Gagnaire, and many others. Varying tastes for egg textures means that no single magic temperature exists, of course; each one-degree increment from 60 °C / 140 °F up to 90 °C / 194 °F produces a different sort of egg, ranging from liquid to brittle and powdery (see Egg Textures, next page).

Things get a bit more complicated when you mix other ingredients with eggs. The textures of egg white, egg yolk, and mixed whole egg still depend on the cooking temperature and the exact course of heating, but they are also affected by the amount and nature of other materials (liquid and solid) that you mix in. As a result, the composition of mixed egg gels varies from scrambled eggs or an omelet—almost all egg, with only a little extra fluid and fat—all the way to very light custards and flans, which are heterogeneous mixtures bound by the gelling power of egg proteins.

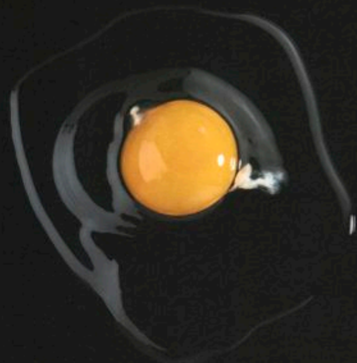
We have conducted careful experiments to map the parameters that give us the best results; you can find the results beginning on page 84. As always, one person's perfect texture is another's ruined breakfast, but our egg gel formulas give you a starting point for your own taste trials.

The most reliable way to cook whole eggs is to bring them to thermal equilibrium—that way, they can't overcook. But you can use higher temperatures for a short time to get results similar to *onsen* eggs. Aki Kamozawa and H. Alexander Talbot of Ideas in Food prefer 75 °C / 167 °F for 13 min for a chicken egg (see page 78). Ferran Adrià uses 7 min at 70 °C / 158 °F for quail eggs.

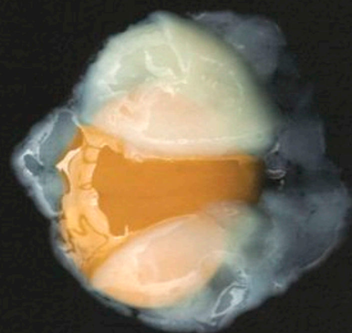
EGG TEXTURES

Temperature, not time, determines the texture of an egg when cooked. The visual chart below tracks the dramatic effects that just a few degrees' increase in temperature has on the white and the yolk. Around 60 °C / 140 °F, the white begins to become opaque, whereas the yolk is not firmly solid until 74 °C / 165 °F, which is our favorite temperature to replace hard-boiled eggs. Individual preferences vary; with modern equipment, you can dial in a core temperature and consistently hit the texture you like best, from pasteurized but raw, to moist and jammy, to brittle and dry.

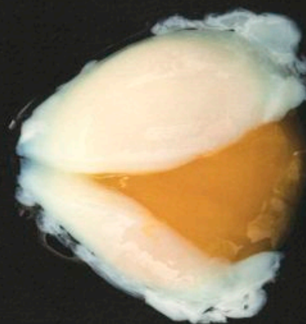
55 °C / 131 °F



60 °C / 140 °F

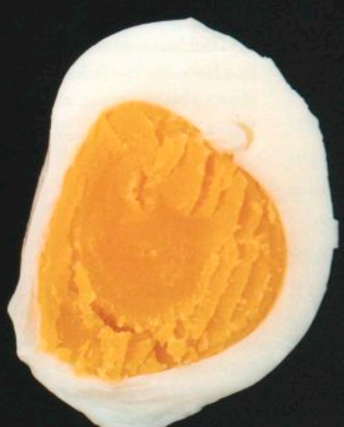


62 °C / 144 °F



	55 °C / 131 °F	60 °C / 140 °F	62 °C / 144 °F
Whole egg:	pasteurized, 2 h	semiliquid	*onsen* egg
Egg white:	pasteurized, 2 h	starting to gel	runny
Egg yolk:	pasteurized, 2 h	runny	viscous

74 °C / 165 °F

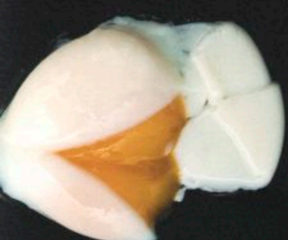


78 °C / 172 °F

80 °C / 176 °F

	74 °C / 165 °F	78 °C / 172 °F	80 °C / 176 °F
Whole egg:	white and yolk set, best bet for whole egg	medium-boiled, elastic	hard-boiled
Egg white:	just set	moderately firm	firm
Egg yolk:	just solid	moist	tender

65 °C / 149 °F



firm *onsen* egg
loose
syrupy

68 °C / 154 °F

poached
barely set
jammy

70 °C / 158 °F

soft boiled
tender
fudgy

72 °C / 162 °F

yolk becomes spherical
silky
pasty

82 °C / 180 °F

rigid
very firm
slightly dry; greening begins

84 °C / 183 °F

rigid
rubbery
dry; greening increases

86 °C / 187 °F

solid
brittle, rubbery
powdery; more greening

90 °C / 194 °F

solid
very brittle and rubbery
very powdery; a lot of greening

PARAMETRIC RECIPE

COOKED WHOLE EGGS

How do you boil the perfect egg? Ask 20 different chefs that question, and you will get 20 different answers. Our research makes one thing clear: to cook whole eggs, stop thinking about time, and concentrate instead on temperature.

Japanese cooks ages ago discovered that eggs left to cook very slowly in natural hot springs (*onsen*) attained a perfect consistency and creamy, rich flavor. You can re-create a more controlled environment than Japanese hot springs. Use a water bath, a combi oven, or a water-vapor oven, if you have such equipment. If not, stick a digital thermometer into hot water on the stove top, and monitor it closely.

At Arzak, in San Sebastián, Spain, chef Juan Mari Arzak removes the shells. He famously flavors raw eggs with truffles and duck fat, reshapes them in plastic wrap, and cooks them in a water bath to make the Arzak Egg Blossom.

Best Bets for Cooking Whole Eggs

Recipe	Cook (°C)	Cook (°F)	Cook (min)	Equipment	See page
pasteurized egg	55	131	2 h	water bath	1·190
onsen egg (Japanese slow-cooked egg)	62–68	144–154	35	water bath	76
perfect soft-boiled egg	100	212	3	water baths and blow torch	next
	64	147	35		
perfect hard-boiled egg	79	174	35	water bath	76
fast hot-spring egg adapted from Aki Kamozawa and H. Alexander Talbot	75	167	13	water bath	
fast hot-spring quail egg adapted from Ferran Adrià	70	158	7	water bath	
Arzak egg blossom	85	185	12	water bath	80

HOW TO Peel an Egg with Liquid Nitrogen

1 **Cook egg (not shown).** For a chart of the textures available at various cooking temperatures, see page 76.

2 **Submerge in ice water until fully chilled, 5–7 min.**

3 **Immerse in liquid nitrogen until surface is frozen, about 30 s.**

4 **Temper in water at room temperature.**

5 **Peel carefully.** The thawed shell will easily break away from the cooked egg white inside.

6 **Serve at room temperature or reheated.** Do not heat to higher than the original cooking temperature.

HOW TO Make a Perfect Soft-Boiled Egg

The classic approach boils an egg for a precise period of time, but this can yield results that are less than ideal. We prefer a two-step procedure. We immerse the egg in boiling water for a short period of time to set the egg white, which gels at a higher temperature than the yolk does. Then we cook the egg at low temperature in a water bath, combi oven, or water-vapor oven (see page 2·150) to make the yolk the exact consistency we like. Note that these steps can be done in either order.

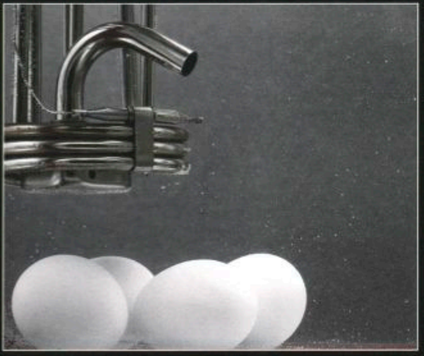
If you serve the soft-boiled egg in its shell, cutting it with an egg topper can make the boiling step as short as 1 min. If you want to serve the egg out of its shell, as shown below, then increase the boiling time to 2–3 min. We don't rely on the temperature of the boiling water to cook the egg fully, so although the cooking time does increase at higher elevations, this is not critical.

The classic soft-boiled texture requires cooking the egg to 64 °C / 147 °F, but you can get a more liquid yolk consistency at lower temperatures, down to 60 °C /140 °F.

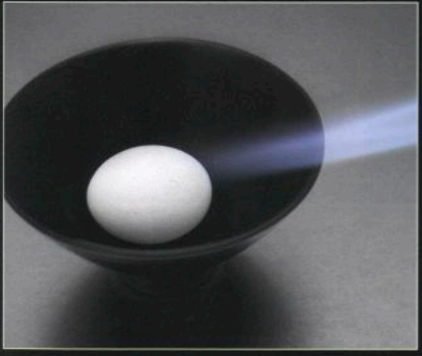
Shelling the eggs can be greatly improved by using either high heat from a blowtorch or intense cold from liquid nitrogen to make the egg shell brittle and to firm up the egg white right below the shell.

1 **Boil the egg for 3 min.** Only the outside layer will cook.

2 **Immerse in ice water until fully cooled.** If you wish to blanch eggs in advance, chill them after blanching, and then refrigerate.

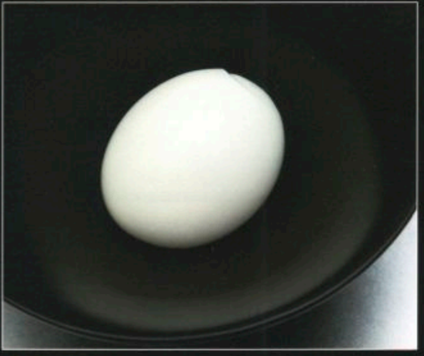


3 **Cook in 64 °C / 147 °F water for 35 min.** Rest for 2 min at room temperature. Partly cooling the egg keeps it from rupturing when heated with a blowtorch.



4 **Heat with a blowtorch for about 2 min.** Rotate the egg constantly while flashing it with the torch to thoroughly dry and heat the shell.

5 **Peel carefully.** The brittle shell should fall away easily.



6 **Reheat to serve.** Reheat in a water bath at 60 °C / 140 °F for 30 min. Alternatively, for enhanced flavor, reheat in a broth or other flavorful liquid.

EGG BLOSSOM INSPIRED BY JUAN MARI ARZAK

Yields four eggs

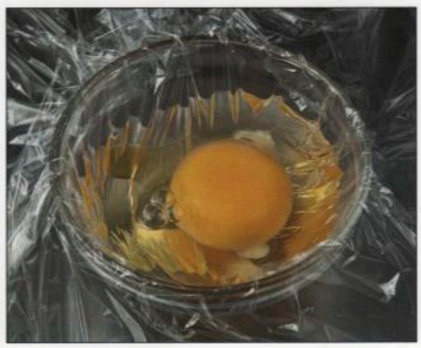
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole eggs	four large		① Line small bowl with plastic wrap.
Duck fat	50 g	100%	② Combine fats, and brush center of plastic wrap.
Extra-virgin olive oil	25 g	50%	③ Break one egg in center of bowl.
Truffle oil	10 g	20%	④ Season with salt and additional fat.
Salt	to taste		⑤ Gather edges of plastic wrap together carefully.
			⑥ Twist wrapped mixture into ball, and tie off top of wrap.
			⑦ Repeat procedure with remaining eggs.
			⑧ Cook eggs in 85 °C / 185 °F water bath for 12 min.
			⑨ Cut away plastic wrap to serve.

(2000)

Add 2 min to the cooking time if using duck eggs.

This recipe uses a single step of 12 min in an 85 °C / 185 °F bath, but you could also cook the eggs in a two-stage manner (as when making soft-boiled eggs as described on the previous page): boil them for 1-3 min, and then cook in a 40–64 °C / 104–147 °F water bath.


1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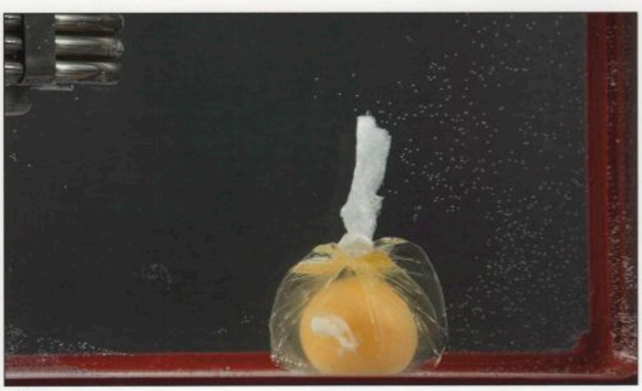
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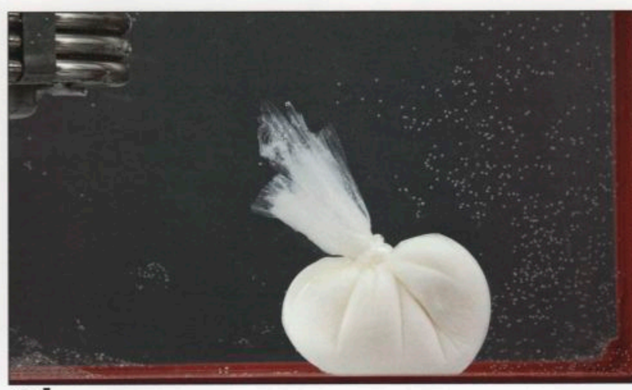
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This recipe uses plastic wrap to make a free-form shape, but you can also put the egg in silicone rubber molds made for pastry, baking, or candies. This allows you to make eggs that are perfect spheres, cubes, or any other shape.

DEVILED EGGS

Yields four portions

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole eggs, in shell	200 g (four large)	100%	① Cook in 72 °C / 162 °F bath for 35 min. ② Plunge in ice water. ③ Peel, and separate yolks from whites. ④ Set yolks aside. ⑤ Retain whites for mayonnaise.
Reserved egg whites, from above	145 g	72.5%	⑥ Blend.
Champagne vinegar	25 g	12.5%	
Dijon mustard	10 g	5%	
Extra-virgin olive oil	100 g	50%	⑦ Drizzle slowly into egg white mixture while blending. ⑧ Emulsify fully to make mayonnaise.
Walnut oil	20 g	10%	
Tarragon, thinly sliced	4 g	2%	⑨ Fold in.
Black pepper, coarsely ground	to taste		⑩ Season mayonnaise.
Cayenne pepper	to taste		⑪ Smear on each plate, and garnish each plate with one yolk.
Salt	to taste		
Bottarga di Muggine (store-bought)	20 g	10%	⑫ Grate finely over each plate.

(2010)

At 72 °C / 162 °F, the yolk sets hard enough that it remains spherical rather than flattening from its own weight—as it does at lower temperatures (see page 76). These yolk balls have a wonderful consistency. They can be used as a kind of dumpling in soups or other dishes.

PARAMETRIC RECIPE

PRESERVED AND PICKLED EGGS

Eggs used to be a seasonal ingredient. Most of us aren't aware of this when we grab a dozen clean, inspected, graded eggs in shock-resistant, date-stamped cartons from the supermarket refrigerator.

Many cultures found ways to slow bacteria growth and reduce the spoilage of eggs. In Britain, brine-pickled eggs are still a traditional accompaniment to fish and chips. In Asia, the practice of preserving eggs evolved from a clever storage method to the development of a uniquely flavored and prized ingredient. Duck or chicken eggs were soaked in a wet mixture of lime, salt, and water, or were packed in a clay and lime mixture with salt and straw and left for months to mature.

Modern "century eggs" are easily made by vacuum sealing them with a brine of water and sodium hydroxide for three weeks. The result: eggs that are soft, smooth, slightly gelatinous, and transformed to a pronounced flavor.

Whether changing the pH level, as with the century egg, or immersing the egg in alcohol or salt, preserving methods alter the electrical charge of the protein molecules. The raw egg coagulates as a result, and takes on a cooked texture.

When eggs are shelled and sealed sous vide with vinegar, they remain clear after cooking. Rather than eating the eggs straight up, the preserved creations can be used like century eggs in new applications.

PRESERVING AND PICKLING EGGS

1 **Select a recipe.** See the table Best Bets for Pickled and Preserved Eggs below for suggestions.

2 **Make the brine or curing agent.** Prepare enough to completely cover all eggs. Weights in the table are scaled to be proportional to the weight of the principal liquid. For example, to make a dozen century eggs, weigh out enough water to cover the eggs completely, and then add 9 g of salt and 4.2 g of sodium hydroxide for every 100 g of water.

3 **Submerge very fresh whole eggs in brine or cure, and refrigerate for the time indicated.** Note that all of the recipes here, except the vinegar-coagulated egg, require that the eggs remain in the shell when immersed in brine.

4 **Cook (optional).** For a more familiar texture, lightly cook the cured eggs, using the time and temperature indicated in the table.

Best Bets for Pickled and Preserved Eggs

Recipe	Coagulant	(scaling)	Brine/cure	(days)	Cook (optional) (°C)	(°F)	(min)	See page
century egg	water	100%	brine	20	68	154	35	next
	salt	9%	soak	2				
	sodium hydroxide (lye)	4.2%	dry	5				
salt-coagulated egg	water	100%	brine	28	68	154	35	
	salt	32%						
vinegar-coagulated egg	vinegar	100%	brine	½–1	62	144	20	next
miso-cured egg yolks	red miso	100%	cure	3		n/a		87
	sake	18.5%						
	sugar	16%						

EXAMPLE RECIPE

PICKLED QUAIL EGGS INSPIRED BY HERVÉ THIS

Yields 150 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Quail eggs	200 g (about 10)	100%	① Crack open; reserve whole quail eggs individually.
Champagne vinegar	500 g	250%	② Combine to make brine, and bring to simmer.
Water	250 g	125%	
Sugar	135 g	67.5%	
Salt	8 g	4%	
Black peppercorns	1 g	0.5%	③ Combine.
White peppercorns	1 g	0.5%	④ Pour hot brine over spice mixture, and cool.
Pink peppercorns	0.5 g	0.25%	⑤ Strain cold brine into large sous vide bag.
Yellow mustard seeds	1 g	0.5%	⑥ Slide eggs gently, one by one, into brine-filled bag, while taking care to avoid collisions that could burst their yolks.
Celery seeds	1 g	0.5%	⑦ Vacuum seal, and refrigerate for 12 h.
Dill seeds	1 g	0.5%	⑧ Drain eggs, and cook in 62 °C / 144 °F bath for 15 min.
Aleppo pepper flakes	0.1 g	0.05%	

(original 2009, adapted 2010)

Although the cooked egg whites remain clear, they are coagulated and safe to eat.

EXAMPLE RECIPE

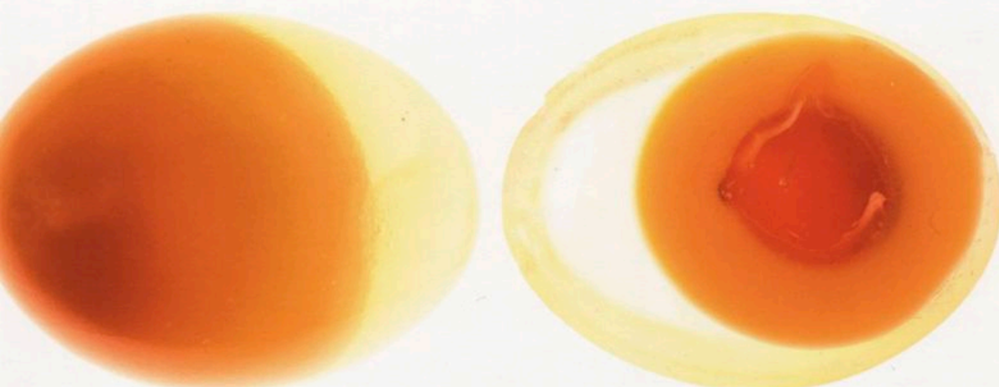
CENTURY EGG

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	1 kg	100%	① Whisk together until fully dissolved to make brine.
Salt	90 g	9%	
Sodium hydroxide (lye)	42 g	4.2%	
Whole duck eggs, washed and checked for cracks	450 g (about six)	45%	② Vacuum seal eggs with brine. ③ Refrigerate in bag for 20 d. ④ Remove from bag, and soak in fresh water for 2 d. ⑤ Air-dry at room temperature for 5 d. ⑥ Optionally, cook in 68 °C / 154 °F bath for 35 min. Cool and peel. ⑦ If desired, garnish with pickled mushrooms and seaweed vinegar.

(2010)

For a pickled mushroom recipe, see page 3·313.
For seaweed vinegar, see page 2·315.



The "white" of a Chinese century egg usually has a translucent brown appearance, and the yolk is tinged green. Many people believe this is the result of packing the eggs in tea leaves, but in fact this color comes from the Maillard reaction. Over time, the high final pH of a century egg (ranging from 9–12) causes proteins and sugars in the egg white and yoke to undergo Maillard browning that transforms the color of the egg. The century egg shown here is too fresh for this to have occurred yet. For more on the Maillard reaction, see page 3·89.

PARAMETRIC RECIPE

CUSTARDS

Heat eggs with milk or cream, and you'll get custard. The ratio of egg to liquid, along with the cooking temperature, determines whether the custard is firm and dense, like a frittata, or pourable, like a crème anglaise. The handy table of custard textures below removes much of the mystery of the process.

Just set the weight of the liquid to 100%, and then figure the quantity of egg relative to that. For example, to make a firm omelet at 83 °C / 181 °F, you'll need 150 g of egg for every 100 g of milk.

A creamy quiche made with 70% egg yolks and cooked to a core temperature of 88 °C / 190 °F will have a texture similar to that of a quiche made with 130% egg yolks cooked only to 75 °C / 167 °F. Whole-egg and yolk-only custards can also be made to have similar textures (at least approximately). In general, yolk-only custards have more egg flavor than whole-egg custards do. They also tend to be a bit more elastic, whereas whole-egg custards tend to be more brittle and may have syneresis (weeping) issues.

The more egg in the mixture, the more pronounced an egg flavor it will have. Heat-sensitive ingredients, such as a seafood quiche, do better at lower temperatures, which in general require using more egg.

Syneresis is a problem with some firmer custards. Adding Activa RM (use 1.5% of the weight of egg-liquid mixture) can solve this while also firming up the texture—for an example, see page 96. Once mixed, the Activa custard should be left to set overnight or parcooked at 55 °C / 131 °F for 10 min before final cooking.

Although dairy liquids are typically used to make custards, stock or water also works. This substitution changes the flavor and texture to some degree, but the table below can still be used as a guideline.

The perfect custard temperature depends on three things: whether you use yolks or whole eggs; the proportion of egg to other liquid; and the final core temperature. Using the table below, you can achieve any result you want. Note that "milk," "quiche," and other terms in the table below refer to the resulting texture, not to ingredients or a specific recipe.

Custard Textures

	Whole egg					Egg yolk				
Cook (°C) (°F)	70 158	75 167	80 176	83 181	88 190	70 158	75 167	80 176	83 181	88 190
Egg (scaling)*										
10%	milk	half-and-half	thin cream	heavy cream	thin crème anglaise	milk	thin cream	heavy cream	thin crème anglaise	crème anglaise
30%	milk	thin crème anglaise	crème anglaise	crème brûlée	flan	milk	thin crème anglaise	crème anglaise	thick crème anglaise	flan
50%	milk	crème anglaise	crème brûlée	flan	soft-scrambled	milk	thick crème anglaise	pudding	flan	firm flan
70%	milk	thick crème anglaise	flan	soft-scrambled	frittata	thin cream	crème brûlée	flan	firm flan	quiche
90%	half-and-half	crème brûlée	quiche	frittata	tender omelet	heavy cream	flan	firm flan	quiche	soft-scrambled
110%	thin cream	flan	frittata	tender omelet	omelet	thin crème anglaise	firm flan	quiche	soft-scrambled	frittata
130%	heavy cream	firm flan	tender omelet	omelet	firm omelet	crème anglaise	quiche	soft-scrambled	frittata	tender omelet
150%	thin crème anglaise	quiche	omelet	firm omelet	dry-scrambled	thick crème anglaise	soft-scrambled	frittata	tender omelet	firm omelet
200%	crème anglaise	soft-scrambled	firm omelet	dry-scrambled	chewy	soft-scrambled	frittata	tender omelet	firm omelet	dry-scrambled
250%	thick crème anglaise	frittata	dry-scrambled	chewy	rubbery	frittata	tender omelet	firm omelet	dry-scrambled	chewy

*(*set weight of liquid to 100%*)

PARAMETRIC RECIPE

SEPARATED EGG GELS

The best way to ensure perfect results when cooking eggs is to separate the yolk from the white and to monitor their individual temperatures closely. Egg yolks gel at lower temperatures than egg whites do.

Another good reason to separate eggs is to capitalize on the very different structures and chemical makeups of the white and the yolk. Egg yolks enrich a dish with color, flavor, and fat. They can vary in texture from creamy to dry and crumbly. Egg whites are vividly white, sticky, lean, and elastic. They make excellent binders and structural elements.

Modern kitchen tools like water baths and steam ovens ensure that the separated whites and yolks are cooked to exactly the right temperature, so there is little or no risk of breaking or curdling.

MAKING GELS FROM COOKED EGG YOLKS AND EGG WHITES

1 **Select a texture.** The table below lists our recommendations.

2 **Measure the yolk, white, liquid, and salt.** Scale the ingredients relative to the weight of the eggs (for example, use 2 g of salt for every 100 g of egg yolk in a sliceable yolk).

3 **Blend eggs with liquid, and whisk in seasoning.** Eggs for the two-stage fried egg should just be separated. For the two-stage baked eggs, blend the whites with the cream and keep the yolks whole.

4 **Cook.** Appropriate methods, times, and temperatures are indicated, along with references to example recipes.

Sous vide is the perfect way to cook egg gels because of the precise temperature control it offers. Unfortunately, cooks often want to mold eggs in a ramekin, which does not work well in a vacuum bag. A combi oven or other low-temperature steam oven works well in such cases.

Best Bets for Separated Egg Gels

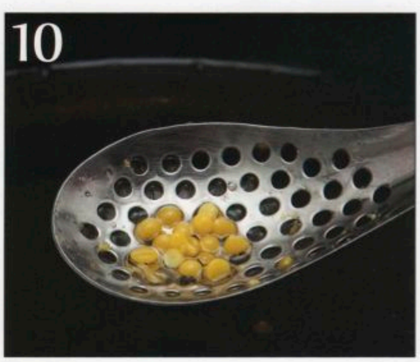
Texture	Egg yolk (scaling)	Egg white (scaling)	Liquid	(scaling)	Salt (scaling)	Cook: Method	(°C)	(°F)	(min)	See page
crème anglaise	100%	n/a	milk or cream	400%	5.5%	sous vide	80	176	12	89
egg yolk droplets	100%	n/a	n/a		1.1%	open container in sous vide bath	77	171	2	86
sliceable yolk	100%	n/a	n/a		2%	sous vide	70	158	1 h	90
crème brûlée	100%	n/a	cream milk	200% 175%	5%	steam oven	79	174	35	88
egg white custard	n/a	100%	cream milk	110% 110%	3.5%	steam oven	83	181	15	
egg white droplets	n/a	100%	n/a		1.1%	stove top	74	165	3	86
two-stage baked eggs	white	100%	cream	35%	1.4%	steam oven	74	165	30	
	yolk	1 per serving	n/a		to taste		64	147	20	
Nathan's two-stage fried egg	white	1 per serving	n/a		to taste	buttered ring mold, steam oven	79	174	15	2·175
	yolk	1 per serving					63	145	25	

EGGS BENEDICT INSPIRED BY PEDRO SUBIJANA AND GRANT ACHATZ

Yields 610 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks	150 g	100%	① Whisk yolks together with salt, and strain through fine sieve.
Salt	3 g	2%	② Transfer to squeeze bottle.
Egg whites	150 g	100%	③ Whisk whites together with salt, and strain through fine sieve.
Salt	3 g	2%	④ Transfer to second squeeze bottle.
Clarified butter see page 213	750 g	500%	⑤ Divide butter evenly among two small pots. ⑥ Heat one pot to 72 °C / 162 °F and second pot to 90 °C / 194 °F. ⑦ Squeeze droplets of yolk mixture into 72 °C / 162 °F bath; keep drops separated. ⑧ Cook for 1 min. ⑨ Lift drops slightly from pot bottom with small spatula to help them float. ⑩ Remove droplets when they begin to float, reserving butter. Reserve warm. ⑪ Repeat procedure to make egg white droplets in 90 °C / 194 °F bath. ⑫ Reserve warm.
English muffins, ground	100 g	67%	⑬ Combine in nonstick pan.
Neutral oil	20 g	13.4%	⑭ Fry until golden, about 5 min, and drain.
Salt	to taste		⑮ Season toasted crumbs.
Sous vide instant hollandaise see page 228	150 g	100%	⑯ Heat in 62 °C / 144 °F bath for at least 10 min.
Canadian bacon, finely diced	45 g	30%	⑰ Warm with spoonful of reserved butter. ⑱ Fold into egg yolk droplets, egg white droplets, and toasted crumbs. ⑲ Portion egg, bacon, and crumb combination in small bowls. ⑳ Garnish with small amount of hollandaise.

(original 2007, adapted 2010)



EXAMPLE RECIPE

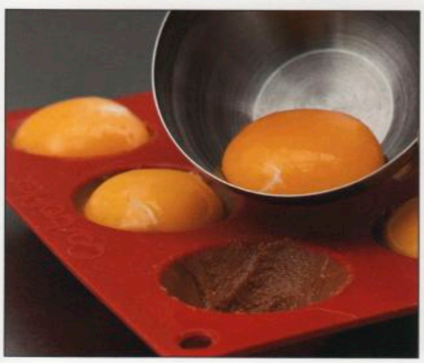
MISO-CURED EGG SHEETS

Yields 60 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Red miso	75 g	75%	① Combine.
Sake	14 g	14%	② Line small bowl with cheesecloth, or use silicone hemispherical mold.
Sugar	12 g	12%	③ Spread mixture in prepared bowl or mold to form well shape.
Egg yolks, whole	100 g	100%	④ Place yolks, individually and intact, in center of well, and cover with remaining miso mixture.
			⑤ Refrigerate for 48 h to cure. Flip yolks over, and refrigerate again for 72 h.
			⑥ Remove yolks from cure.
			⑦ Roll between two thin silicone mats or two pieces of plastic wrap to form sheets 1 mm / 1/32 in thick.
			⑧ Dry at room temperature for 15 min to firm.
			⑨ Use egg sheets for ravioli, or cut into noodles and dress with bonito flakes and olive oil.

(2000)

Cure the yolks for 48 h on each side (96 h total) for a softer, more pliable texture.



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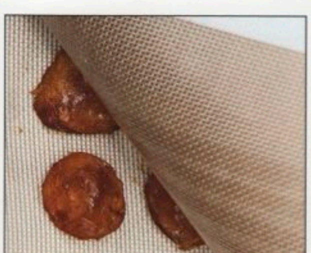

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The cured egg yolk sheets can be cooked in a 70 °C / 158 °F bath for a more flexible texture.

EXAMPLE RECIPE

PARMESAN CRÈME BRÛLÉE

Yields 450 g (about eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Heavy cream	350 g	140%	① Bring cream and cheese to simmer.
Parmesan, finely grated	80 g	32%	② Strain, and reserve 250 g of infused cream.
Cheese-infused cream, from above	250 g	100%	③ Blend together. ④ Divide mixture evenly among individual ramekins.
Egg yolks	67.5 g	27%	⑤ Cover ramekins with plastic wrap.
Salt	1.32 g	0.5%	⑥ Cook in 78 °C / 172 °F bath or steam oven to core temperature of 77 °C / 171 °F, about 35 min. ⑦ Refrigerate until cool, about 45 min.
Muscat grape syrup or onion sugar see page 52 or page 5·261	40 g	16%	⑧ Pour syrup over each crème brûlée to serve. Alternatively, dust onion sugar over surface of custards, and flash with blowtorch until caramelized.

(2010)

Sweet crème brûlée can be made with the same basic recipe. Omit the cheese, add 15%–20% sugar, and cook in a 82 °C / 180 °F bath to a core temperature of 81 °C / 178 °F.

For a lighter custard, substitute milk for part of the heavy cream. A typical ratio would be half milk, half cream.

EXAMPLE RECIPE

SAUCE ALLEMANDE

Yields 370 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White chicken stock see page 2·301	120 g	200%	① Blend until smooth. ② Pass through fine sieve.
Heavy cream	100 g	167%	③ Vacuum seal.
Egg yolks, blended and sieved	60 g	100% *(20%)**	④ Cook sous vide in 79 °C / 174 °F bath for 35 min. ⑤ Blend until smooth once more.
Mushroom jus see page 2·348	50 g	83%	
Unsalted butter, melted	40 g	67%	
Nutmeg, freshly grated	to taste		⑥ Season.
Salt	to taste		⑦ Serve with poached artichokes (see page 3·292) and braised chicken thighs (see page 3·99).
White pepper	to taste		

(2010)

(% of total weight of all other ingredients*)

This is a slightly Modernist version of a French haute cuisine classic perfected by Auguste Escoffier in the early 20th century. We think he would approve. The savory custard base can be flavored with other stocks or juices.

EXAMPLE RECIPE

CAULIFLOWER CRÈME ANGLAISE

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cauliflower, thinly sliced	400 g	160%	① Roast in 160 °C / 320 °F oven until deep amber, about 25–30 min. Alternatively, deep-fry in 190 °C / 375 °F oil for 5–6 min. ② Cool completely.
Whole milk	500 g	200%	③ Vacuum seal with roasted cauliflower. ④ Cook in 85 °C / 185 °F bath for 1 h to infuse milk. ⑤ Remove from bag, and strain. ⑥ Measure 250 g of cauliflower milk. ⑦ Cool milk to room temperature.
Cauliflower milk, from above	250 g	100%	⑧ Blend together until smooth, and vacuum seal.
Egg yolks	63 g	25%	⑨ Cook sous vide in 80 °C / 176 °F bath for 35 min. ⑩ Remove from bag, and cool. ⑪ Add additional cauliflower milk or heavy cream to achieve desired viscosity. ⑫ Vacuum seal and refrigerate.
Nutmeg, freshly grated	to taste		⑬ To serve, reheat crème anglaise in 70 °C / 158 °F bath for 10 min.
Salt	to taste		⑭ Pour into serving container. ⑮ Season.

(2010)

For more on deep-frying vegetables, see page 3·320).

EGG SALAD SANDWICH INSPIRED BY WYLIE DUFRESNE

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks, blended	200 g	100%	① Make sleeves measuring 2.5 cm by 30.5 cm / 1 in by 12 in from sous vide bags by using sealing strips of vacuum sealer. ② Pipe yolks into sleeves, and tie tops of sleeves tightly to make tube shapes. ③ Clip tubes to top of bath. ④ Cook in 70 °C / 158 °F bath for 1 h. ⑤ Remove yolks from sleeves, and cool completely. ⑥ Cut yolks into slices 2 mm / 1⁄16 in thick. ⑦ Cover with plastic wrap, and refrigerate.
Egg yolks	50 g	25%	⑧ Blend until smooth.
Lemon juice	15 g	7.5%	
Champagne vinegar	1 g	0.5%	
Neutral oil	200 g	100%	⑨ Drizzle slowly into yolk mixture, while blending, until fully emulsified. ⑩ Set aside mayonnaise.
Salted pollock roe (store-bought)	30 g	15%	⑪ Combine. ⑫ Fold into mayonnaise. ⑬ Set mixture aside.
Cornichons, minced	10 g	5%	
Salt	3 g	1.5%	
Chives, finely minced	2 g	1%	
Sriracha sauce	1 g	0.5%	
Pain de mie or white bread, crusts removed and sliced 5 mm / 3⁄16 in thick	150 g	75%	⑭ Cut bread into sandwich-size slices. ⑮ Brush outside of slices with clarified butter. ⑯ Toast carefully in pan until golden, about 1 min on each side. ⑰ Spread inside of each slice with mayonnaise. ⑱ Arrange egg yolks on one slice of bread.
Clarified butter, melted see page 213	as needed		
Black pepper	to taste		⑲ Season each yolk-covered slice.
Flaky sea salt	to taste		
Watercress leaves	40 g	20%	⑳ Garnish with leaves. ㉑ Top each with second slice of toasted bread to complete sandwich.

(original 2008, adapted 2010)

Wylie Dufresne came up with these molded egg yolk tubes to serve with his version of Eggs Benedict, which also involves Deep-Fried Hollandaise (see page 228) and crispy Canadian bacon. We've used them to make this delicious egg sandwich to show how versatile a preparation they can be.

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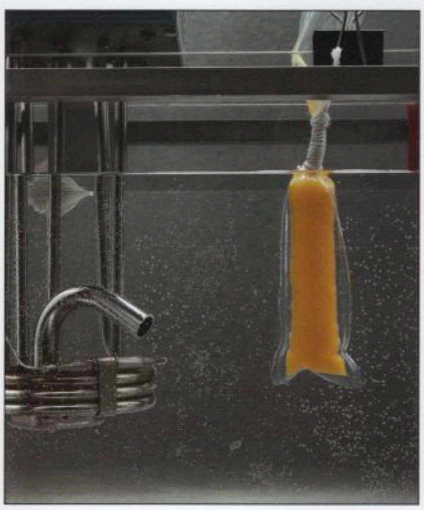

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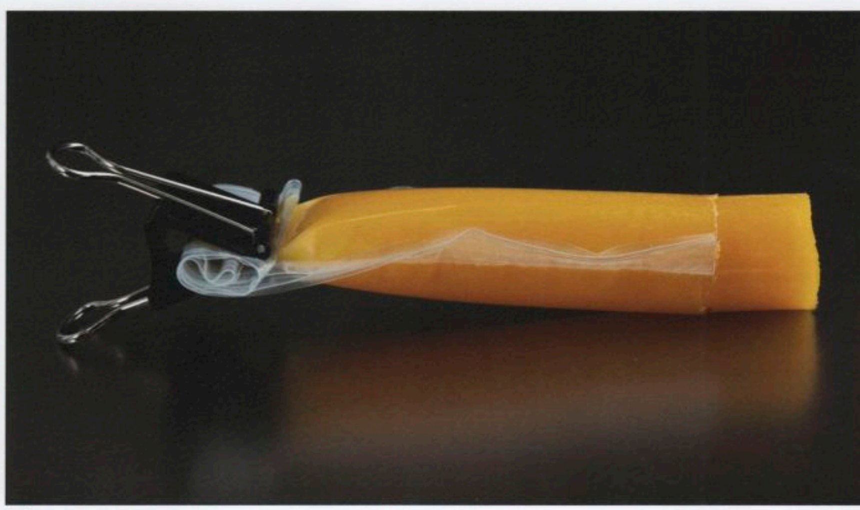

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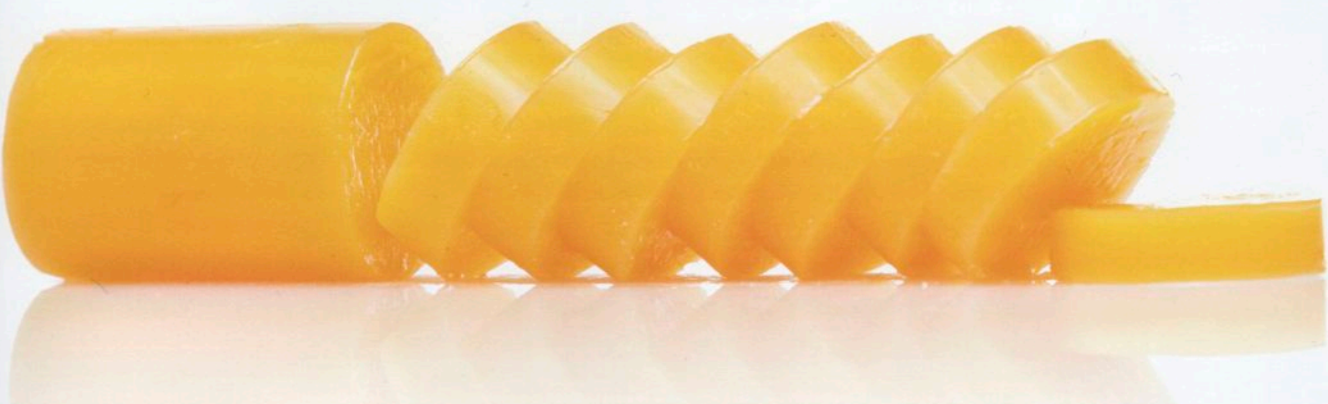
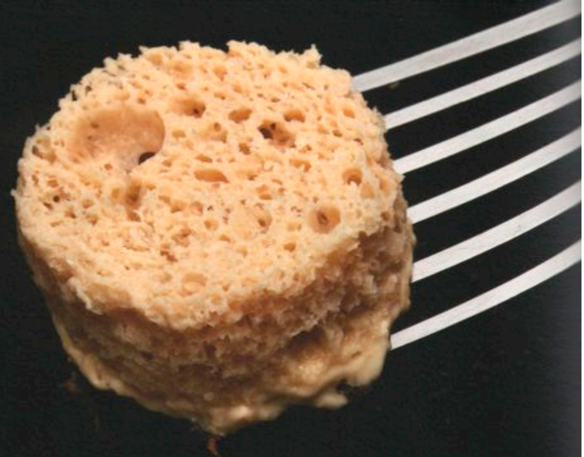


PARAMETRIC RECIPE

BLENDED EGG GELS



Inexperienced cooks claim "I can't even scramble an egg"—as if it were the simplest of tasks. Yet the creation of a flawless, plain omelet is often considered the ultimate test of a chef's skill.

Traditionally, scrambled eggs and omelets have been slightly undercooked to allow the residual heat to finish the cooking as the dish is plated and served. That is one of the things that makes scrambled eggs difficult to do. The cook must judge the heat and the time and the amount of overshoot in order to get a perfect texture. Cooking in sous vide baths or steam ovens is much more precise; the cook can carefully monitor the core temperature of an egg dish and serve it at exactly the right time, every time.

You can use Activa RM to prevent very moist egg preparations, such as Japanese *chawanmushi*, from undergoing syneresis and weeping (see page 116).

MAKING A BLENDED EGG GEL

1. **Measure yolks, whites, liquid ingredients, and seasonings.** Use the weight of egg whites as 100%, and measure other ingredients proportionally—for instance, use 60 g of yolk and 10 g of cream for each 100 g of white in an omelet, and so on.
2. **Blend all ingredients thoroughly.**
3. **Vacuum seal if cooking sous vide (optional).**
4. **Cook.** See the table below for recommended final core temperatures. The time required will vary depending on the thickness of the layer of egg mixture and of the cooking vessel.

Best Bets for Blended Egg Gels

Recipe	Egg yolk (scaling)	Egg white (scaling)	Liquid	(scaling)	Other ingredients	(scaling)	Cook Method	Cook (°C)	Cook (°F)	See page
American scrambled eggs	70%	100%	whole milk	10%	salt	1.8%	water bath	70	158	
French scrambled eggs	110%	100%	whole milk unsalted butter, melted	45% 45%	salt	3%	water bath	72	162	next
omelet	60%	100%	heavy cream	10%	salt	2%	steam oven	82	180	95
savory flan (crème caramel)	50%	100%	whole milk	300%	salt	2%	steam oven or water bath	83	181	101
chawanmushi (savory Japanese custard)	50%	100%	mirin hon-dashi see page 2·306	3% 210%	salt Activa RM	2% 1%	steam oven or water bath	82	180	96
royale custard	400%	100%	whole milk heavy cream	600% 300%	flavorful puree, juice, or stock	800%	steam oven or water bath	80	176	94
frittata*	50%	100%	whole milk olive oil	50% 15%	Taleggio cheese, grated salt	25% 3%	steam oven	80	176	
quiche filling*	50%	100%	bacon-infused heavy cream see page 2·310	190%	salt	3%	steam oven	80	176	

*(*many different flavors can be adapted to these recipes*)

EXAMPLE RECIPE

FRENCH SCRAMBLED EGGS

Yields 520 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks	150 g (from about eight large)	100%	① Combine, and blend until smooth. ② Vacuum seal. ③ Cook in 72 °C / 162 °F bath until thick, about 25 min. ④ Optionally, transfer eggs to whipping siphon, and charge with two nitrous oxide cartridges for light, foamy texture. ⑤ Reserve warm.
Egg whites	130 g (from about four large)	87%	
Unsalted butter, melted	60 g	40%	
Whole milk	60 g	40%	
Salt	4 g	2%	
Beech mushrooms (hon-shimeji), washed thoroughly	120 g	80%	⑥ Sauté until cooked through, about 4 min.
Unsalted butter	30 g	20%	
Pancetta, thinly sliced	45 g	30%	⑦ Add to mushrooms, and cook for 2 min.
Mushroom jus see page 2·348	45 g	30%	⑧ Add to mushrooms, and reduce until syrupy, about 3 min.
Crème fraîche	30 g	20%	⑨ Whisk into mushroom mixture.
Scallions, thinly sliced	15 g	10%	
Salt	to taste		⑩ Season. ⑪ Portion scrambled eggs into four bowls, and garnish with mushroom mixture.

(2010)

This recipe, and its more formal cousin in volume 5 (see page 5·215), are among our favorites.

Daniel Patterson of Coi in San Francisco published a recipe for poached scrambled eggs in 2007. He carefully drops blended eggs into seasoned simmering water, while stirring, as if making traditional poached eggs. He then drains the eggs and serves them with olive oil and salt. They are extremely fluffy.

EXAMPLE RECIPE

ASPARAGUS ROYALE INSPIRED BY ALAIN DUCASSE

Yields 550 g (about eight royales)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Asparagus puree or juice see page 2·341 or page 2·424	200 g	100%	① Blend until smooth. ② Press mixture through fine sieve. ③ Pour layer 2.5 cm / 1 in thick into individual bowls. ④ Cover bowls with plastic wrap. ⑤ Cook in 80 °C / 176 °F bath or steam oven to core temperature of 79 °C / 174 °F, about 30 min. ⑥ Reserve royales warm, or refrigerate.
Whole milk	150 g	75%	
Egg yolk	105 g	52.5% (*24%*)*	
Heavy cream	75 g	37.5%	
Egg white	25 g	12.5% (*5.8%*)*	
Salt	6.5 g	3.25%	
Roasted-hazelnut oil	5 g	2.5%	
Porcini oil (store-bought)	5 g	2.5%	
Brown chicken jus see page 2·344	80 g	40%	⑦ Combine. ⑧ Whisk over low heat until just warm, about 2 min.
Black truffle concentrate see page 2·427	20 g	10%	
Unsalted butter	20 g	10%	
Lemon juice	to taste		⑨ Season warm truffle mixture. ⑩ Divide equally among royales.
Salt	to taste		

(2010)

(% of total weight of all other ingredients in royales*)

Royales are savory custards, either served as is or cut into designs and floated on the surface of a consommé. We think even Antonin Carême would approve of this recipe, which uses Modernist temperature control to achieve the perfect texture.

EXAMPLE RECIPE

DASHIMAKI TAMAGO

Yields 295 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg whites	125 g	167%	① Combine, blending completely. ② Vacuum seal to remove bubbles. ③ Remove from bag, and cast into nonstick mold in layer 4 cm / 1½ in thick. ④ Steam, covered, at 79 °C / 174 °F until set, about 25 min. ⑤ Refrigerate to cool completely, about 30 min. ⑥ Remove from mold. ⑦ Slice tamago into desired dimensions.
Egg yolks	75 g	100%	
Hon-dashi see page 2·306	40 g	53%	
N-Zorbit M (National Starch brand)	30 g	40%	
Agave syrup	20 g	27%	
White soy sauce	7 g	9.3%	
Sugar	5 g	6.7%	
Salt	1 g	1.3%	
Frying oil	as needed		⑧ Heat thin film of oil over medium heat. Sear each tamago on one side until evenly browned. ⑨ Serve tamago while crust is warm and center is still cold for pleasant temperature contrast.

(2010)

EXAMPLE RECIPE

HAM AND CHEESE OMELET

Yields four omelets, about 75 g each

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole eggs	145 g (about three)	100%	① Blend thoroughly. ② Spread in layer 20 cm by 20 cm / 8 in by 8 in and 2 mm / 1⁄16 in thick on nonstick tray. ③ Steam at 80 °C / 176 °F until set, about 7 min. ④ Cool completely, and cut into four square portions, 5 cm by 5 cm / 2 in by 2 in. ⑤ Set aside.
Heavy cream	15 g	10%	
Egg yolk	12 g	8%	
Salt	2.5 g	1.7%	
Cooked French ham, brunoise	75 g	52%	⑥ Combine. ⑦ Fill each omelet evenly. ⑧ Fold omelets over.
Gruyère cheese, thinly spread (or brunoise) see page 223	60 g	41%	
Basil, minced	0.35 g	0.24%	
Chervil, picked	0.35 g	0.24%	
Chives, minced	0.35 g	0.24%	
Tarragon, minced	0.35 g	0.24%	
Clarified brown butter see page 213	as needed		⑨ Brush onto omelet. ⑩ Steam at 80 °C / 176 °F until cheese has melted, about 4 min.

(2010)

By using a combi oven or a low-temperature steamer (see page 2·162), perfectly done omelets can be made simultaneously for dozens or even hundreds of people.

This omelet can also be made in a conventional oven, but doing so requires great vigilance. Pour a thin layer of omelet base in a nonstick pan, wrap tightly with cling film or cover with a lid, and bake in a 120 °C / 250 °F oven until just set, 7–10 min depending on the wet-bulb temperature.

A dramatic mushroom omelet—a more complex version of the omelet recipe above—can be found on page 5·215. We use a pastry comb to create flavorful stripes of mushroom puree thickened with albumin and egg yolk powder.

CHAWANMUSHI

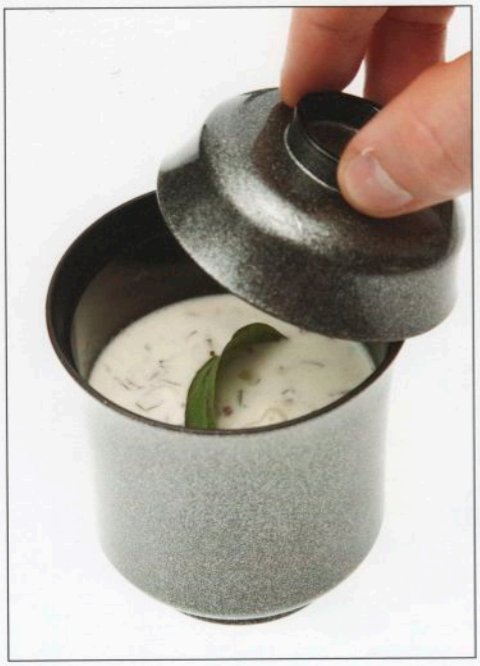
Yields 850 g (about eight chawanmushi)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Scallop stock or chicken stock see page 2·296 or page 2·301	350 g	350%	① Blend. ② Vacuum seal. ③ Cook sous vide in 45 °C / 113 °F bath for 10 min to activate enzyme. ④ Pour chawanmushi base into porcelain bowls to depth of 2.5 cm / 1 in. ⑤ Wrap bowls tightly with plastic wrap. ⑥ Cook in 82 °C / 180 °F water bath or steam oven to core temperature of 81 °C / 178 °F, about 40 min.
Diver scallops, pureed and sieved	65 g	65%	
White soy sauce	18 g	18%	
Whole eggs, blended	*100 g (about two)*	*100% (23%)**	
Activa RM	8 g	8% (*1.5%*)**	
Scallop stock or chicken stock see page 2·296 or page 2·301	100 g	100%	⑦ Simmer stock and sake together for 3 min.
Sake	75 g	75%	
Xanthan gum	0.3 g	0.3%	⑧ Blend into stock mixture.
Unsalted butter, cubed	50 g	50%	⑨ Blend into stock mixture until fully emulsified.
Salt	to taste		⑩ Season sauce.
Prosciutto crudo, finely diced	30 g	30%	⑪ Whisk into sauce.
Dates, finely diced	25 g	25%	⑫ Garnish each chawanmushi evenly.
Scallions, thinly sliced	20 g	20%	
Lemon verbena, thinly sliced	3 g	3%	

(2010)

(% of total weight of first three ingredients*)
**(*% of total weight of first four ingredients*)

Chawanmushi is a traditional part of a formal Japanese meal. It is served as an appetizer in a cup. Unlike typical egg custards, it is made with stock instead of milk or cream, which makes it prone to syneresis (weeping). The Activa in this recipe prevents syneresis. You can replace the Activa with 0.5 g of Nutrifos 088 or 1 g of sodium hexametaphosphate, and achieve the same result.



EXAMPLE RECIPE

PRESSURE-COOKED EGG TOAST ADAPTED FROM NILS NORÉN AND DAVE ARNOLD

Yields 180 g (about six toasts)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks	200 g (about 11 yolks)	100%	① Blend until smooth. ② Vacuum seal to remove excess air.
Baking powder	9 g	4.5%	③ Transfer egg mixture to small greased ramekins; fill each halfway full.
Salt	2 g	1%	④ Add enough water to pressure cooker to reach halfway up ramekin sides. ⑤ Pressure-cook at gauge pressure of 1 bar / 15 psi for 40 min to form cooked, muffin-like eggs. ⑥ Cool quickly by running cold water over cooker.
Clarified butter, unsalted	as needed		⑦ Cut egg rounds in half horizontally, and brush with butter. ⑧ Fry rounds, cut side down, until golden.
Chives, finely minced	10 g	5%	⑨ Garnish.
Sturgeon caviar	as desired		

(original 2009, adapted 2010)

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Do not vent the pressure cooker at any point, or the egg rounds will explode!

A similar result can be achieved by steaming the yolk-filled ramekins for 1 h.

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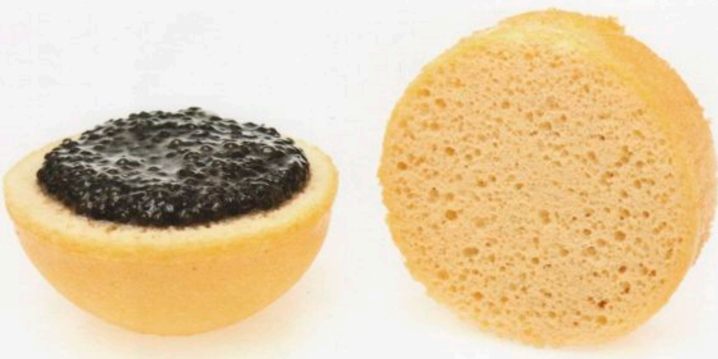

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These unique toasts are essentially a flourless quick bread. Egg is leavened with baking powder to create a unique, bread-like texture.

EXAMPLE RECIPE

CHORIZO FRENCH TOAST

Yields 250 g (four slices)

INGREDIENT	QUANTITY	SCALING
Whole milk	600 g	300%
Spanish chorizo, ground	150 g	75%
Chorizo milk, from above	600 g	300%
Whole eggs, blended	245 g	122.5% (*41%*)*
Salt	9 g	1.5%
Brioche, cut into 5 cm / 2 in rounds	200 g	100%
Quail eggs	four eggs	
Frying oil	as needed	
(2008)	*(*% of weight of chorizo milk*)	

1 **Combine milk and chorizo.**

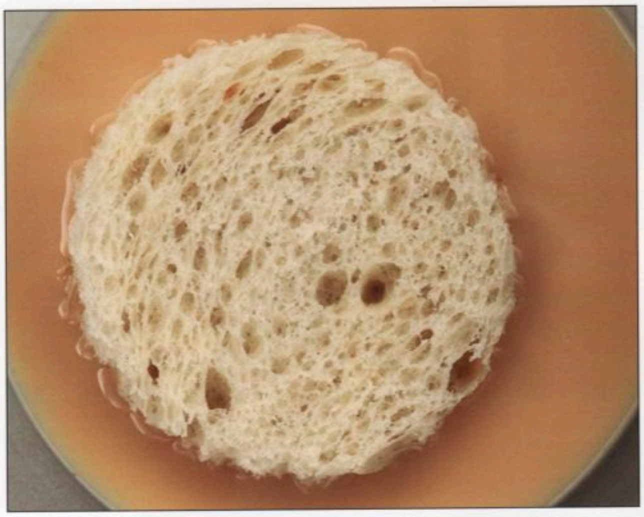
2 **Vacuum seal, and cook sous vide in 85 °C / 185 °F bath for 1 h.**

3 **Cool completely.**

4 **Strain, and reserve 600 g.**

5 **Blend reserved chorizo milk with eggs and salt until smooth.**

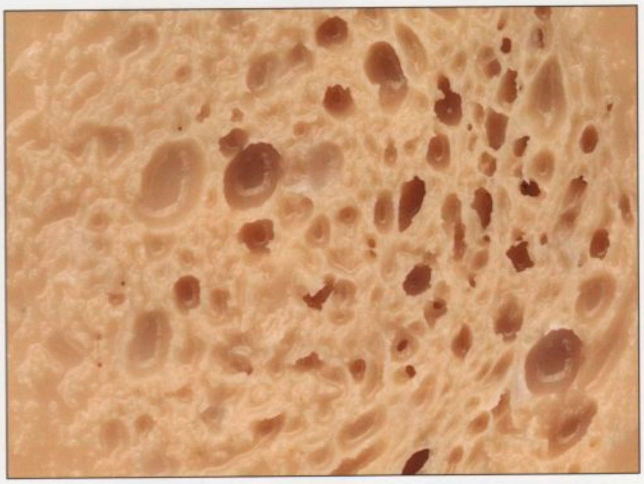
6 **Place brioche rounds in open container, and pour chorizo custard over brioche.**



French toast is good when made with many savory flavors, such as aged cheese, foie gras, sweet peas, corn—even savory nut milks. To make a foie gras version of this recipe, simply blend 400 g of milk with 200 g of raw foie gras, and use this mixture instead of the chorizo-infused milk. We also had great success with a blend of 300 g of milk and 300 g of toasted almond milk (see page 59).

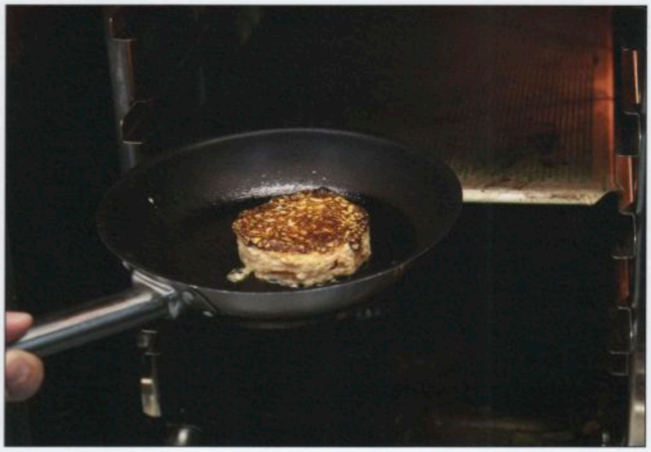
This vacuum infusion technique also works well with sweet custard to make a sweet French toast, or *pain perdu*.

7 **Place container in vacuum chamber, and pull vacuum until custard boils.**



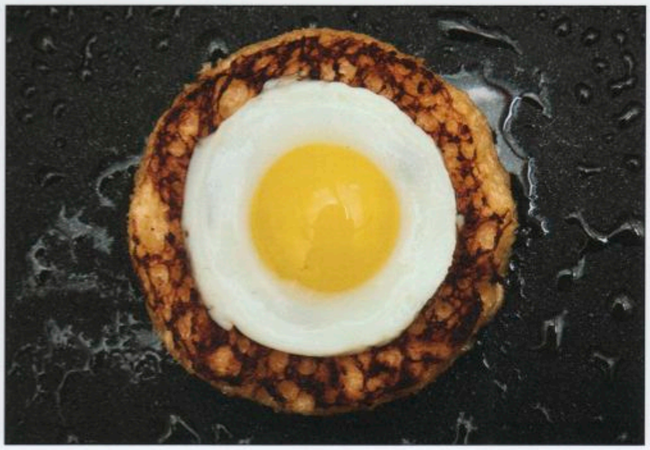
8 **Release vacuum; custard will be fully absorbed by brioche.**

9 **Sauté brioche rounds until golden on both sides.** (This step can be reversed with step 10 if desired.)



10 **Cook in 150 °C / 300 °F oven to core temperature of 80 °C / 176 °F, about 7 min.** Alternatively, vacuum seal under weak vacuum, and cook sous vide in 80 °C / 176 °F bath or steam oven for 10 min.

11 **Fry quail eggs in nonstick pan until whites are cooked through but yolks are still runny.** If making large quantities, consider using the two-stage "fried" egg approach—see page 85.



12 **Top toast rounds with fried eggs.** Serve with olive marmalade.

OLIVE MARMALADE

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fennel, finely minced	30 g	100%	① Sauté over low heat until tender, about 12 min.
			② Cool completely.
Olive oil	30 g	100%	③ Fold into fennel.
Shallots, minced	10 g	33%	
Picholine olives, minced	30 g	100%	
Candied orange rind, minced	15 g	50%	
Niçoise olives, minced	10 g	33%	
Thyme, leaves	0.1 g	0.33%	④ Season.
Salt	to taste		

(2008)

We garnish our chorizo French toast with thyme, but there are many other possibilities.

PARAMETRIC RECIPE

SMOKED EGGS AND DAIRY PRODUCTS

For centuries, cooks have mingled smoke with the fats and proteins in cheeses to deepen their flavors. The same phenomena work as well for eggs and other dairy items, but these are just now gaining popularity. Victor Arguinzoniz, chef and owner of Asador Etxebarri in Spain's Basque Country, has pioneered techniques that introduce the flavor of smoke and fire to classic dairy ingredients, including freshly churned butter.

Cold-smoked butter is a mild, spreadable condiment, while warm-smoking gives the butter a stronger flavor. Smoked cream adds a new dimension to classic sauces and can also be turned into intriguing cream cheeses or simply whipped to form an unusual topping. Smoky eggs make excellent mayonnaise and boost the flavor of savory custards or simple omelets.

Smoke the food in equipment that allows you to carefully control the temperature and relative humidity. Modern smokers produce the best results, but home smokers can also be adapted to offer some control over humidity—see Smoking, page 2·132.

H. Alexander Talbot and Aki Kamozawa offer a solution to making smoked eggs without a smoker. They take advantage of the porosity of egg shells by soaking whole eggs in a mixture of 2 l of water and 10 g (0.5%) of hickory smoke powder, available from specialty stores, or 70 g (3.5 %) of liquid smoke. They refrigerate the soaking eggs for 48 h. The same process can be used to put herb flavors such as basil and rosemary into eggs: just soak them in a dilute herb infusion. For details, see Infusing Essences, page 2·318.

Smoked butter

Smoked mozzarella

Smoked cheddar

Smoked egg

SMOKING EGGS, CHEESES, AND OTHER DAIRY PRODUCTS

1. **Select the ingredient.** The table below lists several good options.
2. **Preheat and prehumidify the smoker to the temperature and relative humidity indicated in the table.** Some smokers allow you to set the temperature and relative humidity directly; otherwise, place a pan of water on the bottom rack of the smoker, and use gauges to monitor the heat and humidity.
3. **Smoke for the time indicated.**
4. **Use immediately, or chill quickly and thoroughly.**

For more on the safe handling of eggs and dairy products, see page 1·162.

Best Bets for Smoking Dairy and Eggs

	Dry-bulb temperature		Wet-bulb temperature					
Ingredient	(°C)	(°F)	(°C)	(°F)	Relative humidity	(h)	Example use	See page
cold-smoked eggs, shelled	60	140	48	118	50%	7	flan, crème anglaise, mayonnaise	next
cream	7	45	5	42	75%	4½	cream sauce, cream cheese	
butter, hot-smoked	30	85	22	72	50%	4	spread for toast	
butter, cold-smoked	10	50	6	43	55%	24	poached salmon with smoked beurre blanc	5·161
cheese (mozzarella, Parmesan, cheddar)	10	50	6	43	55%	24	pizza, cheese plate	

EXAMPLE RECIPE

SMOKED EGG CRÈME CARAMEL

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	150 g	150%	① Vacuum seal together, and cook sous vide in 90 °C / 194 °F bath for 1½ h.
Bacon, minced	100 g	100%	② Remove from bag, and strain; reserve 100 g of milk.
Shallots, finely minced	30 g	30%	③ Cool milk.
Bacon-infused milk, from above	100 g	100%	④ Blend together until smooth.
Cold-smoked eggs, shelled see previous page	50 g	50%	⑤ Vacuum seal to remove any trapped air bubbles.
Salt	2.3 g	2.3%	
Sugar	40 g	40%	⑥ Combine in pan. Cook over medium heat until sugar becomes dark caramel, about 7 min.
Water	20 g	20%	⑦ Pour caramel into four ramekins, and cool.
Black pepper, coarsely ground	0.1 g	0.1%	⑧ Spoon 2.5 cm / 1 in thick layer of custard over caramel.
			⑨ Steam ramekins at 83 °C / 181 °F for 15 min, and cool completely.
			⑩ To serve, invert onto plates.

(2010)

If cold smoking the eggs is not an option, use fresh eggs, and add 0.75 g (0.5% of the total weight of infused milk and eggs) of good quality liquid smoke instead.

Smoked Egg Crème Caramel, unmolded

This simple, elegant preparation of Pecorino cheese is smoked only by the aroma from the cedar plank on which it is cooked.

EXAMPLE RECIPE

PECORINO WITH TRUFFLE HONEY ON CEDAR ADAPTED FROM SCOTT CARSBERG

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Smoked Tuscan Pecorino cheese, aged 18 months	250 g	100%	① Cut cheese into four triangular chunks, each 1.25 cm / ½ in thick. Set aside at room temperature.
Black truffles, finely chopped	50 g	20%	② Combine.
Acacia honey	10 g	4%	③ Set aside at room temperature.
Cedar plank			④ To serve, preheat oven to 260 °C / 500 °F.
			⑤ Place cheese chunks on plank, and bake until bubbling and very soft, about 5 min.
			⑥ Remove plank from oven. Ignite edges of plank with blowtorch to create smoke.
Candied chestnuts (store-bought), cut into small cubes	25 g	10%	⑦ Garnish bubbling cheese with truffle honey and candied chestnuts (marrons glacé).
			⑧ Serve on smoking plank to imbue room with smoked-wood aroma.

(original 1997)

DAIRY AND TOFU GELS

Many brands of heavy cream, even organic varieties, contain xanthan gum, carrageenan, and other gums, which are added to prevent the cream from separating, thus extending its shelf life. Unfortunately, this can alter how the cream works in dairy gels. Check the ingredients or talk with your supplier.

Milk—and the complex set of proteins that it contains—has for millennia been the foundation of a particular set of traditional gels: cheeses, which are dairy gels created by coagulating milk. Cheesemakers most often employ rennet, a natural enzyme originally extracted from the stomachs of calves, lambs, or young goats (but now available from purely vegetable or microbial sources), to start the coagulation process. They also produce simple fresh cheeses such as ricotta and cottage cheese by using acid coagulants.

After the initial solidification, a cheesemaker may treat the resulting dairy gel (called curd) in various ways. Seemingly tiny differences in how the curd is drained, heated (particularly with a key process known as cheddaring), and aged (with or without mold cultures) account for the enormous diversity in cheeses made around the world. A detailed treatment of cheesemaking is beyond the scope of this book, but we will discuss a few simple cheese gels, including our own versions of ricotta and mozzarella.

Thanks to modern advances in coagulant chemistry, we now have many options beyond rennet and the classic acids for forming dairy gels. Glucono delta-lactone (GDL) is a substance found naturally in honey, fruit juice, and wine; it is manufactured by fermentation. GDL reacts with water to become mildly acidic over time. Its acidity flavors gels with a tangy taste that is less harsh than that of most kitchen acids. GDL works slowly and progressively, so it provides a gentle and measured way to trigger acidic coagulation and control firmness. In contrast, common acids such as lemon juice and vinegar operate immediately, which makes coagulation difficult to control.

Cooks use methods other than the direct coagulation of milk to make dairy gels. Dessert gels made with dairy ingredients, like flan, crème brûlée, and panna cotta, actually rely on eggs, gelatin, or other gelling agents to achieve their distinctive textures.

Certain hydrocolloid gelling agents are particularly effective at solidifying dairy products. Carrageenan, a gelling agent derived from Irish moss seaweed, is a good example. For centuries, Irish cooks boiled bits of the seaweed with milk to make traditional puddings and other dessert gels. Modern technology provides us with refined and purified versions of carrageenan to make dairy-based gels that have a wide range of textures under various conditions.

Tofu is another classic protein-based food gel, which differs from cheesemaking primarily in the protein source: a bean rather than a cow. Asian cooks were the first to extract proteins from soybeans to make soy "milk" and treat it with a coagulant, traditionally a magnesium or calcium salt called *nigari*. The resulting soy curd is then strained and molded. Like soybeans, almonds and other nuts can be converted into nut milks, many of which can be coagulated into tofu-like gels.

Tofu is a traditional protein gel. When prepared fresh by using Modernist methods (see page 112), it is superior in flavor and texture to commercial tofu.

14

Protein Coagulants

Setting an egg, creating curds from dairy or soy, thickening milk into yogurt: these are all familiar examples in which the introduction of a coagulant transforms proteins into gels.

Coagulants fall naturally into several classes, which are listed below along with some common applications and notes on their particular characteristics.

Class of coagulant	Varieties	Typical use	Note
temperature-activated (egg, milk, soy milk)	hot	hard-boiled egg, flan	egg coagulates above 60 °C / 140 °F, milk above 130 °C / 266 °F, and soy milk above 90 °C / 194 °F
	cold		egg yolks gel when frozen
acid	citric acid, tartaric acid, glucono delta-lactone	cream cheese, ricotta, paneer	separates curd from whey
base	sodium and calcium hydroxide	century egg	raises pH of century egg to 9–12 within 10 days
alcohol	wine, grain alcohol	syllabub	long used in Britain with milk and cider
enzyme	animal rennets	milk curd, cheese	digestive enzymes from calves; separate milk into curds and whey
	plant rennets	milk curd, cheese	derived from nettles, thistles, and soy
	other proteases (papain, bromelain)	tofu	activities are highest in alkaline fluids
	transglutaminase	yogurt	often added to strengthen gel and improve mouthfeel and stability
salt	calcium chloride, magnesium chloride, calcium sulfate, magnesium sulfate	silken or firm tofu	donors of calcium or magnesium ions

PARAMETRIC RECIPE

PROTEIN CURDS

Fresh curds are quick, simple, and economical to prepare, either traditionally or sous vide. Fresh goat, sheep, or buffalo milk can be substituted for cow's milk. Fresh curds are best when used within a day of making; keep them sealed, cold, and moist.

MAKING PROTEIN CURDS

1. **Select a curd recipe and texture.** The table presents good options that use a variety of coagulants with different flavors and textures.

2. **Adjust soluble solids concentration, if using soy milk, to 10–14 °Brix.** Use a refractometer or a float that measures the density (see page 2·313). You may need to reduce fresh soy milk to achieve this concentration; the higher the density, the richer, firmer, and less elastic the tofu will be.

3. **Measure liquid.** Scale ingredients relative to the weight of the liquid; in ricotta, for example, use 0.3 g of lactic acid for every 100 g of milk.

4. **Preheat the liquid to the cooking temperature.** Use a water bath, if available. Do not preheat if making silken tofu or ricotta.

5. **Dissolve the coagulant in a small amount of water, and then stir the mixture into the milk or cream.** The amounts of lactic acid, citric acid, and glucono delta-lactone indicated were selected to achieve the pH shown. If curd texture is too firm (pH too high) or too loose (pH too low), adjust the coagulant quantity accordingly (see page 2·316).

6. **Heat at temperature indicated for the time shown.**

7. **Remove from heat, and allow to curdle.** Approximate setting times are given in the table.

8. **Season (optional).** See example recipes on the pages indicated.

9. **Cut, drain, and press evenly (for firm-textured curds only).** Press both dairy and soy curds while they are still warm (65–75 °C / 149–167 °F) to ensure proper bonding and a good final texture.

Best Bets for Protein Curds

						Heat			Set			See
Recipe	Liquid	(scaling)	Texture	Coagulant*	(scaling)	(°C)	(°F)	(min)	(min)	Note	pH	page
basic milk curd	raw milk or unhomogenized, pasteurized milk	100%	tender, brittle	rennet	0.35%	38	100	1	7	set in serving container; for firmer curds, cut curds, and heat at 47 °C / 116 °F for ½–1 h, and then drain, and cut again	8.2	105
ricotta	whole milk heavy cream	100% 10%	tender, brittle	lactic acid	0.3%	85	185	1	35	for salted and aged ricotta, fold in 0.7% salt, press refrigerated for 1–3 d, drain, and hang for 1–3 wk	5.4	108
fresh cottage cheese	whole milk	100%	tender, brittle	rennet	1%	38 38	100 100	1 1 h	7	whisk to break apart curd, hold at 38 °C / 100 °F for 1 h, and drain whey; fold in cream to taste	8.2	
paneer	whole milk cultured yogurt	100% 1%	firm, elastic	lactic acid	0.35%	82	180	5	20	press while warm, and refrigerate for 24 h	5.8	
tofu	soy milk see page 58	100%	silken	glucono delta-lactone	0.2%	80	176	1	15	milk density affects tofu texture; let silken tofu set in serving container, and then steam undisturbed at 80 °C / 176 °F	6.3	113
			medium firm	nigari granules	0.35%	85	185	1	30		n/a	
			firm	calcium sulfate	0.4%	80	176	3	20		n/a	112
farmer's cheese	whole milk heavy cream	100% 5%	firm, brittle	rennet buttermilk	0.4% 0.4%	23 36	73 97	1 1¼ h	n/a	heat milk for 1 min at 23 °C / 73 °F, then add other ingredients, and hold for 1¼ h at 36 °C / 97 °F; press while warm, and refrigerate for 12–24 h	8.1	
posset	heavy cream (stabilizer-free)	100%	tender, smooth	citric acid	0.7%	88	190	1	4 h	add 15%–25% sugar to make a posset dessert	6.7	

*(*BioRen rennet tablets were used for all of our recipes; other brands may alter the formulations slightly*)

EXAMPLE RECIPE

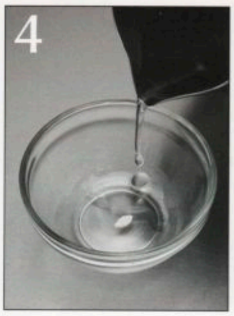
COCOA NIB CURD INSPIRED BY MICHEL TROISGROS

Yields 1 kg (10 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk, unhomogenized	1 kg	100%	① Vacuum seal together, and refrigerate for 12 h to infuse.
Cocoa nibs	50 g	5%	② Remove from bag, and strain.
			③ Heat milk to 38 °C / 100 °F.
Rennet tablet (BioRen brand)	3.5 g	0.35%	④ Dissolve rennet tablet in water.
Water	10 g	1%	⑤ Stir in warm milk.
			⑥ Stir for 10 s.
			⑦ Leave mixture in pot, or pour quickly into small bowls to depth of 2.5 cm / 1 in.
			⑧ Let stand at room temperature until set, about 7 min.
Cocoa nibs, toasted	to taste		⑨ Garnish as desired, and season evenly.
Fleur de sel	to taste		
Grapefruit zest, finely grated	to taste		
Maple syrup	to taste		
Olive oil	to taste		
Shiso leaves, fine julienne	to taste		

(original 2008, adapted 2010)

You can use glucono delta-lactone in place of the rennet and still achieve the same texture. Dissolve the GDL in cold milk, pour the mixture into molds or bowls, and then steam at 80 °C / 176 °F for 20 min.



EXAMPLE RECIPE

GOAT CHEESE DUMPLINGS ADAPTED FROM H. ALEXANDER TALBOT AND AKI KAMOZAWA

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Goat cheese, fresh	300 g	100%	① Blend completely.
Ricotta, fresh	200 g	67%	② Transfer mixture to pastry bag.
Egg yolk	36 g	12%	③ Pipe into silicone sphere molds measuring 2.5 cm / 1 in. in diameter (see page 135).
Activa YG	5.4 g	1.8% *(1%)**	④ Tap molding sheet on counter to eliminate bubbles.
Salt	3.5 g	1.2%	
Cayenne pepper	0.25 g	0.08%	⑤ Refrigerate, covered, for 12 h to set.
			⑥ To serve, warm spheres gently in simmering water. When hot, serve with desired sauce or glaze.

(original 2008, adapted 2010)

(% of total weight of first three ingredients*)

FRESH CHEESE CURDS

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	4 kg	100%	① Verify that pH of milk is 8–9. ② Heat to 30 °C / 86 °F, and hold at that temperature in warm bath.
Mesophilic starter (Mesophile Type II)	1 g	n/a*	③ Sprinkle over surface of warm milk, and let sit 5 min. ④ Stir in until evenly distributed.
Thermophilic starter (Thermophile Type II)	1 g	n/a*	⑤ Sprinkle over surface of warm milk, and let sit 5 min. ⑥ Stir in until evenly distributed.
Water	40 g	1%	⑦ Dissolve rennet in water.
Rennet tablet (BioRen brand)	0.5 g	0.01%	⑧ Stir mixture into warm milk, and wait for milk to set into one large curd, 15–30 min. ⑨ Remove from heat, and cut into 2 cm / ¾ in cubes. ⑩ Heat cut curds in 40 °C / 104 °F bath, removing whey from surface every 10–20 min until texture resembles elastic egg white, 1–1½ h. ⑪ Check that pH is 5–5.2. If it is not, hold curd at 40 °C / 104 °F until pH reaches target range. ⑫ Drain curd, and cut to desired size. ⑬ Refrigerate for 2 h. ⑭ Serve or use within 24 h; cultures cause curd to start to sour after 1 d.

(2010)

*(*these are live cultures; follow directions on manufacturer's packaging when scaling quantities*)

To make squeaky curds, follow the recipe above, but in step 10 heat the curds to 47 °C / 117 °F, and hold there for 1 h. Drain, cut, and season. Serve, or cool quickly and store, refrigerated, for up to 2 d.

To make curds without rennet or cultures, heat them in a pressure canner or autoclave to at least 128 °C / 262 °F for 30–40 min. The curds will turn light brown and develop a flavor reminiscent of crème caramel. Add 0.3% of sodium hexametaphosphate to yield a more cohesive, firm puck.

To make feta, use the recipe above with at least 70% sheep's milk. At step 12, press curds lightly into a basket to drain, and rest for 24 h at about 20 °C / 68 °F. The pH should drop to 4.7–4.8. Soak, refrigerated, in a brine containing 3% salt and 0.07% calcium chloride for 1 wk. For drier curds, cure briefly with dry salt at room temperature, and rinse.

To make fresh mozzarella, follow the recipe above through step 11, and then drain curds, and cut into 1.25 cm / ½ in cubes. Heat reserved whey to 85 °C / 185 °F, and ladle over cubes to just cover. Let rest 4 min until softened, and then drain. Repeat process three times, covering curds with hot whey until they begin to melt together. Mold curds by hand into teardrop shapes, or pour into a mold. The mozzarella becomes stretchier and firmer with handling. Hold formed balls in a bowl of cold water. Season, and serve warm or soak in a brine containing 4% salt and 0.07% calcium chloride for 12–24 h.

1

3

4

8

9

10a

10b

10c

12

These cheese curds serve as a good base for making mozzarella, burrata, scamorza, string cheese, and other similar, elastic fresh cheeses. They can also be used directly in dishes such as poutine, a Canadian classic, in which they are used as a topping for fries with gravy.

GOAT MILK RICOTTA

Yields 850 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For ricotta:			
Lactic acid	4 g	0.2%	① Dissolve acid into water, and stir acid solution into cold milk.
Water	25 g	1.4%	② Heat milk to 85 °C / 185 °F, stirring gently. As soon as milk starts coagulating, stop stirring.
Goat milk	1.8 kg	100%	③ Continue to heat as needed until milk reaches 85 °C / 185 °F.
			④ Remove from heat, and allow to curdle at room temperature for 30 min.
			⑤ Strain curds through cheesecloth, and then drain curds, refrigerated, for 3 h for wet ricotta or for up to 12 h for drier cheese. Discard liquid.
Heavy cream	250 g	14%	⑥ Fold into drained curds. Refrigerate if not serving immediately.
For frozen honey powder (optional):			
Water	200 g	11%	⑦ Whisk together.
Buckwheat honey	80 g	4.4%	⑧ Pour into Pacojet beaker.
			⑨ Freeze to −20 °C / −4 °F or below.
			⑩ To serve, Pacotize once to make fine powder.
			⑪ Spoon around ricotta.
Thyme (several varieties such as lemon, English, caraway, silver)	to taste		⑫ Garnish as desired.
Extra-virgin olive oil	to taste		
Black pepper, coarsely ground	to taste		

(2010)

For tender, coarse ricotta, stop stirring as soon as coagulation begins, regardless of the temperature of the milk. For ricotta with a finer, more traditional grain, keep stirring until the target temperature is reached.

2

5a

5b

5c

5d

6

11

To make a frozen powder of the ricotta, add 0.7% low-acyl gellan to the cream, hydrate, and then blend with the curds until smooth. Freeze the mixture, and then Pacotize to make the powder, which can be served at up to 80 °C / 176 °F. For details on making frozen cheese powders, see page 2·398.

EXAMPLE RECIPE

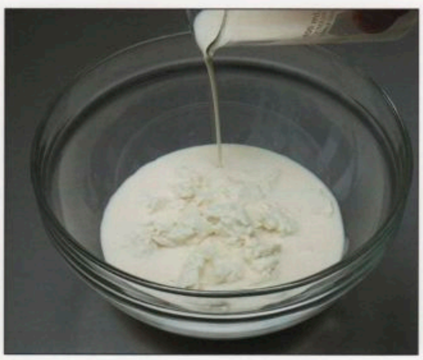
MODERNIST BURRATA

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the filling:			
Fresh cheese curds see page 106	300 g	100%	① Puree 100 g curds, and shred remaining 200 g.
Heavy cream	300 g	100%	② Mix cream and salt into curds to make cream-curd filling. ③ Refrigerate.
Salt	6 g	2%	
For the skin:			
Whole milk	300 g	100%	④ Mix milk, cream, salt, and gelatin.
Heavy cream	100 g	33%	⑤ Bring to 65 °C / 149 °F to dissolve gelatin.
Salt	4 g	1.3%	⑥ Cool to 50 °C / 122 °F.
Activa YG	6 g	2%	⑦ Add Activa.
160 Bloom gelatin	8 g	2.7%	⑧ Cast onto level, nonstick surface.
			⑨ Rest at room temperature for 1 h, and then refrigerate overnight.
			⑩ Cut to desired size, and lay over plated cream-curd filling.
Extra-virgin olive oil	to taste		⑪ Garnish and season.
Salt	to taste		
Seasonal herbs, leaves	to taste		

(2010)


1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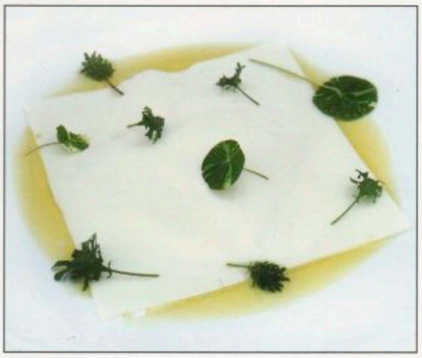
11

Traditional burrata is essentially a balloon of mozzarella filled with a cream-curd mixture. Here, we layer a curd-cream mixture between milk gel sheets in the manner of lasagna.

MOZZARELLA BALLOONS INSPIRED BY GRANT ACHATZ

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fresh cheese curds see page 106	800 g	100%	① Cut into 2 cm / ¾ in cubes. ② Reserve 150 g of curds for cream filling. ③ Reserve 650 g of curds in large bowl to make balloon skins.
Whole milk	180 g	22.5%	④ Blend thoroughly to form cream filling.
Fresh cheese curds, from above	150 g	18.8%	⑤ Pour into 1 l siphon.
Heavy cream	30 g	3.75%	⑥ Charge with one cartridge of nitrous oxide.
Salt	2.75 g	0.34%	⑦ Refrigerate.
Xanthan gum (Keltrol T, CP kelco brand)	0.1 g	0.01%	
Water	5 kg	625%	⑧ Heat water to 75 °C / 167 °F.
Fresh cheese curds, from above	650 g	81%	⑨ Ladle water into bowl to cover curds. ⑩ Let curds sit undisturbed for 3 min. ⑪ Pour out first covering of water. ⑫ Ladle in second covering of water. ⑬ Let curds sit undisturbed again for 3 min. ⑭ Pour out second covering of water. ⑮ Ladle in third covering of water. ⑯ Touch curds. If they begin to stretch and shine, they are ready. If not, let sit longer, and cover with fresh hot water every 3–5 min. ⑰ Pick up lime-size ball of curd. Knead surface to develop smooth and shiny skin. Reserve remaining curds in warm water. ⑱ Shake siphon vigorously. ⑲ Place ball of curd over tip of inverted siphon. ⑳ Fill curd ball quickly with cream filling; try to keep out excess air. Complete filling process within 20 s. ㉑ Once desired size is reached, pinch each balloon closed. ㉒ Repeat steps 17–21 to fill remaining curds. ㉓ If curds will not be served immediately, reserve in cold water bath.
Tomato whey broth or tomato water see page 49 or page 2·366	200 g	25%	㉔ To serve, place balloons in bowls, and pour seasoned broth or tomato water around balloons. ㉕ Garnish with basil and, optionally, with basil oil (see page 2·325).
Cinnamon basil, leaves	to taste		

(original 2004, adapted 2010)

This is a Modernist form of burrata, or mozzarella balloon, filled with a siphon-produced foam. We serve the dish with a tomato whey broth and basil oil.

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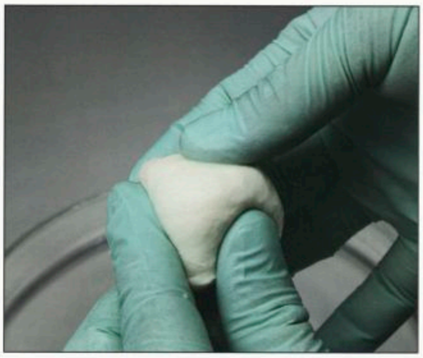
16a

16b



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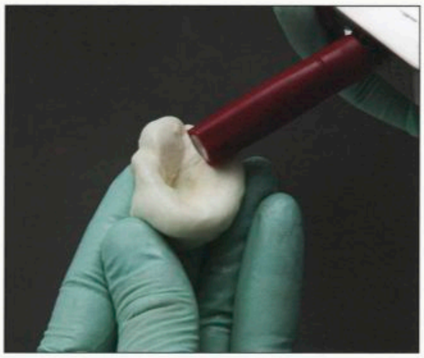

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Traditional burrata is rich; this Modernist interpretation is much lighter because of the foam inside.

FIRM TOFU

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Calcium sulfate	2 g	0.4%	① Dissolve calcium sulfate in cold water.
Water	20 g	4%	② Set aside.
Soy milk (12 °Brix) see page 58	500 g	100%	③ Check solid content of soy milk, and dilute or reduce as needed to reach 12–14 °Brix.
Salt	3 g	0.6%	④ Add salt, and bring to 80 °C / 176 °F while stirring constantly.
			⑤ Add calcium sulfate water to hot milk, and remove from heat.
			⑥ Coagulate at room temperature for 3–4 min.
			⑦ Line mold for tofu with cheesecloth.
			⑧ Ladle coagulated soy milk into mold.
			⑨ Seal mold quickly while curds are warm (68–70 °C / 154–156 °F), and put heavy weight on lid.
			⑩ Press at room temperature for 25 min, and then remove from mold, and refrigerate until firm.
Scallions, thinly sliced	50 g	10%	⑪ Cut to desired dimensions, and garnish.
Daikon radishes, finely grated	40 g	8%	
Fresh ginger, fine julienne	40 g	8%	
Bonito flakes (katsobushi)	20 g	4%	
White soy sauce	50 g	10%	⑫ Combine to make sauce.
Dark soy sauce	30 g	6%	⑬ Garnish tofu with sauce as desired.
Mirin	15 g	3%	
Rice vinegar	7 g	1.4%	

(2010)

These tofu recipes use fresh, homemade soy milk (see page 58). Store-bought soy milk often will not work with these recipes because it contains various additives.

A quick alternative for making instant firm tofu is to hydrate 0.2% low-acyl gellan and 0.15% high-acyl gellan in soy milk at 85 °C / 185 °F. The mixture will set as it cools.

The amount of calcium sulfate or other coagulant required depends on the amount of protein available in the mixture. Soy beans vary in their protein content, so always test a small amount of soy milk before making each batch. When the proper amount of coagulant is used, the whey becomes transparent. A yellow hue to the whey and a coarse curd texture signal overcoagulation; a cloudy whey is a sign of undercoagulation.

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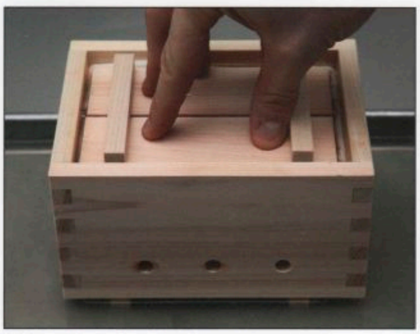

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SILKEN TOFU

Yields 585 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Soy milk see page 58	400 g	100%	① Check density of soy milk, and dilute or reduce as needed to reach 12 °Brix.
Glucono delta-lactone (GDL)	0.8 g	0.2%	② Dissolve GDL in small amount of soy milk, and then whisk solution into remaining milk for 10 s to distribute evenly. ③ Pour into small bowls or mold to depth of 2.5 cm / 1 in. ④ Steam in 80 °C / 176 °F combi oven or water-vapor oven until set, 30–40 min. ⑤ Transfer to molds, and cool at room temperature until slightly firmed, about 15 min, and then refrigerate.
Tomato water see page 2·366	100 g	25%	⑥ Combine to make dressing. ⑦ Check seasoning; add salt if necessary. ⑧ Set aside.
White soy sauce	10 g	2.5%	
Rice vinegar	8 g	2%	
Salmon roe	60 g	15%	⑨ Garnish tofu.
Basil, leaves	8 g	2%	
Extra-virgin olive oil	as needed		⑩ Season, and pour dressing at table.
Black pepper, coarsely ground	to taste		

(2010)


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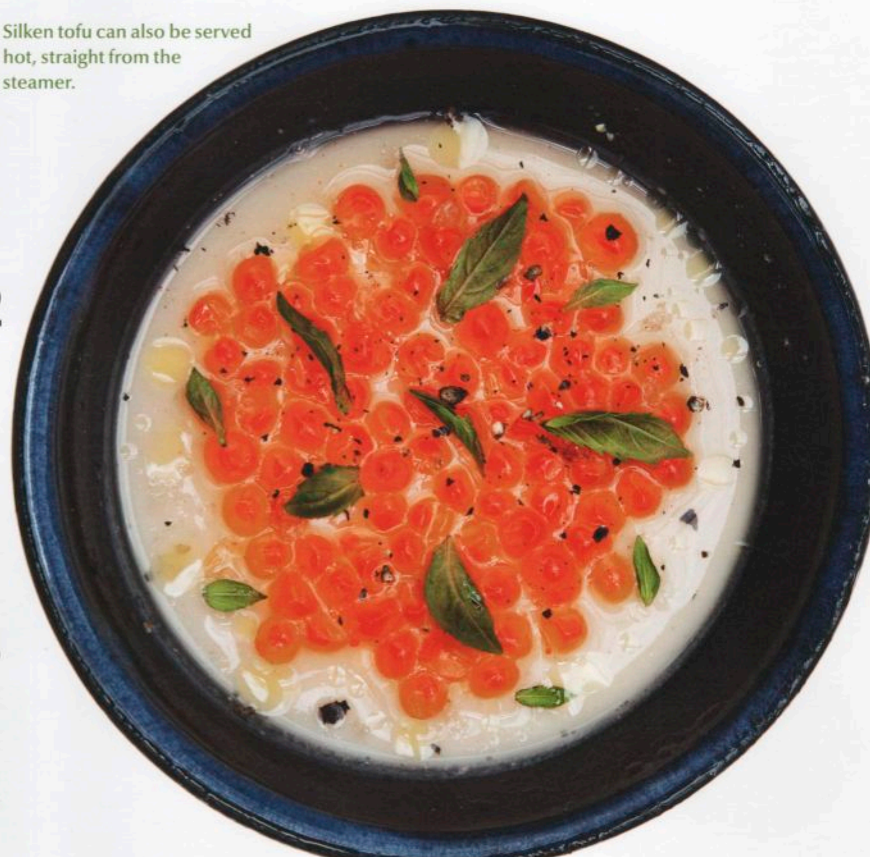
Silken tofu can also be served hot, straight from the steamer.



We were shocked by how much better this soft and silken tofu is than commercial tofu. Glucono delta-lactone—a natural, vegan product found in honey, fruit juice, and wine—is the secret.

A quick alternative for making instant soft tofu is to hydrate 0.2% iota carrageenan and 0.1% kappa carrageenan in soy milk at 85 °C / 185 °F, and chill to set.

MILK SKIN WITH GRILLED SALSIFY AND TRUFFLE PUREE

ADAPTED FROM RENÉ REDZEPI

Yields 600 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Raw or nonhomogenized whole milk	1 kg	100%	① Blend. ② Pour into pot whose diameter is desired size of milk skin.
Skim milk powder	30 g	3%	③ Cut parchment paper circles to match diameter of pot. Parchment paper will help transfer and store milk skins. ④ Bring milk to boil, and hold at 80 °C / 176 °F until skin forms, about 7 min. ⑤ Discard first skin, which is too tender to work with. ⑥ Place parchment circle on top of second skin, and delicately peel skin off. ⑦ Rest skin on parchment circle at room temperature. ⑧ Repeat process to make four skin sheets. (Although 1 kg of milk will make many more than four sheets, it can be difficult to work with very small quantities of milk.)
Salsify roots, peeled and cut into tubes 10 cm / 4 in long	400 g	40%	⑨ Sauté salsify in thin film of oil in nonstick pan, while basting constantly with oil, until tubes are golden on all sides, about 4 min.
Neutral oil	as needed		⑩ Drain, and pat dry.
Salt	to taste		⑪ Season salsify. ⑫ Cool to room temperature. ⑬ Divide salsify into four portions, and place each one on center of plate. ⑭ Remove each milk skin from parchment, and cover salsify portion.
Black trumpet mushroom puree see page 2·424	50 g	5%	⑮ Blend together mushroom and truffle purees until smooth. ⑯ Garnish plates evenly.
Black truffle concentrate see page 2·427	10 g	1%	
Extra-virgin canola (rapeseed) oil	30 g	3%	
Wild watercress leaves (or regular watercress)	20 g	2%	

(original 2008, adapted 2010)

Yuba, a skin from soy milk, is a traditional Asian food specialty. Dariy milk also forms a skin, which chefs traditionally have discarded. Michel Bras and Ferran Adrià pioneered the use of milk skin in Modernist cuisine. René Redzepi and other chefs have also made use of it as a wrapper for foamy mozzarella, or for a truffle-salsify mix (shown), as well as for other uses. Adding skim milk powder provides more protein, which helps the skin form readily and adds strength. An alternative to milk skin is a thin Activa-gelatin gel (see page 109).

6 Use parchment paper to lift the skin off the milk.

EXAMPLE RECIPE

GREEN PEA YUBA INSPIRED BY TAKASHI SUGIMOTO

Yields 150 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Soy milk see page 58	950 g	100%	① Reserve 50 g of soy milk for later use.
Green pea puree see page 2·424	400 g (from 500 g of frozen peas)	42%	② Blend pea puree with 900 g soy milk until smooth. ③ Strain pea milk through fine sieve, and transfer to pot. ④ Bring to 80 °C / 176 °F over medium heat. ⑤ Lower heat. Yuba will form on surface of pea milk mixture in about 3 min. ⑥ Line baking sheet with plastic wrap, and brush sheet with reserved soy milk. ⑦ Lift yuba carefully from pot, and transfer to milk-brushed sheet. Cover with plastic wrap. ⑧ Refrigerate for 1 h until firm.
Chervil, leaves	as needed		⑨ Arrange several yuba sheets on each plate.
Flaky sea salt	to taste		⑩ Garnish.
Ginger oil	to taste		
Fresh horseradish, finely grated	to taste		

(2010)

Yuba is traditionally made of soy milk alone. Here, we mix in green pea puree for flavor and color. Many other purees can be substituted, although you may need to adjust the amount to get the proper texture. If the soy protein is too diluted, the skin will not form properly. Add soy protein concentrate to make the skin stronger, in much the same way that adding skim milk powder strengthens dairy milk skin. You can use parchment paper, as shown on the previous page, to help lift the skin without tearing it.

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PARAMETRIC RECIPE

TRANSGLUTAMINASE GELS

Modernist cooks often refer to the natural enzyme transglutaminase as "meat glue," thanks to the strong bonds it can form between protein surfaces. Initially developed commercially in Japan for use in surimi fish pastes, powdered transglutaminase is sold under the brand name Activa.

Activa comes in several varieties; some work well with dairy, egg, and soy proteins. Because Activa is derived from microbes, most versions are suitable for vegetarian diets.

Transglutaminase creates gels by cross-linking proteins. It does this without tightening the links so much that liquid squeezes out. As a result, it does not cause the weeping that other kinds of coagulants frequently do. Activa is often used to enhance yogurt for this very reason.

Transglutaminase needs moisture, protein, and time to work. Refrigeration for 12–24 hours is usually required to set an Activa gel completely, but the setting time can be reduced to just one hour by warming the solution to 45 °C / 113 °F for 10 min, or to 55 °C / 130 °F for 5 min, before chilling it. Take care not to heat transglutaminase above 60 °C / 140 °F before the gel has set, or the enzyme will denature and become useless.

Activa is made by Ajinomoto, the same Japanese company that commercialized monosodium glutamate in 1909 (see page 1·213).

Avoid inhaling Activa or any other enzyme or powder.

MAKING GELS WITH ACTIVA

1. Select a recipe. The table at right gives some examples.
2. Blend Activa into the liquid or puree. Quantities in the table are given as a proportion of the main fluid. For example, to make a flourless gnocchi, use 1.3 g of Activa GS, 3 g of 160 Bloom gelatin, and 6.6 g of heavy cream for every 100 g of potato puree.
3. **Refrigerate 12–24 hours to set.** If the base is heat-tolerant, you can reduce the setting time to 1 h in the refrigerator by first warming the mixture to 40–45 °C / 104–113 °F for 10 min, or 55 °C / 130 °F for 5 min. Warming it above 60 °C / 140 °F destroys the enzyme activity.

For more on the origin of transglutaminase and how this enzyme works, see page 3·250.

Best Bets for Gelling with Transglutaminase (Activa)

Application	Type	Components	Typical concentration (scaling)*
dairy gels	Activa YG	transglutaminase, lactose, yeast extract, maltodextrin	0.05%–3.0%
egg gels and soy gels	Activa RM	transglutaminase, sodium caseinate, maltodextrin	0.1%–2.0%
gelatin gels	Activa GS	transglutaminase, gelatin, trisodium phosphate, maltodextrin	0.05%–1.8%

EXAMPLE RECIPE

SOUR CREAM SPAETZLE

Yields 150 g

INGREDIENT	QUANTITY	SCALING
160 Bloom gelatin	6 g	3.3%
Water	40 g	22.2%
Sour cream	180 g	100%
Ricotta	180 g	100%
Whey protein isolate	65 g	36%
Activa YG	4 g	2.2% (*0.9%*)*
Salt	3.6 g	1.7%
Clarified butter	50 g	27.8%
Salt	to taste	
(2008)	*(*% of total weight of all ingredients except butter and salt*)	

1. Disperse gelatin into cold water, and heat to dissolve. Allow to cool.
2. Blend sour cream with gelatin mixture, and rest at room temperature for 5 min.
3. Set spaetzle maker or perforated pan over an ice-water bath, and grate spaetzle base to form individual dumplings.
4. Transfer in one layer to sheet lined with plastic wrap.
5. Refrigerate for at least 4 h to set protein.
6. Drain spaetzle, and fry in clarified butter until golden, about 3 min.
7. Season to taste.

Example recipe	Base	(scaling)	Activa (scaling)	Prep	Set (°C)	Set (°F)	Set (h)	See page
yogurt	low-fat yogurt	100%	0.15%	stir in	55	131	5 min	
mozzarella noodle adapted from Aki Kamozawa and H. Alexander Talbot	mozzarella ricotta	100% 34%	1.3% (*1%*)*	puree until smooth with Pacojet or food processor; cast onto acetate 1 mm / 1⁄32 in thick	refrigerated		18	
heat-stable milk skin	milk 160 Bloom gelatin	100% 1%	1%	cast onto acetate 1 mm / 1⁄32 in thick	45	113	10 min	109
ricotta gnocchi	ricotta	100%	0.7%	shape logs for cutting gnocchi before setting	refrigerated		12	
sour cream spaetzle	sour cream ricotta water whey protein isolate	100% 100% 40% 36%	2.2% (*0.9%*)*	see above	refrigerated		12	above
chawanmushi	whole egg pureed scallop flavorful liquids	100% 65% 368%	8% (*1.5%*)*	cast onto acetate 1 mm / 1⁄32 in thick	45	113	10 min	96
flourless potato gnocchi	potato puree heavy cream 160 Bloom gelatin	100% 6.6% 3%	1.3% (*1%*)*	stir into cold puree; shape logs for cutting gnocchi before setting	refrigerated		12	119

(% of total weight of base ingredients*)

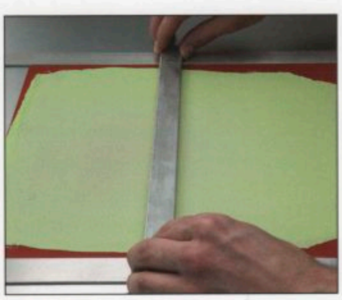
EDAMAME SHEETS, KING CRAB, CINNAMON DASHI ADAPTED FROM WYLIE DUFRESNE

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fresh edamame (or defrosted frozen edamame)	250 g	125%	① Blend to fine puree. ② Pass through fine sieve.
Water	100 g	50%	③ Reserve 200 g for later use.
160 Bloom gelatin	13.75 g	6.8%	④ Disperse gelatin in cold water.
Water	50 g	25%	⑤ Heat until melted.
Edamame puree, from above	200 g	100%	⑥ Combine with gelatin mixture.
Water	25 g	12.5%	⑦ Blend until completely smooth.
Activa RM	3.5 g	1.75% (*1.2%*)*	⑧ Cast onto silicone mat, and spread into even layer 0.5 mm / 1/64 in thick. ⑨ Refrigerate until set, at least 6 h, and cut into squares 7.5 cm/ 3 in wide.
Activa GS	2 g	1% (*0.69%*)*	
Hon-dashi see page 2·306	200 g	100%	⑩ Combine and warm. Add more cinnamon extract to taste. If the broth coagulates, strain through fine sieve.
Cinnamon extract see page 2·326	2.5 g	1.25%	
Salt	to taste		⑪ Season cinnamon dashi. ⑫ Add edamame sheets to stack, warming them. ⑬ Set aside.
King crab tails or claws	160 g (about four pieces)	80%	⑭ Sear until just cooked through, about 1 min per side.
Clarified butter	50 g	25%	
Salt	to taste		⑮ Season crab pieces. ⑯ Place one piece on each plate. ⑰ Drape warmed edamame sheet over each piece. ⑱ Pour cinnamon dashi over edamame, and sprinkle with seasonal herbs. Serve immediately.
Seasonal herbs	as needed		

(original 2008, adapted 2010)

(% of total weight of gelatin mixture, edamame puree, and water*)



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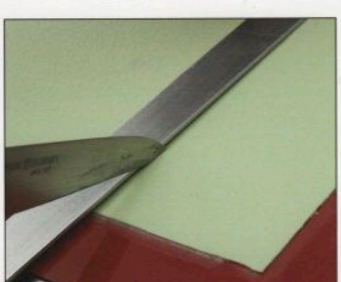

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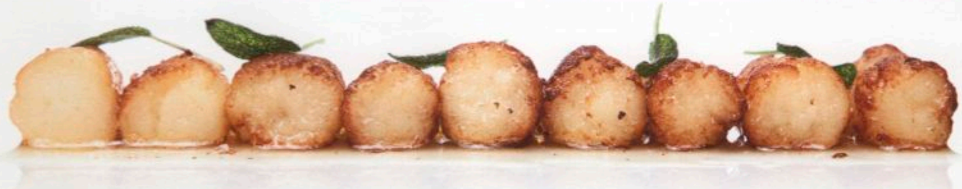
EXAMPLE RECIPE

FLOURLESS GNOCCHI



Yields 650 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes, washed	900 g (about four large)	150%	① Cook sous vide in 92 °C / 198 °F bath for 2 h. ② Cut potatoes in half, and scoop out hot potato flesh. ③ Press, while still hot, through ricer or food mill. ④ Cool. ⑤ Reserve 600 g of puree.
160 Bloom gelatin	19.2 g	3.2% *(3%)**	⑥ Bloom gelatin in cold cream. ⑦ Warm cream mixture until gelatin is dissolved.
Heavy cream	40 g	6.6%	⑧ Cool.
Activa GS	6.4 g	1.07% *(1%)**	⑨ Whisk into cream.
Potato puree, from above	600 g	100%	⑩ Fold cream into potato mixture to form dough.
Salt	to taste		⑪ Season dough. ⑫ Gently roll into log 2 cm / ¾ in. in diameter. ⑬ Cut into desired size gnocchi. ⑭ Transfer to parchment paper-lined tray. ⑮ Refrigerate until firm, about 12 h. ⑯ Bring gnocchi to room temperature, about 20 min.
Unsalted butter, cut into cubes	120 g	20%	⑰ Cook butter in sauté pan until solids begin to brown, about 3 min. ⑱ Add gnocchi, gently stirring until warmed through, about 2 min. ⑲ Remove from heat.
Sage, thinly sliced	6 g	1%	⑳ Fold in.

(2008)

(% of total weight of potatoes and cream)

EXAMPLE RECIPE

SALMON CUSTARD

Yields 120 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Salmon belly, skinless	700 g	700%	① Combine in food processor, and blend to smooth paste.
White fish stock see page 2·303	450 g	450%	② Vacuum seal. ③ Cook in 40 °C / 104 °F bath for 1 h.
Salt	7 g	7%	④ Centrifuge at 12,000*g* for 1 h.
Nutrifos 088 (ICL Performance Products brand)	2 g	2%	⑤ Separate salmon liquid and rendered salmon fat, and reserve. Discard solids.
Salmon liquid, from above	100 g	100%	⑥ Disperse PGA into salmon liquid.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	0.5 g	0.5% *(0.42%)**	⑦ Heat gently to 50 °C / 122 °F to hydrate fully.
Rendered salmon fat, from above	20 g	20%	⑧ Slowly drizzle into warm salmon liquid while homogenizing.
Activa RM	0.9 g	0.9% *(0.75%)**	⑨ Add to mixture, and blend until smooth. ⑩ Transfer to molds, and chill.
Xanthan gum (Keltrol T, CP Kelco brand)	0.1 g	0.1%	⑪ To serve, cook custard in 53 °C / 127 °F bath or steam oven to core temperature of 52 °C / 126 °F, about 25 min.

(2010)

(% of total weight of salmon liquid and fat)

STARCH GELS

If you saturate a liquid carefully, with just enough of the right starch particles, it will become not a paste or glue, but an appealing gel. It is an ancient technique originally practiced with traditional starches such as chickpea flour and kudzu. But the old recipes have been given new life in dishes such as kudzu gnocchi, rich with aged Idiazábal cheese from the Basque Country, or cubes of peanut tofu in spicy tom yum broth.

The starch must first be blended with water and then very finely sieved to remove coarse particles that can make the gel coarse or brittle. Each starch has a slightly different threshold. Like many modern techniques, the process can be time-consuming and delicate, but the results are uniquely rewarding.

EXAMPLE RECIPE

DEEP-FRIED CUSTARD

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
All-purpose flour	32 g	12.8%	① Whisk together.
White chicken stock see page 2·301	250 g	100%	② Bring to boil, and cook for 5 min.
Egg yolks, blended	25 g	10%	③ Whisk together into smooth paste.
Cornstarch	9 g	3.6%	④ Temper hot stock into egg mixture.
			⑤ Return to pan, and cook over low heat until mixture thickens, about 2 min.
Unsalted butter, cubed	10 g	4%	⑥ Stir butter into cooked custard until melted.
			⑦ Quickly cast hot mixture into silicone mold in 2.5 cm / 1 in thick layer.
			⑧ Refrigerate until set, about 3 h.
Potato starch	as needed		⑨ Cut custard into cubes or desired shapes, and dredge in potato starch; shake off excess.
Frying oil	as needed		⑩ Deep-fry cubes in 190 °C / 375 °F oil until golden, about 2 min.
Salt	to taste		⑪ Drain and season.
XO Sauce see page 52	100 g	42%	⑫ Pour over fried cubes generously just before serving.

(2010)

The starch in the custard, and dusted on its exterior, allows us to deep-fry it without a batter. This recipe is essentially a deep-fried savor pastry cream. For a sweet version of the recipe, replace the chicken stock with whole milk, and add 26 g of sugar (20% of the overall weight)

EXAMPLE RECIPE

BURMESE CHICKPEA TOFU LAKSA

Yields 1.4 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	1 kg	100%	① Blend until completely homogenized.
Chickpea flour	350 g	35%	② Line fine sieve with three layers of cheesecloth.
			③ Strain chickpea mixture through fine sieve into pot.
			④ Bring to boil.
			⑤ Remove from heat.
Salt	14 g	1.4%	⑥ Whisk into hot chickpea mixture.
Turmeric powder	0.5 g	0.05%	⑦ Divide mixture evenly among molds 5 cm / 2 in thick.
			⑧ Refrigerate for 4 h until firmly set.
			⑨ Cut into cubes.
Kumamoto or Olympia oysters	12 pieces		⑩ Shuck, reserving juices separately.
Laksa broth see page 2·307	200 g	20%	⑪ Warm broth.
			⑫ Add oyster juice to taste.
Oyster juice, from above	to taste		⑬ Add half of tofu cubes and oysters to broth, and warm through.
Frying oil	as needed		⑭ Deep-fry remaining cubes in 190 °C / 375 °F oil until golden, about 3 min.
Mint, leaves	as needed		⑮ Garnish.
Cucumber, peeled, seeded, and sliced	as needed		

(2010)

The particles in the chickpea mixture must be very fine to yield an elastic, homogenized gel instead of one with a grainy, brittle texture. Sieving with a fine sieve or through cheesecloth is crucial to achieve a good result.

The chickpea tofu is delicious when deep-fried and served with a sweet-and-sour glaze or a spicy paste, as in the recipe on the previous page.

This so-called tofu is really a starch gel that plays a big role in the traditional cuisine of Myanmar (formerly Burma).

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EXAMPLE RECIPE

CORN CUSTARD INSPIRED BY DAVID KINCH

Yields 340 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Frozen organic sweet yellow corn, thawed	500 g	500%	① Juice corn, preferably with Champion-style juicer (see page 2·332), reserving 100 g juice.
Corn juice, from above	100 g	100%	② Blend starch and salt into cold juice to distribute evenly.
Cornstarch	4 g	4%	③ Pour 25 g of juice in layer 1 cm / ⅜ in deep into each of four molds.
Salt	1.7 g	1.7%	④ Steam at 88 °C / 190 °F until custards are just set, about 30 min.
			⑤ Cool completely.
Fava beans, peeled	50 g	50%	⑥ Vacuum seal in one even layer.
Olive oil	8 g	8%	⑦ Cook sous vide in 75 °C / 167 °F bath for 25 min.
			⑧ Remove from bag.
Fresh sweet peas, shucked	50 g	50%	⑨ Vacuum seal in one even layer.
Olive oil	8 g	8%	⑩ Cook sous vide in 70 °C / 158 °F bath for 18 min.
			⑪ Remove from bag.
Sous vide vegetable jus see page 2·344	70 g	70%	⑫ Combine while bringing to simmer.
Tomato water see page 2·366	30 g	30%	
Unsalted butter, cubed (use olive oil if serving cold)	35 g	35%	⑬ Blend into simmering liquid until fully emulsified.
			⑭ Remove from heat.
Anise hyssop, fine julienne	5 g	5%	⑮ Whisk into warm butter sauce.
			⑯ Steep for 3 min, and strain.
Lime juice	to taste		⑰ Season sauce.
Salt	to taste		⑱ Fold in warm beans and peas.
			⑲ Reheat custards, and garnish with sauce.
			⑳ Finish with hyssop blossoms, if available.

(original 2002, adapted 2010)

For a tender starch custard, a 9% ratio of cornstarch to liquid seems to be ideal. The percentage of starch in fresh corn varies dramatically—this recipe assumes that the corn juice itself contains 5% starch. You can test the recipe using a small amount of your corn juice, and adjust the quantity of cornstarch to achieve the texture you prefer.

In this interpretation of David Kinch's Corn Pudding, we have presented the typical flavors of a late summer succotash. The accompaniments can be varied seasonally, but the custard can be made year-round with good quality frozen corn.

EXAMPLE RECIPE

PEANUT "TOFU" INSPIRED BY YOSHIHIRO MURATA

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	400 g	100%	① Combine in pot.
Coconut milk	50 g	12.5%	② Stir until palm sugar is completely dissolved.
Fish sauce	25 g	6.25%	
Palm sugar	10 g	2.5%	
Peanut butter (smooth)	50 g	12.5%	③ Blend into mixture.
Kuzu starch	42.5 g	10.6% *(8%)**	④ Add to mixture, blending until starch is completely dispersed.
			⑤ Pass through fine sieve.
			⑥ Simmer for 20 min until thick.
Salt	to taste		⑦ Season mixture.
			⑧ Pour quickly into silicone molds.
			⑨ Refrigerate until set, about 12 h.
Tom yum broth see page 2·309	200 g	50%	⑩ Bring broth to simmer.
Scallions, shredded	as needed		⑪ Transfer tofu to bowl, and garnish with scallions and warm broth.

(2010)

(% of total weight of first five ingredients*)

This recipe makes a typical Asian peanut sauce, which is then set into a gel by using Kuzu starch. The result isn't true tofu, but it has a tofu-like texture.

EXAMPLE RECIPE

IDIAZÁBAL GNOCCHI ADAPTED FROM ANDONI LUIS ADURIZ

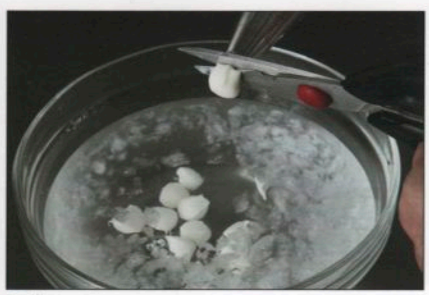
Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cheese water (made with Idiazábal) see page 2·310	130 g	100%	① Blend together. ② Vacuum seal. ③ Cook in 95 °C / 203 °F bath for 1½ h to create starch base.
Kuzu root starch	32 g	25% *(18%)**	
Idiazábal cheese (or other semifirm cheese such as Pecorino), grated	50 g	38%	④ Blend into starch base over medium heat until fully incorporated. ⑤ Transfer dough to piping bag. ⑥ Extrude directly into ice water; cut equally sized dumplings with scissors as dough is extruded.
Salt	2.5 g	2%	
Ham broth see page 2·306	260 g	200%	⑦ Heat broth. ⑧ Stir in gnocchi to warm through.
Extra-virgin olive oil	to taste		⑨ Garnish.
Perilla (red and green), leaves	as needed		
Lemon balm, leaves	as needed		
Micro scallion greens	as needed		

(original 2003, adapted 2010)

(% of total weight of water and cheese*)


5a


5b


5c


Photo courtesy of José Luis López de Zubiría—Mugaritz

GELLING WITH HYDROCOLLOIDS

Modernist cooks especially value an exciting set of gelling agents known as hydrocolloids. Most of the newer hydrocolloids are long chains of molecules called **polysaccharides**, which means "many sugars." Sugar molecules in them link together to form long chains. Unlike starches, many hydrocolloid molecules pass relatively unprocessed through our digestive system, much the way fiber does. Some hydrocolloids have a flavor, but they are used at such small concentrations that their affect on flavor is negligible.

While many of the new hydrocolloids are polysaccharides, not all long-chain polysaccharides form gels. Cellulose is an example of one that does not.

Kitchen hydrocolloid agents come from extracts of seaweed (agar, alginate, carrageenan); from plant seeds (locust bean gum, guar gum); from plant sap or resin (gum acacia, gum arabic); or from fermentation by bacteria (xanthan gum, gellan). All are natural substances produced by living things, and most, if not all, are available in certified organic form.

Technically, a hydrocolloid is any substance that forms a colloidal suspension with water. Food technologists tend to use the term only for substances that thicken or gel water-based liquids. Gelatin, starch, and other gelling substances are hydrocolloids, but in most cases, chefs use the term only for newer and less familiar products. It's rare to use "hydrocolloids" to mean flour, even though technically that could be correct.

The first step in using a hydrocolloid is to disperse it in water, as is the case with a thickener (see page 24); the second is to hydrate it. Technically, proper hydration means surrounding each molecule of the hydrocolloid with a layer of water. Practically, the goal of dispersion is to mix the gelling agent thoroughly with water so that there are no lumps. This often requires a blender or other powerful source of shear, and complete hydration often requires heat as well.

Many people refer to hydrocolloids as gums or plant gums, but that is accurate only for some ingredients, like gum arabic. Other hydrocolloid gelling agents are not gums at all. We use the term "hydrocolloid" when discussing them as a group and refer to each ingredient specifically by name (e.g., low-acyl gellan gum) when appropriate.

Surprisingly small concentrations of hydrocolloids can yield firm gels. Many gelling agents form a solid at a concentration of only 0.5% (i.e., just half a gram of hydrocolloid for every 100 grams of liquid); some can achieve gels in even smaller amounts. At the other extreme, high concentrations of hydrocolloids result in the very stiff gels that characterize gummy bears and jelly beans. The texture and mouthfeel depends on the gel, its concentration, and factors like the dissolved solids, acidity, and (in some cases) ion concentration.

For more on **freeze-filtering**, see page 2·351.

Once formed, the gels can exist in a wide temperature range. Hot gels are one of the exciting new offerings from Modernist cuisine. Whereas gelatin melts at around 37 °C / 98.6 °F (body temperature) and must be served cold, many hydrocolloids form gels that remain solid at temperatures up to 85 °C / 185 °F and above.

Locust bean gum is derived from the seeds of the carob tree. It was well known to the ancient Egyptians, who used it as a binder for the wrappings of mummies, among other things.

Hot gel dishes are particularly dramatic when they are clear because most people have experienced only cold gel dishes made with gelatin. Hot gels include faux noodles that contain no starch, and eggless custards and flans. A hot gel coating can encapsulate food, essentially wrapping it in a solid, or a gel presented as a thin sheet can form a veil of "sauce" covering the dish.

Ion-Coagulated Gels

Some hydrocolloid gelling agents require an ion-based coagulant, usually calcium, to work properly. Important examples of ion-setting gels include alginate, gellan (particularly low-acyl [LA] gellan), iota carrageenan, and low-methoxyl (LM) pectin. These gels require special handling in order to get good results. Of these, LA gellan is by far the most sensitive to ion concentration, so we discuss it first.

If the ion concentration is too high in the liquid used to make the gel, the gelling agent will not hydrate properly or will require excessive temperature to hydrate. For LA gellan, the hydration temperature depends strongly on ion concentration. In **deionized water** or distilled water, it hydrates at 75 °C / 167 °F. In soft tap water, which contains more calcium, the hydration temperature rises to 88 °C / 190 °F, and with calcium-rich hard tap water, the hydration temperature goes above 100 °C / 212 °F.

Sodium ions, such as those released by salt as it dissolves, similarly obstruct the hydration of LA gellan, although it is not as sensitive to sodium as it is to calcium. Dissolved solids such as sugar also raise the hydration temperature, as do overly acidic conditions (below pH 4.0). And temperature is not the only important factor for hydration: it also requires vigorous mixing by using a blender, immersion blender, or **rotor-stator homogenizer.**

You can use milk or cream at about 90 °C / 194 °F to hydrate LA gellan. That may seem counterintuitive, given milk's high calcium

Gel noodles can be served either hot or cold. For a recipe, see page 143.

content. Most of that calcium, however, is bound up with other components of the milk and thus not free to coagulate the gel. So milk behaves much like soft water.

It is not always easy to know just how much calcium is in stocks, fruit juices, and other food liquids. In general, the simplest way to hydrate an ion-sensitive gel is to use a known liquid, such as milk, or deionized or distilled water. Bottled drinking water is another convenient choice, as most brands are quite soft. Once you find a brand that works, stick to it to ensure consistency. Having hydrated your gelling agent, you can then add the other food ingredients, keeping the solution at the hydration temperature.

Alternatively, you can use a sequestrant, which mops up stray ions by binding to them. The sequestrant with the highest performance is **sodium hexametaphosphate** (also known as "hex" or SHMP). It has no taste at the concentrations used, and it can sequester ions even in acidic solutions.

The other most common kitchen sequestrant is sodium citrate, which works well at pH levels above 6.0 but loses its sequestering ability below a pH of 4.5. You can exploit this pH-specific behavior to make a gel that sets only when it becomes acidic and causes the sodium citrate to release ions.

Sequestrants allow us to hydrate gelling agents at much lower temperatures—down to 22 °C / 72 °F, in the case of LA gellan. Note that even deionized or distilled water requires a sequestrant to reach that hydration temperature because the gel itself carries some calcium in it.

By using a sequestrant and heat, you can hydrate a gelling agent in a sugar solution of up to about 60%. The alternative is to hydrate in water and to mix in the sweet ingredients later.

Gelling agents are typically used in concentrations ranging from 0.25%–0.5% of the weight of the liquid; you can, however, hydrate a much more concentrated gel solution (a liquid solution containing, say, 5% gelling agent) if necessary. You may find it useful to prepare a stock solution for mixing into other food liquids (to make a more dilute concentration). To do this, use deionized or distilled water and a sequestrant in the stock solution. It will require a lot of shear force and will be very viscous.

After the gelling agent has been hydrated, ions

In the kitchen, "salt" means sodium chloride (NaCl), but to a chemist, salts are a whole class of **ionic compounds** formed from the neutralization reaction of an acid and a base. Calcium chloride ($CaCl_2$) is one salt of calcium, and calcium lactate ($C_6H_{10}CaO_6$) is another.

For a recipe for spherified olives, see page 193. Spherification is also discussed further beginning on page 184.

Modern Gels

Gels and gelling agents are a playground for curious chefs. With modern ingredients, chefs can manage the consistency and structure of liquids without altering their flavor. Gels inspire the contemplation and exploration of physics, flavor, texture, and presentation. Modern gels are rooted in classical cuisine and cultural traditions but have been refined in the lab to create ingredients with improved convenience, consistency, and economy.

Gelling agent	Ingredient	Example use	Note
enzymes	transglutaminase	tofu, cheese, egg custard	gels protein-rich liquids by cross-linking protein molecules
	rennet		
	other protease enzymes		
starches	modified starch	instant puddings, eggless custards	Modernist version of traditional starch gels
	pregelatinized starch paste		
hydrocolloids derived from fruits	high-methoxyl pectin	pâte de fruit, fruit jellies	fruit pectin gels set even in the presence of high sugar concentration or calcium
	low-methoxyl pectin	low-sugar, low-acid pâte de fruit	
hydrocolloids derived from tubers or roots	tapioca starch	set puddings, eggless custards	at high concentrations, starch thickens enough to set into a gel
	konjac flour	konnyaku (Japanese noodles)	sets firmly in alkaline solutions
	kudzu starch, mallow root, salep	tofu, chewy puddings	forms elastic gels
hydrocolloids derived from marine plants	agar	yōkan, hot savory gels	forms firm brittle gels with almost any liquid
	iota carrageenan, kappa carrageenan, lambda carrageenan	eggless custards, yogurt, and other dairy gels	gels best in dairy solutions
	sodium alginates	spherification	gels in the presence of calcium
	propylene glycol alginates	high-fat gels	good emulsifier, so appropriate for oil gels
hydrocolloids derived from other plants	aloe vera	dairy gels	forms elastic gels
	mastic	dondurma (Turkish ice cream)	
	chicle gum	chewing gum	
	locust bean gum	dairy gels	makes elastic gels with xanthan gum
	guar gum		
	gum arabic (gum acacia)	chewing gum	forms elastic gels
	gum tragacanth	sugar craft	forms malleable gels with cooked sugar
hydrocolloids derived from microbes	high-acyl gellan	elastic, opaque heat-stable gels	for more details on gellan, see page 124; for more on xanthan gum, see page 40
	low-acyl gellan	brittle, clear, very heat-stable fluid gels	
	xanthan gum	elastic gels, with locust bean gum	
cellulose gums	methylcellulose	custards, puddings, baked goods	gels at low concentrations; can add unpleasant flavors
	hydroxypropyl methylcellulose	onion rings, gel noodles	

Some hydrocolloids form gels when sodium or potassium is added as a coagulant, but calcium ions generally work best. Calcium is one of a class of elements known as alkali earth metals, along with beryllium, magnesium, strontium, and barium. Of these, only calcium and magnesium are commonly found in food; the others are either exotic, toxic, or both.

must be present for it to form a gel. Plenty of ions will already be in the food if you hydrated the agent with distilled or deionized water, milk, or some other calcium-rich liquid, as long as you did not add a sequestrant to the mix. Many foods contain enough calcium already. That's the case with Ferran Adrià's famous spherified olives, for example; the olive puree filling has sufficient calcium to form a gel with any of the ion-setting gels. When ions are abundant, just cool the gel from the (relatively high) hydration temperature, and it will set.

If you use a sequestrant to reduce the hydration temperature, however, be aware that the food may not have enough ions remaining in it to gel. In the case of the special technique called **spherification**, the whole idea is to prepare a solution that refuses to gel until you supply the ions. In that case—or if your hydrating solution and food are ion-poor—you'll need to add calcium salt to form a gel (see page 129).

It may seem strange to first add a sequestrant to get rid of calcium, only to later add the calcium back in, but that is often exactly what we must do.

Alginate, LM pectin, and iota carrageenan are less finicky than LA gellan. Any sequestrant and calcium levels worked out for gellan will also work for them. HA gellan is far less sensitive to ions than LA gellan is, but because it yields an opaque and elastic gel, it is not a substitute for LA gellan.

One family of hydrocolloids, the cellulosic gums such as methylcellulose, differs from the other gelling agents in a significant way: they are thermo-reversible gels that set with heat and melt with cold. With these, you can make a plate of warm "noodles" that gel instantly from liquid (see page 138), and other unusual dishes.

Food manufacturers often use methylcellulose to prevent boilover in foods like chicken potpies and berry cobblers. As the liquid filling heats up, the methylcellulose solidifies it. The liquid returns to its original state when the food cools.

One drawback of cellulosic gums is that they are difficult to disperse and hydrate in a cold liquid. The problem is like trying to mix dry cocoa powder into cold milk before heating it for hot chocolate; the process requires lots of shear force and is hard to achieve even with a high-speed blender. As in making hot chocolate, it's best to disperse the methylcellulose first in a small volume of hot liquid. Then you can blend the mix to thin the granules, which will start hydrating as the liquid begins to cool.

One of the quests of Modernist cuisine is to develop the fabled "hot ice cream" dish, a goal that so far has eluded eminent chefs. You can use methylcellulose to make something like hot ice cream, but to many tasters the dish lacks a true ice-cream-like texture and instead resembles an odd, dumpling-like object that melts as it cools.

THE SURPRISING USES OF

Alginate

One of the most common hydrocolloids in the Modernist kitchen is alginate (also known as sodium alginate), a hydrocolloid extracted from brown seaweed. Modernist cooks use alginate to achieve spherification (see page 184), but it has been employed in the food industry for decades for far more mundane purposes, like thickening pie fillings and preventing ice crystal formation in ice cream and frozen desserts.

Alginate makes possible restructured and engineered food products like the pimento-stuffed olive in your martini cocktail. Processors prepare the pimento filling by grinding red peppers into a puree, adding alginate, and then spraying the mixture into thin sheets. When set, the sheets are machine-sliced into little portions that are stuffed into pitted olives. The result is a far more consistent product than hand-stuffed olives, and it avoids the need for trimming or handling other waste.

Alginate has been used to make artificial "cherries" in cans for cherry pie filling. They look like cherries, but in fact, they are an industrial example of spherification because they are accurately molded spheres of cherry puree. These manufactured cherries maintain their texture and shape far better than canned whole cherries do. The process is also more economical because it can make use of slightly bruised or misshapen cherries that would otherwise be wasted. The restructured cherries' exact uniformity is a dead giveaway that the cherries are man-made.

Another example of a food made with alginate is the mass-produced onion ring. Some fast-food onion rings are composed of restructured onion bits. Again, uniformity is the key to efficient commercial processing, which would otherwise have to cope with rings of many sizes and shapes. As with the cherries, onions are ground to a puree, alginate is added, and identical rings are cast. These are then breaded and, later, fried. Note that these onion rings can still be labeled "all natural."

In a nonfood application, dentists use alginate to make bite impressions. A patient bites into an alginate paste on a jaw-shaped tray. The paste then hardens to produce an exact mold of the patient's teeth. The same kind of paste is also used for "life-casting," in which an alginate paste is smeared over a living human body as the first layer (often reinforced with plaster) of a realistic mold.

THE USES OF

Carrageenan

What agar has been to traditional gelling technique in Asian cuisines, carrageenan has been to the classic cooking of Ireland, where its namesake coastal town is located. For many generations, the local inhabitants have harvested a red seaweed that they use to make milk puddings and other dairy-based gel dishes. Traditionally cooks simmered the seaweed with milk and other ingredients to unlock the red algae's gelling properties.

Modern food scientists have derived three types of carrageenan, named for the Greek letters ι (iota), κ (kappa), and λ (lambda). Each has different properties, such as how firmly (and whether) it sets to a gel, its freeze-thaw stability, and its syneresis activity. They're made by blending different species of seaweed to achieve the desired properties. All three versions of carrageenan are available commercially, so select the one that best fits your goals. Kappa carrageenan is quite effective at solidifying milk proteins in very low concentrations (less than 0.5%) and is widely used in dairy applications. Water-based carrageenan gels require roughly twice as much gelling agent as those made with milk.

Note that lambda carrageenan does not cause gelling without the presence of another carrageenan compound. Lambda carrageenan is, however, often used alone to modify the mouthfeel and viscosity of dairy products.

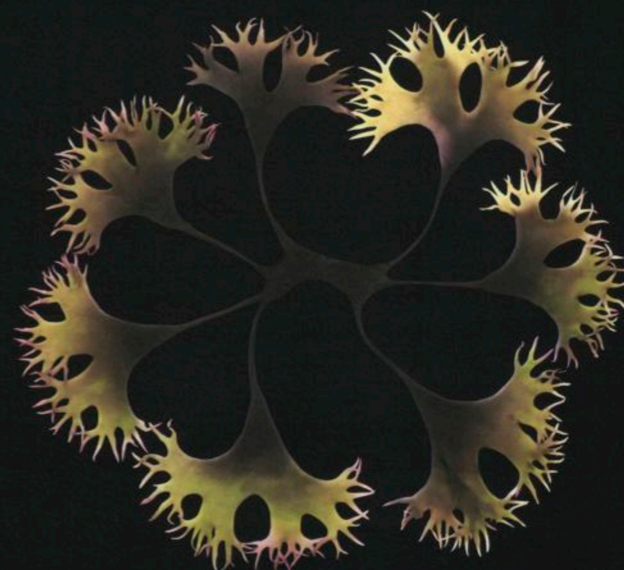


Photo courtesy of Andrea Ottesen

THE HISTORY OF

France, the Land of Agar

Agar, also called "agar-agar," is one of the world's great traditional gelling agents. It originated in Asia ("agar-agar" is a Malay word that means "gel" or "jelly"), and it has been used for centuries in the cuisines of Japan, China, Korea, Indonesia, Thailand, and Malaysia. Agar is the extract of a seaweed, traditionally harvested in the wintertime in Japan. Agar can remain gelled at far higher temperatures than gelatin—up to 85 °C / 185 °F.

Agar is famous among biologists. In 1882, Angelina Hesse suggested using agar as a medium for growing bacteria to her husband Walther, a researcher in the laboratory of microbiologist and Nobel Prize-winner Robert Koch. She had learned to cook with agar from a Dutch neighbor in New York who had emigrated from Java, where agar use was common. Since then, nutrient-enriched agar gels in petri dishes (invented by another Koch technician) have been used to grow bacteria in laboratories around the world.

Given these roots, it may surprise you to learn that the country where agar is most used in cooking is France! Here is one example: a search on Amazon.fr found seven cookbooks in French with "agar" in the title and over 30 cookbooks for which "agar" was listed as a keyword. As recently as mid-2010, the same searches on Amazon.com found zero cookbooks in English. Agar has been widely adopted in France, in home cooking as well as in professional kitchens. This includes many chefs who do not cook in the Modernist style but have incorporated agar into their traditional cuisine.

We don't fully share the French chefs' enthusiasm. Agar is a good gelling agent, but we find it most useful for forming fluid gels. In solid gels, agar creates a firm and brittle texture that not everybody loves. Many of the tasks for which French chefs use it could be better done with gellan, pectin, carrageenan, or a mixture of other gels (see above and page 42). But to paraphrase an old saying, 10,000 Frenchmen can't be wrong.

HOW TO Use Ion-Coagulating Gels

Alginate, LA gellan, LM pectin, and iota carrageenan gel only in the presence of ions—of which calcium is the most important. A sufficient calcium concentration must be present in order to gel. Unfortunately, calcium and other ions also get in the way of hydration. So to get a gel, we must make sure that there is low or no calcium at hydration time.

The simplest approach is to always hydrate in a known liquid—bottled, deionized, or distilled water or milk. One must then add enough calcium after hydration for a gel to form. The other approach is to use a sequestrant, which binds to calcium ions and prevents them from inhibiting hydration.

Although calcium is the main barrier to good hydration, other ions, salt, dissolved sugar, and acidity can raise hydration temperature as well and may also necessitate using a sequestrant.

Sources of Calcium

Sodium citrate, calcium chloride, and calcium sulfate tend to absorb water from the air (in fact, they are sometimes used as desiccants—see page 2·428). The quantities given here are for the water-free (anhydrous) forms.

Calcium source	Calcium content	Add to make 0.04% calcium solution (scaling)*
Calcium chloride (anhydrous)	36.1%	0.11%
Calcium sulfate (anhydrous)	29.4%	0.14%
Calcium lactate	18.4%	0.22%
Calcium gluconate	9.3%	0.43%

*(*set weight of liquid to 100%*)

After hydration, calcium must typically be added to form a gel. There may be enough in the foods mixed with the gel, but if not, then calcium salts will supply the needed ions. The correct calcium concentration required for gelling is about 0.04%, but to get this concentration of calcium, different amounts of the salts must be used because they are not pure calcium.

1. **Disperse gelling agent in distilled, deionized, or bottled water, or with milk or cream.** Use a high-shear mixer, if available.
2. **Hydrate while mixing at a temperature appropriate for the gel.** For instructions on hydrating a gelling agent, see page 26.
3. **Add other liquids to be gelled.** Keep the temperature at or above hydration temperature.
4. **If the food liquids have sufficient calcium, cool to gel them.** If you are uncertain about the calcium content of the food, test it by cooling a small sample. If a gel fails to set, supplement it by adding a calcium salt; several options are listed in the table Sources of Calcium at left.

VARIATION: Using a Sequestrant

1. **Mix the sequestrant into the liquid, and stir until dissolved.**
2. **Disperse and hydrate the gel by using high-shear mixing at an appropriate temperature.**
3. **Select a source of calcium, mix it into the liquid, and cool the liquid to gel.** If the food ingredients are not sufficiently rich in calcium, select a supplemental source from the table Sources of Calcium at left. Hold the food at hydration temperature while mixing. Add sufficient calcium to increase the concentration of calcium ions to 0.04%—suggested quantities are listed in the table.

Using Sequestrants

The two most useful sequestrants are anhydrous sodium citrate (SC) and sodium hexametaphosphate (SHMP). SHMP works over a wide range of pH and is the best all-around sequestrant. The quantities listed in this table work for a 0.3% LA gellan solution. When working with a solution of higher gellan concentration, add 0.004% of SC, or 0.00267% of SHMP, for every 0.1% increment of LA gellan above 0.3%. For example, if using 0.5% LA gellan solution, add 0.008% SC or 0.00534% SHMP to the scaling values in the table.

	Hydrate alone		Sequestrant		Hydrate with sequestrant	
			SC	SHMP		
Liquid	(°C)	(°F)	(scaling)*	(scaling)*	(°C)	(°F)
Milk or cream	90	194	0.15%	0.10%	22	72
Deionized or distilled water	75	167	0.07%	0.05%	22	72
Water, <65 ppm calcium (soft water, bottled drinking water)	88	190	0.12%	0.08%	22	72
Water, 65–130 ppm calcium (slightly hard water)	n/a		0.16%	0.11%	22	72
Water, 130–180 ppm calcium (hard water)	n/a		0.20%	0.13%	28	82
Water, >180 ppm calcium (very hard water)	n/a		0.34%	0.22%	58	136

*(*set weight of liquid to 100%*)

EXAMPLE RECIPE

EVERYTHING BAGEL BROTH

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tomato juice	200 g	100%	① Combine juices.
Cucumber juice	50 g	25%	
Red onion juice	30 g	15%	
Bagels, toasted until golden and finely ground	50 g	25%	② Combine with juice mixture. ③ Vacuum seal.
Toasted sesame seeds	7 g	3.5%	④ Infuse in refrigerator for 24 h.
Dried onion flakes	5 g	2.5%	⑤ Centrifuge at 27,500*g* for 1 h.
Black poppy seeds	3 g	1.5%	⑥ Measure 200 g of clear broth.
Sodium hexametaphosphate	0.6 g	0.3%	⑦ Dry blend together.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.2 g	0.1%	
Infused bagel broth, from above	200 g	100%	⑧ Bring broth to room temperature. ⑨ Add gellan mixture to broth, and shear until gellan is fully dispersed.
Red wine vinegar	to taste		⑩ Season broth, and refrigerate.
Salt	to taste		

(2010)

This broth and the squid ink on the next page are both examples of fluid gels (see page 176).

EXAMPLE RECIPE

DILL SPHERES

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Low-acyl gellan (Kelcogel F, CP Kelco brand)	1.6 g	0.64% *(0.48%)**	① Dry blend.
Sodium hexametaphosphate	0.4 g	0.16% *(0.12%)**	
Dill sprigs	130 g	52%	② Blanch dill sprigs in boiling water until tender, about 2 min.
Deionized water	150 g	60%	③ Cool quickly, drain, and puree until smooth with deionized water. ④ Pass mixture through fine sieve, and measure 85 g for recipe.
Water	250 g	100%	⑤ Disperse gellan blend in dill puree. Bring to simmer while shearing, and cool completely.
Dill puree, from above	85 g	34%	⑥ Transfer mixture to squeeze bottle with 0.4 mm / ⅛ in tip. ⑦ Pipe small droplets into liquid nitrogen to freeze. ⑧ Drain frozen spheres, and reserve.
Celery juice, clarified	500 g	200%	⑨ Whisk together until fully dissolved to make setting bath.
Calcium gluconate	30 g	12% *(6%)***	⑩ Drop frozen spheres into setting bath, and allow to skin to form for 2 min. ⑪ Drain set spheres, and transfer to fresh water bath to rinse.
Citric acid	0.4 g	0.16% *(0.08%)***	⑫ Drain once more, and hold in fresh water bath until ready to serve.

(2010)

**(% of total weight of water and dill puree)*
***(% of total weight of water)*

This recipe is an example of direct spherification (see page 186). Add a very small amount (0.2%) of xanthan gum to the dill puree to make spherical drops.

EXAMPLE RECIPE

SQUID INK FLUID GEL

Yields 140 g (400 g with other components)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	100 g	100%	① Blend until smooth.
Capers, brined	15 g	15%	
Squid ink	10 g	10%	
Champagne vinegar	to taste		② Season squid ink mixture.
Salt	to taste		
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.5 g	0.5% *(0.4%)**	③ Dry blend, and disperse in squid ink mixture. ④ Boil mixture for 1 min to fully hydrate.
Sodium hexametaphosphate	0.125 g	0.125% *(0.1%)**	⑤ Pour into desired container, and refrigerate until set, about 5 min. ⑥ Puree squid ink gel to fluid gel, transfer to squeeze bottle, and reserve.
Olive oil	10 g	10%	⑦ Whisk to make black pepper oil.
Black pepper essential oil	1 g	1%	
Brominated vegetable oil (weighting agent)	0.1 g	0.1% *(1%)***	
Bagel broth see previous page	200 g	200%	⑧ Divide cold broth evenly among four bowls.
Dill spheres see previous page	100 g	100%	⑨ Spoon individually into each bowl.
Tobiko roe, washed in aquavit	50 g	50%	
Chives, minced	as desired		
Dill tips	as desired		
Squid ink fluid gel, from above	40 g	40%	⑩ Stir contents gently to evenly distribute roe, spheres, and herbs. Drip some squid ink fluid gel and black pepper oil into consommé, and stir once, gently, to create suspended black streaks and oil droplets.

(2010)

(% of total weight of first three ingredients*)
**(*% of total weight of olive oil*)

This dish showcases several aspects of gellan: a clear fluid gel broth supports spherified dill and tobiko roe, as well as a free-form fluid garnish of squid ink. For a larger photo, see page 1·52. The black-pepper oil droplets keep their shape because of the static viscosity of the fluid gel broth and the weighting agent that helps prevent them from rising to the top.

HOW TO Cast Gels

Presentation is part of the intrinsic appeal of gelled liquids, and there are many different ways to achieve a pleasing form. The basic technique for casting a tender gel is described below, followed by variations for making gels in molds, suspending solids within molded gels, making thick and thin sheets of gel, and casting small droplets of gel. For techniques used in making extruded gel noodles, see page 138; spherification of gels is described on page 186.

Take care when casting a tender gel. Very delicate gels cannot be moved, so they must set in the same vessel in which they will be served. Rigid or brittle gels can be spooned on as coatings, poured into sheets, or cast into whimsical shapes, but they will not flex after setting. Strong, elastic formulations can be cut into noodles or ribbons, formed into veils or puddles, and manipulated in other ways well after gelling.

1 **Select a serving vessel.** Tender gels are best cast directly into whatever container you will serve them in. See steps below for variations using other kinds of gels.

2 **Disperse and hydrate the gel.** For instructions, see pages 24 and 26.

3 **Cast the gel to the desired thickness.**

4 **Set.** Refer to the table of hydrocolloid properties on page 42 for setting times and temperatures, which vary among gels.

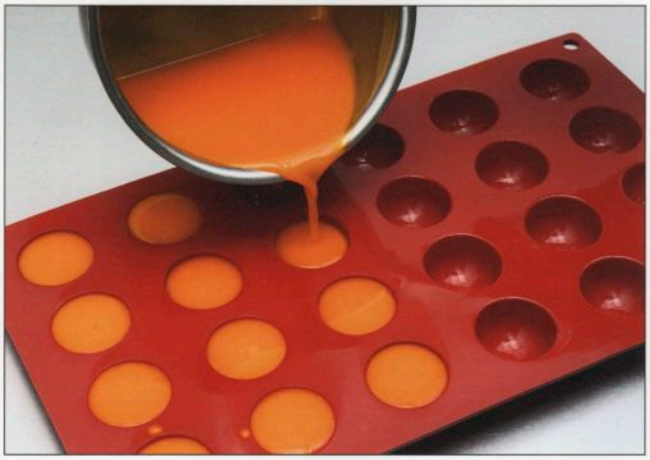
5 **Add another layer of gel (optional).**

6 **Garnish (optional).**

In general, tender or delicate gels should be cast into the serving container, while tougher gels are suitable for taking out of their mold. One trick for removing delicate gels from molds is to freeze them first, which makes them much stronger. Note, however, that this works only for gels that are freeze-thaw stable.

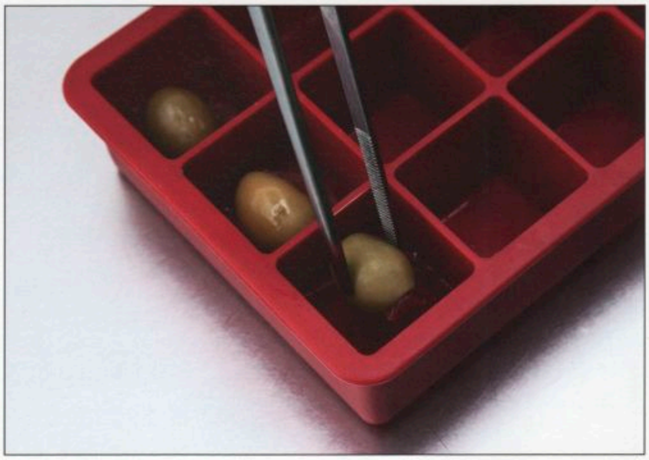
VARIATION: Molding Gels

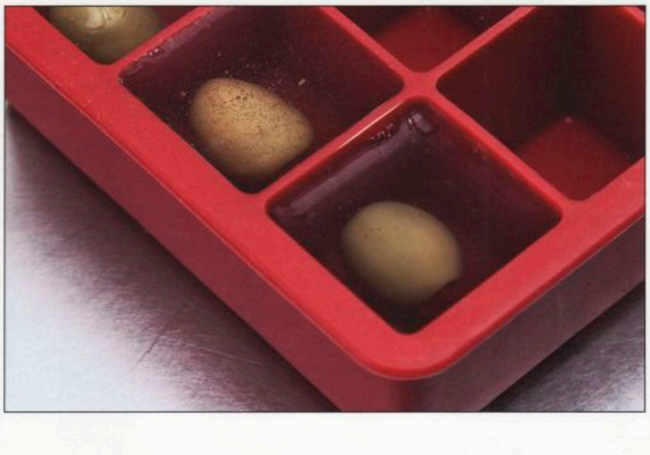
Many shapes and sizes of nonstick molds are available; flexible silicone molds work well. Be sure to test the molds with water first to see how much material you will need, and then adjust the recipe yield accordingly. See page 148 for an example recipe.



VARIATION: Molding Gels with Suspended Solids

Cast only part of the gel, let it set partially until soft, place the solid carefully on the soft gel, and then cast the remaining gelling liquid.





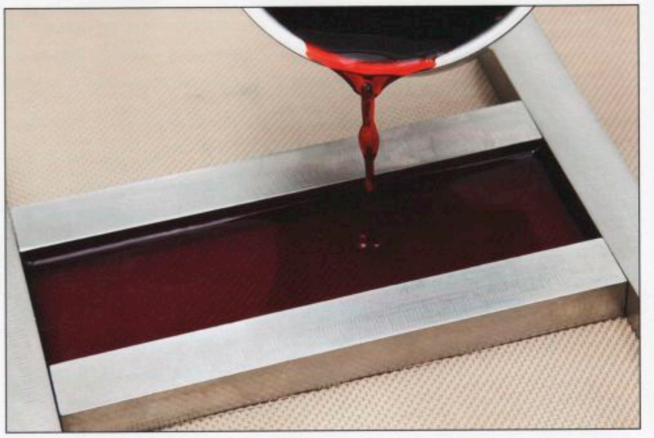
VARIATION: Casting Thick Gel Sheets

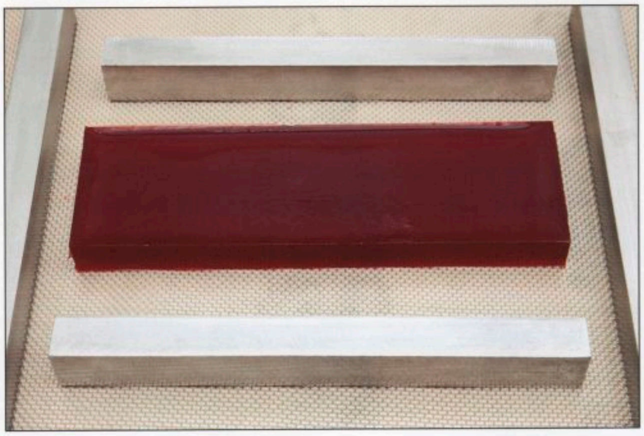
Casting a gel into a mold formed from pastry bars conveniently allows you to adjust the distance between the bars to match the yield.

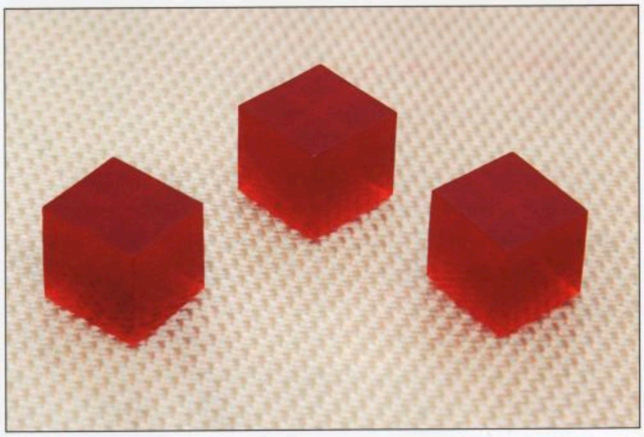
1 **Arrange pastry bars on a nonstick surface such as a silicone mat or oil-brushed plastic wrap.** Take care to level the mold so that the gel sheet will be even in thickness.

2 **Pour gel; adjust the bar spacing to achieve the desired thickness.** When set, remove bars.

3 **Cut into desired shapes.**



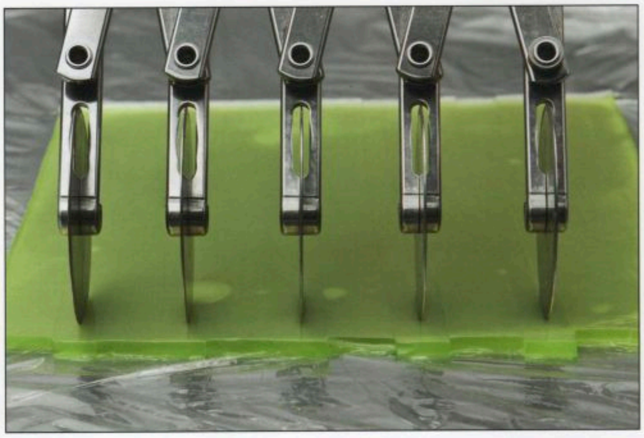




VARIATION: Making Gel "Linguine"

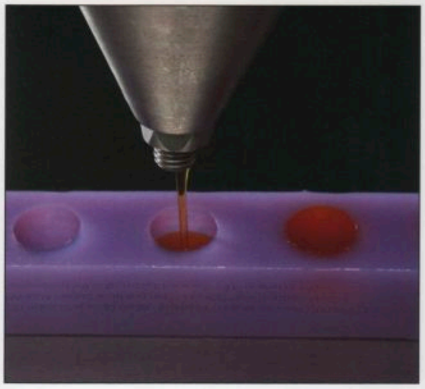
1 **Cast a thin gel sheet into a mold made from pastry bars (see steps above) arranged on plastic wrap.**

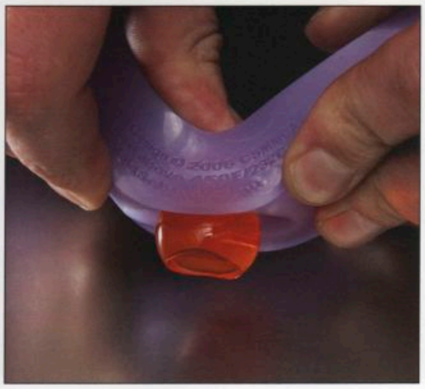
2 **Cut strips.** Remove the bars once the gel has set. Use a pasta cutter to cut the gel into strips.

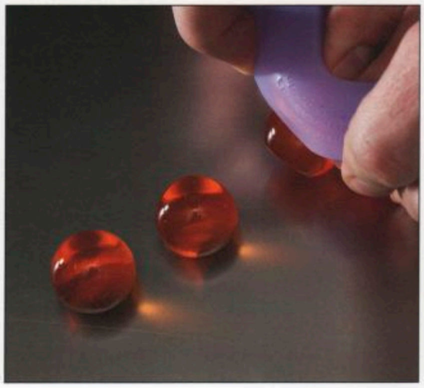


VARIATION: Molding Gel Spheres

Perfect gel spheres can be difficult to produce consistently. Modern silicone molds are practical to use and come in many different sizes.





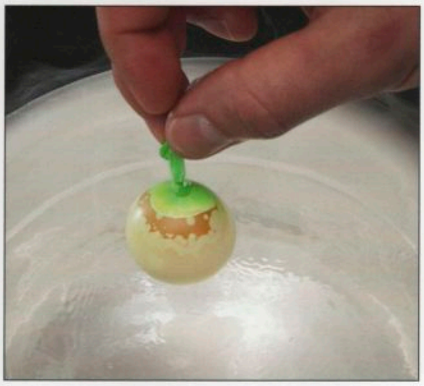


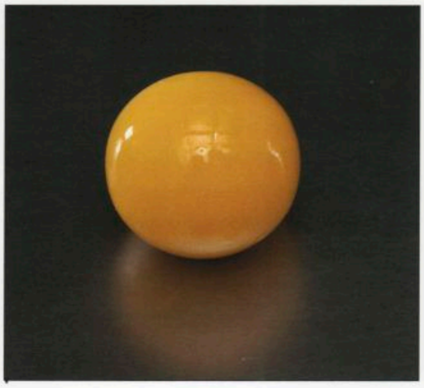
1 **Pour hot gel base into cavities of silicone mold.**

2 **Set gel.** Some gels require refrigeration; others set at room temperature after a few minutes. For more details, see page 42.

3 **Carefully pop out set spheres from mold.**

VARIATION: Freezing Gel Spheres



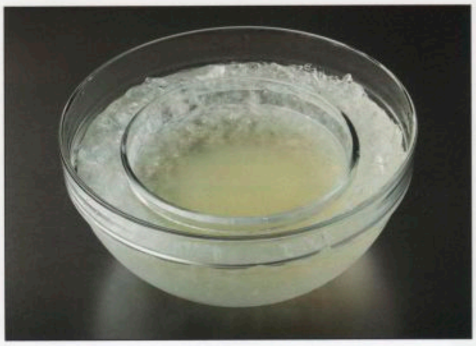


1 **Fill squeeze bottle with gel base, and fill a water balloon with gel base to desired diameter.**

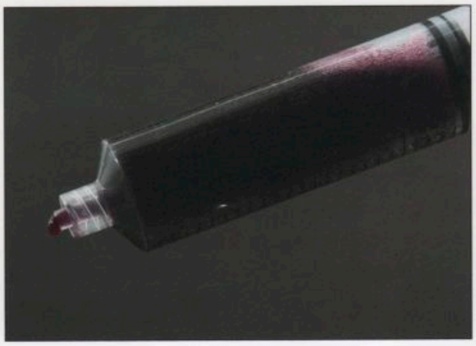
2 **Twist neck of liquid-filled balloon until no air remains, and tie a tight knot.**

3 **Dip balloon in liquid nitrogen until partially frozen, about 1 min.** Roll between your hands to form a perfect sphere, and then freeze sphere completely.

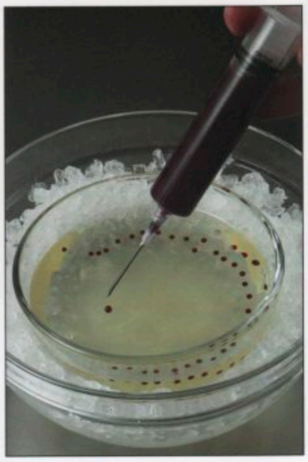
VARIATION: Making Firm Gel Beads in Cold Oil

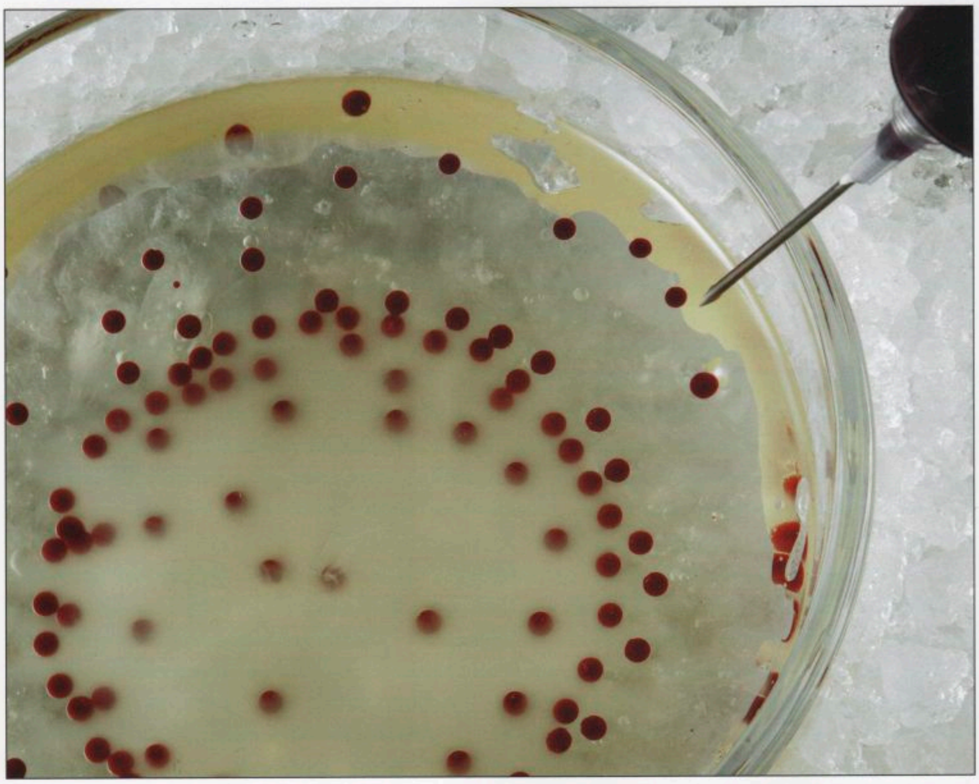


1 **Place oil in a bowl over ice water.** The oil should be very cold but not congealed.



2 **Fill a syringe with hydrated gel base.** Work quickly because the liquid sets when it cools.





3 **Dispense the gel base, one drop at a time, directly into the cold oil.** It will form small, firm beads.

These droplets form into spherical shapes because oil and water do not mix. Unlike beads created by spherification, these consist of solid gel; they do not contain liquid centers.

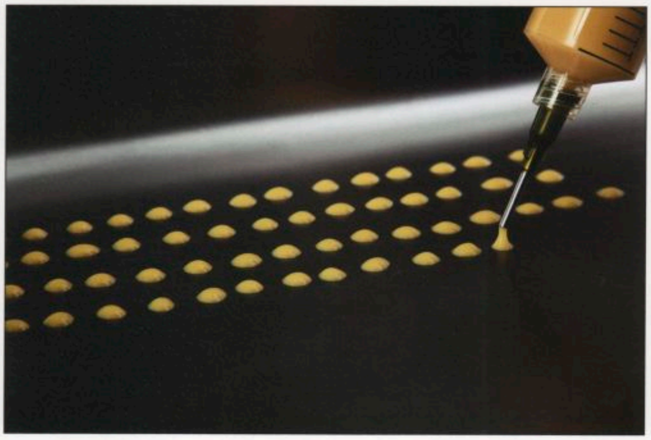
Tip: If you want to remove the oil from the surface of the beads, rinse them with cold, high-proof alcohol, such as vodka.

For a recipe that illustrates this technique, see Chili Pearls, page 145.

4 **Remove the beads with a perforated spoon when they are fully set.**

A different way to make small frozen spheres is to dispense the gel base drop by drop into liquid nitrogen, as shown on page 2·460. That approach only works well for gels that remain stable after they thaw.

VARIATION: Making Firm Gel Droplets

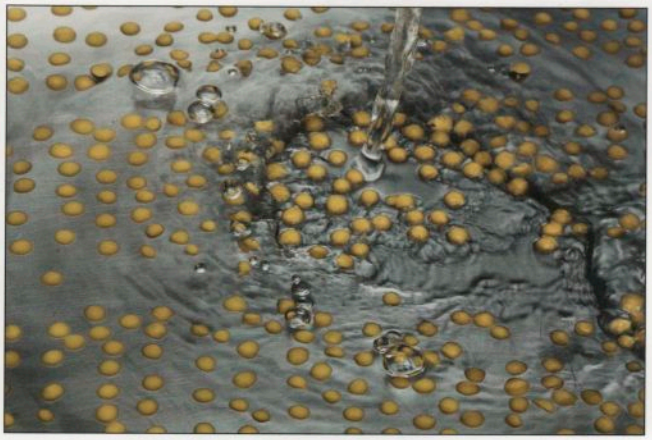


1 **Prepare the setting tray.** Set an empty hotel pan on top of one filled with ice.

2 **Fill a syringe with hydrated gel base.** Work quickly because the gel sets when it cools.

3 **Dispense gel droplets onto the chilled hotel pan.**

4 **Set (not shown).** The droplets set to form half-moon shapes.



5 **Pour water over the gel droplets.**

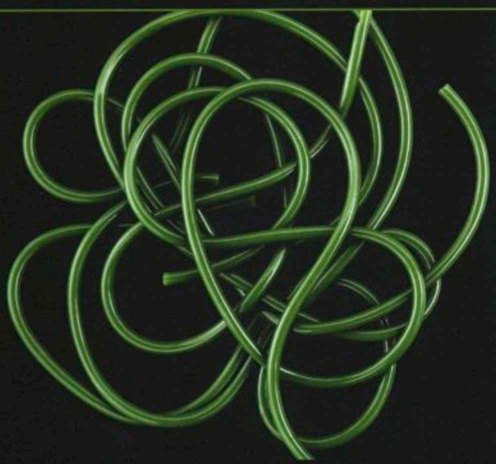
6 **Gently dislodge the droplets with a silicone spatula.**

7 **Drain water from droplets.**

These cold-set gel beads have the flattened shape of lentils or split peas. Unlike spherified droplets, they are solid inside.

HOW TO Extrude Gel Noodles

Those wizards of modern gelling at elBulli created this method of shaping flavorful gels as noodles. Flexible, food-grade tubing is filled with a liquid gel and then left to set. When ready to serve, air is forced into one end of the tube, extruding a long spaghetto (yes, that's the singular form of spaghetti). Only elastic, firm gels work with this technique; very brittle or tender gels are too fragile to extrude. If you happen to have a peristaltic pump, we recommend using it to expedite the process and increase the yield.

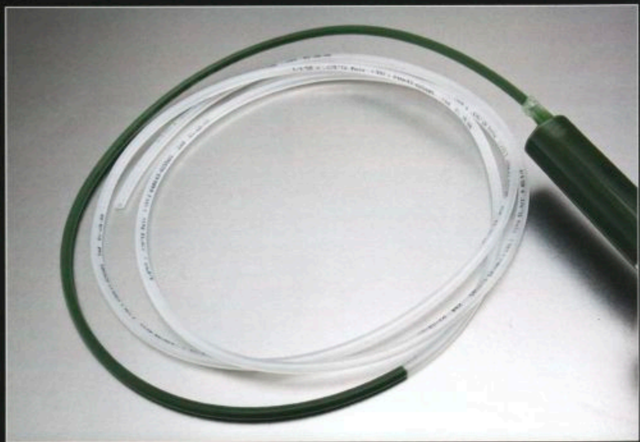


For a recipe that illustrates this technique, see page 143.

1 **Prepare an ice-water setting bath (not shown).**

2 **Disperse and hydrate the gel (not shown).** See the table of hydrocolloid properties on page 42 for hydration times and temperatures.

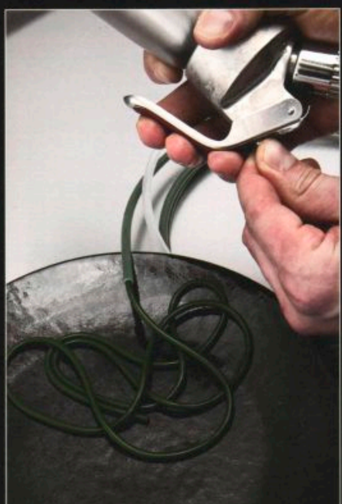
3 **Fill a syringe.** The gel is transferable only when hot, so work quickly.



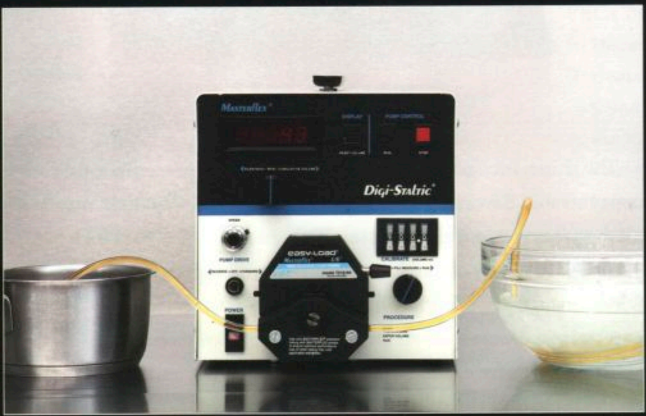
4 **Dispense the gel directly into soft, food-grade plastic tubing of the desired diameter.**

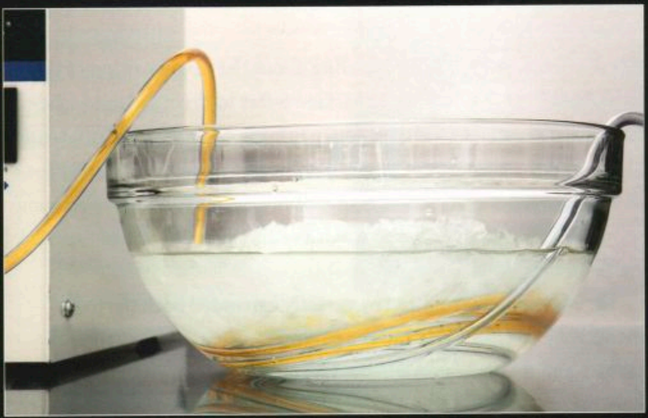
5 **Place the tube into the cold bath to set.**

6 **Blow air or gas through the tube to remove the gel.** A 1 l whipping siphon charged with one cartridge of nitrous oxide works well to produce the necessary gas pressure, as does a clean bicycle pump.

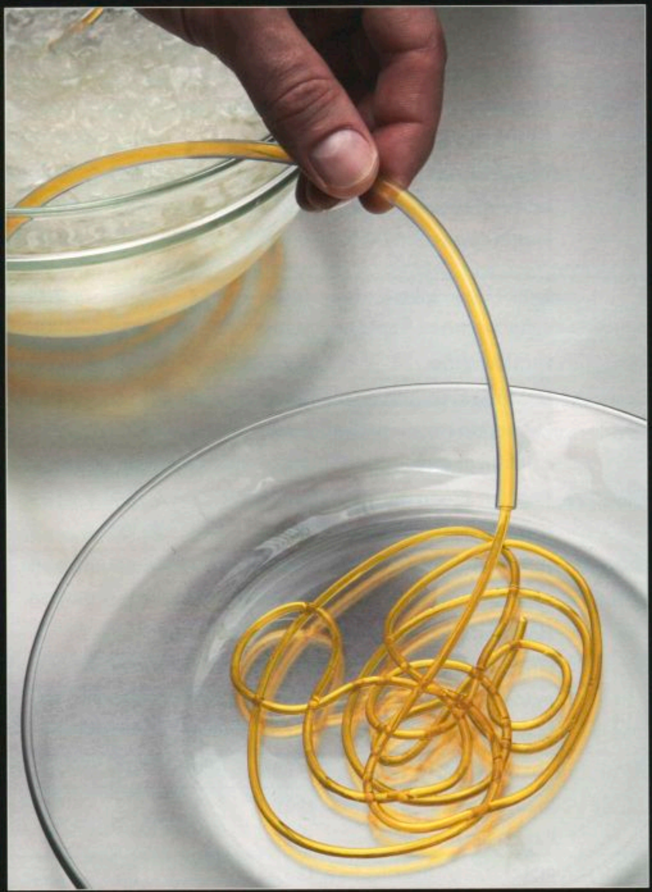


VARIATION: Extruding Gel Noodles with a Peristaltic Pump





1 **Feed tubing.** Run a tube of soft, food-grade plastic, like Tygon, through the peristaltic pump, into one or more loops in an ice-water bath, and finally into the serving container that will receive the set gel. Leave enough tubing free on the intake side of the pump to reach the bottom of the pot of gelling liquid. The length of the looped tubing in the ice-water bath determines how much setting time the gel experiences. Some trial and error may be needed to determine the appropriate length of time required to achieve the desired texture.



2 **Disperse and hydrate the gel (not shown).** Only quick-setting gels work well with this approach.

3 **Insert the intake end of the tubing directly into the hot gel solution.** Work quickly because the gel is transferable only when hot.

4 **Turn on the pump.** The pump will continuously push the gel through the ice water, where it will set, and then into the receiving vessel.

Peristaltic pumps, or cow pumps, work by squeezing flexible tubes—like milking a cow. The pumps are easy to clean because only the tubing contacts the liquid, and the tubing can be washed.

PARAMETRIC RECIPE

COLD GELS

There is something oddly appealing about the juxtaposition of liquid with solid in cold gels. Harold McGee refers to them as "solid sauces." Elaborate banquets in 18th-century Europe often featured towering aspics and jellied terrines. In the days before refrigeration, gel kept the food shiny, moist, and inviting. Many dishes from those days remain elegant buffet classics, such as *pâté en croûte*, *jambon persillé*, and *chaudfroid*.

The Modernist revolution has greatly expanded both the ingredients used to create gels and the parameters that can vary their texture and tenderness. Alginate, LM pectin, gellan, and carrageenan have reduced setting times to almost nothing. They are also vegetarian (whereas gelatin is not).

The shine, intriguing mouthfeel, and creative presentation of concentrated flavors are making clear gels popular again in modern kitchens and restaurants. Heston Blumenthal at The Fat Duck has played with nearly invisible nuggets of flavored gellan in dishes with tastes that surprise. Wylie Dufresne at wd~50 in New York City has entertained diners with strips of gel tied into knots (see page 144).

The options for casting and presenting gels depend in large part on the texture of the substance. Handle very soft gels as little as possible. You can take more liberties with firm, elastic gels.

MAKING A COLD GEL

1. **Select a texture and firmness.** Possibilities range from brittle to rubbery, and from very tender to very firm.
2. **Choose the gelling agents.** The table at right offers at least two options for each texture. Many of the formulas use a mixture of two or more gelling agents.
3. **Measure the gelling agents.** Quantities are given relative to the weight of the liquid, which is set to 100%. For example, use 8.5 g of 160 Bloom gelatin for every 1 kg of wine to make a tender, elastic wine gel.
4. **Dry blend the gelling agents, and disperse them into the cold flavorful liquid.**
5. **Hydrate fully.** Blend while heating to ensure the gelling agents are evenly distributed during hydration. The table lists appropriate hydration times and temperatures.
6. **Cast the gel into a mold.** For detailed instructions, see page 132.

Best Bets for Cold Gels

				Hydrate		
Texture	**Firmness**	**Gelling agents**	(scaling)*	(min)	(°C)	(°F)
elastic	very tender	160 Bloom gelatin	0.75%	5	60	140
		kappa carrageenan	0.1%	3	85	185
		iota carrageenan	0.1%			
		high-acyl gellan	0.20%	3	95	203
		kappa carrageenan	0.05%			
	tender	160 Bloom gelatin	0.85%	25	60	140
		iota carrageenan	0.20%	3	85	185
		kappa carrageenan	0.15%			
	firm	locust bean gum	0.15%	3	95	203
		agar	0.10%			
		xanthan gum	0.20%			
		160 Bloom gelatin	1%	25	60	140
		LM pectin	2%	3	100	212
		calcium gluconate	1%			
		iota carrageenan	0.25%	3	85	185
		kappa carrageenan	0.25%			
	very firm	160 Bloom gelatin	1.5%	25	60	140
		sucrose	65%	1	110	230
		HM pectin	1.75%			
		citric or tartaric acid	1.5%			
brittle	firm	low-acyl gellan	0.25%	3	95	203
		high-acyl gellan	0.15%			
		agar	0.35%	3	95	203
		locust bean gum	0.4%	3	85	185
		kappa carrageenan	0.2%			
	very firm	agar	0.5%	3	95	203
		low-acyl gellan	0.35%	3	95	203

**(% of total weight of all liquids)*

EXAMPLE RECIPE

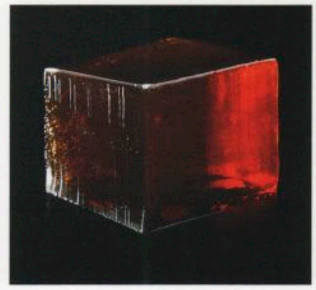
LONG ISLAND ICED TEA GEL SHOT

Yields 435 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	50 g	42%	① Disperse gelatin into cold water.
160 Bloom gelatin	6.75 g	5.6% (*1.6%*)*	② Heat until fully dissolved. ③ Remove mixture from heat, and let cool.
Cola	120 g	100%	④ Combine, and whisk in gelatin mixture.
Lemon juice	60 g	50%	⑤ Pour into serving containers.
Gin	40 g	33%	⑥ Refrigerate until fully set, about 5 h.
Rum	40 g	33%	
Tequila	40 g	33%	
Triple Sec	40 g	33%	
Vodka	40 g	33%	

(2010)

(% of total weight of all liquids*)



This is a fancy version of a Jell-O shot (see page 70).

Cast or mold	Note	Example use	See page
cast directly into serving vessel	keep cold; softens rapidly at room temperature	coating gelées, layered tender jellies	
	highly stable when used with dairy liquids	set yogurt	
	opaque; not suitable for consommé gels	eggless crème brûlée	
pour directly into serving vessel and mold; cutting not recommended	firmness of gel increases for 24 h	cauliflower panna cotta	142
	works well with dairy liquids	eggless custard/flan	
best molded; cut with care	texture very similar to that of gelatin but doesn't melt in the mouth as gelatin does	chili pearls	145
	tenderize by tempering at room temperature	firm panna cotta	
	firm texture develops when made with liquid of 18 °Brix	savory pâte de fruit	
	highly stable when used with dairy liquids	cold terrines	
best suited for cutting and shaping	tenderize by tempering at room temperature	firm aspics, suspended solids	
	firm texture develops when made with liquid of 75 °Brix	pâte de fruit	
	highly stable	firm aspics, suspended solids	
	works well with all liquids but tends to weep over time		
	highly stable when used with dairy liquids	sunny-side up egg	148
	works well with all liquids but tends to weep over time	Parmesan spaghetti	143
		gel noodles	

CAULIFLOWER PANNA COTTA ADAPTED FROM THOMAS KELLER

Yields 850 g (about 16 panna cottas)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the panna cotta:			
Water	500 g	200%	① Simmer over low heat for 1 h.
Cauliflower trimmings, thinly sliced	300 g	120%	② Strain through fine sieve.
			③ Cool stock at room temperature, and reserve 400 g for later use.
Cauliflower stock, from above	350 g	140%	④ Combine in pot.
Cauliflower florets, thinly sliced	250 g	100%	⑤ Simmer for 35 min or until florets are very tender.
Heavy cream	215 g	86%	⑥ Puree until smooth.
Unsalted butter	30 g	12%	⑦ Strain puree through fine sieve.
Salt	to taste		⑧ Season.
			⑨ Measure 400 g of puree, and reserve.
Cauliflower stock, from above	50 g	20%	⑩ Bloom gelatin in cooled stock.
160 Bloom gelatin	3.8 g	1.52% *(0.85%)**	
Cauliflower puree, from above	400 g	160%	⑪ Stir stock into warm puree until gelatin has dissolved, 3–5 min.
			⑫ Spoon into 16 small serving bowls or cups.
			⑬ Refrigerate panna cotta for at least 4 h to set.
For the oyster juice gelée:			
Water	28 g	11.2%	⑭ Bloom gelatin in cold water in small, stainless steel bowl.
160 Bloom gelatin	0.2 g	0.08% *(0.28%)***	⑮ Warm until dissolved.
Oyster juice (from shucked oysters)	42 g	17%	⑯ Combine with gelatin mixture.
Black peppercorns, finely ground	to taste		⑰ Season mixture.
			⑱ Refrigerate gelée for 30 min.
			⑲ Strain.
			⑳ Add about 6 g of oyster juice gelée to top of each panna cotta portion to coat.
			㉑ Refrigerate until completely set, about 4 h.
Sturgeon caviar	as needed		㉒ Garnish.

(original 1999, adapted 2010)

(% of total weight of cauliflower stock and cauliflower puree used in panna cotta*)
**(*% of total weight of water and oyster juice used in oyster juice gelée*)

You can produce the panna cotta more quickly if you replace the gelatin with 0.1% of iota carrageenan and 0.1% of kappa carrageenan. Bring the cauliflower cream mixture to a simmer to hydrate the gums.

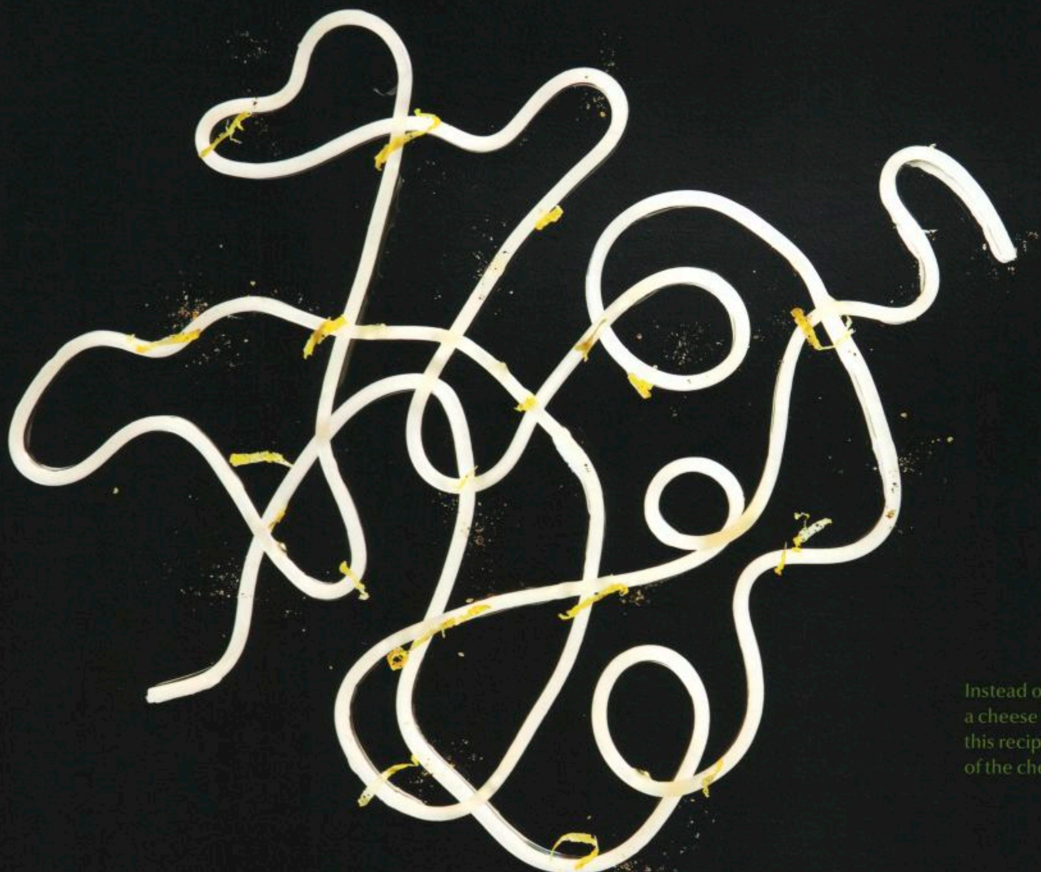
EXAMPLE RECIPE

TWO-METER PARMESAN SPAGHETTO ADAPTED FROM FERRAN ADRIÀ

Yields 300 g (about 15 spaghetto strands)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Parmesan cheese, finely grated	450 g	150%	① Combine, and bring to boil.
Water	450 g	150%	② Remove from heat, and infuse for 1 min at room temperature.
			③ Strain through fine sieve lined with cheesecloth, and cool.
			④ Measure 300 g of Parmesan water.
Parmesan water, from above	300 g	100%	⑤ Dry blend agar and locust bean gum, and disperse into cold Parmesan water.
Agar (Texturas brand)	2.1 g	0.7%	⑥ Bring to boil, and hold for 2 min to fully hydrate. Skim any surface scum that appears.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.45 g	0.15%	⑦ Fill Texturas-style syringe immediately with Parmesan water.
			⑧ Pipe quickly into coiled PVC tubes measuring 2 m / 6½ ft long and 0.5 cm / ¼ in. in diameter; hold opposite end of each tube shut with one hand to prevent Parmesan water from shooting out.
			⑨ Seal tubes.
			⑩ Submerge filled tubes in ice-water bath until set, about 2 min.
			⑪ Shoot air from soda siphon into one end of each tube to extrude noodles.
Black pepper, coarsely ground	to taste		⑫ Season.
Flaky sea salt	to taste		
Lemon zest, finely grated	to taste		
Warm Parmesan oil (or olive oil) see page 35	to taste		

(original 2003, adapted 2010)



Instead of topping pasta with a cheese sauce or grated cheese, this recipe makes a "pasta" out of the cheese itself.

KNOT FOIE ADAPTED FROM WYLIE DUFRESNE

Yields 300 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Foie gras torchon see page 3·176	225 g	100%	① Microwave or otherwise heat to 82 °C / 180 °F. Torchon fat will melt, and terrine will split.
Konjac gum (Ticagel Konjac HV-D, TIC Gums brand)	1.05 g	0.47%	② Dry blend. ③ Blend with warm foie gras.
Agar (Telephone brand)	0.6 g	0.27%	
Xanthan gum	0.45 g	0.2%	
Water	75 g	33.3%	④ Heat water to 80 °C / 176 °F.
Egg yolk	10 g	4.4%	⑤ Blend in egg yolk. ⑥ Blend in foie gras mixture until fully incorporated. ⑦ Pour into nonstick mold in layer 1.5 cm / ⅝ in thick. ⑧ Refrigerate foie gras until set, about 3 h.
Kimchi	250 g	111%	⑨ Puree until smooth.
Xanthan gum	0.4 g	0.18%	⑩ Transfer to squeeze bottle.
White raisins	200 g	88%	⑪ Combine.
Water	125 g	55.6%	⑫ Refrigerate for 3 h to steep.
Xanthan gum (Keltrol T, CP Kelco brand)	0.4 g	0.17%	⑬ Shear with raisins to form puree.
Salt	to taste		⑭ Season raisin puree. ⑮ Transfer to second squeeze bottle.
Cilantro Delfino springs or cilantro stems, cut into 1 cm / ⅜ in batons	30 g	13.3%	⑯ Cut set foie gras into strips 8 mm by 12.5 cm / ¼ in by 5 in. ⑰ Tie strips carefully into knots without breaking them.
Japanese puffed rice	50 g	22.2%	⑱ Divide knotted foie gras among four plates. ⑲ Garnish with cilantro and puffed rice. ⑳ Dot plates with reserved kimchi and raisin purees.

(original 2007, adapted 2010)

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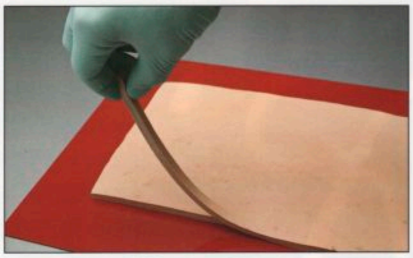

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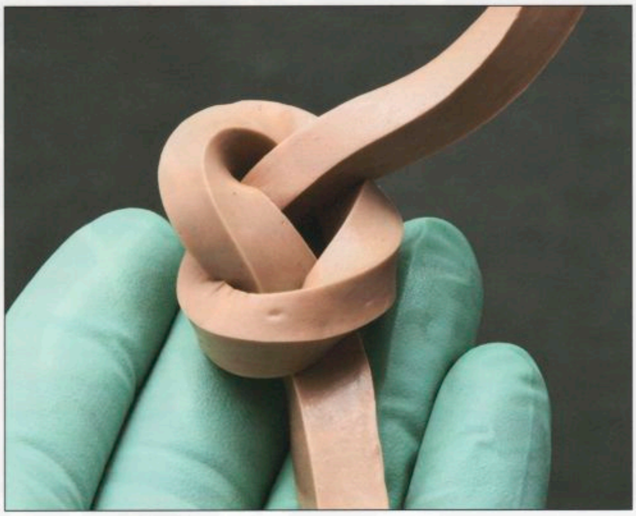


EXAMPLE RECIPE

CHILI PEARLS INSPIRED BY MICHAEL LAISKONIS

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For chili oil:			
Grapeseed oil	250 g	250%	① Combine.
Aleppo pepper flakes	30 g	30%	② Vacuum seal, and cook sous vide in 70 °C / 158 °F bath for 12 h.
Cayenne	10 g	10%	③ Strain through fine sieve, and cool.
Chili flakes	7 g	7%	④ Reserve 250 g of oil in bowl over ice.
For chili pearls:			
Piquillo peppers, roasted and peeled (store-bought)	260 g	260%	⑤ Blend. ⑥ Press through sieve.
Salt	6 g	6%	⑦ Measure 250 g of puree; keep hot.
Fresh red Thai chili peppers	2.5 g	2.5%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.3 g	0.3%	
Red pepper puree, from above	250 g	250%	⑧ Combine to form chili pearl base.
Water	100 g	100%	
Salt	3 g	3%	⑨ Blend.
Agar (Texturas brand)	1 g	1% (*0.18%*)*	⑩ Disperse into chili pearl base. ⑪ Bring base to boil.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.4 g	0.4% (*0.07%*)*	⑫ Simmer for 2 min. ⑬ Transfer hot mixture quickly to syringe or fine-tipped squeeze bottle.
Chili oil, from above	250 g	250%	⑭ Expel chili pearl base one drop at a time while still hot onto surface of cold chili oil. Beads will set almost instantly. ⑮ Serve immediately, or store beads in chili oil, refrigerated.

(original 2008, adapted 2010)

(% of total weight of first six ingredients in chili pearls*)

EXAMPLE RECIPE

GUINNESS "PÂTE DE FRUIT"

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sugar	150 g	150%	① Mix together in pot.
Isomalt	100 g	100%	
HM pectin (Brown Ribbon HV, Obipektin brand)	10 g	10% (*2%*)*	
Guinness beer	300 g	300%	② Combine with sugar and isomalt mixture, and cook to 110 °C / 230 °F.
Glucose syrup DE 40	50 g	50%	③ Use refractometer to check soluble solids concentration, and cook until reduced to 75 °Brix.
Tartaric acid	10 g	10%	④ Cast hot mixture into mold. ⑤ Cool at room temperature for 4 h to set gel. ⑥ Chill in freezer for 5 min to simplify cutting. ⑦ Cut into 2 cm / ¾ in squares.
Pretzels, ground	50 g	50%	⑧ Blend together to fine powder.
Isomalt	20 g	20%	⑨ Dust over cut pâte de fruit.
N-Zorbit M (National Starch brand)	10 g	10%	⑩ Serve, or reserve dusted squares on nonstick sheets at room temperature.

(2010)

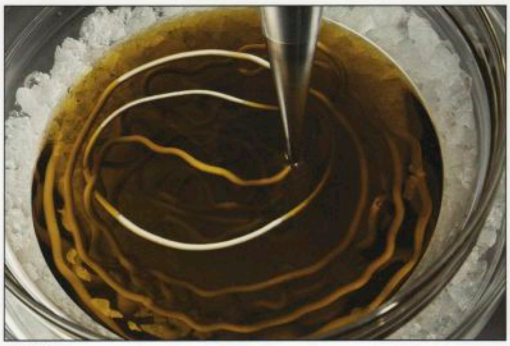
(% of total weight of sugar, isomalt, beer, and glucose*)

OLIVE OIL NOODLES INSPIRED BY JORDI CRUZ

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tapioca starch	100 g	62.5%	① Vacuum seal, and cook sous vide in 80 °C / 176 °F bath for 2 h.
Water	100 g	62.5%	② Measure 80 g of pregelatinized starch paste, and reserve warm.
Olive oil	160 g	100%	③ Heat to 30 °C / 85 °F. ④ Hold warm.
Salt	5 g	3.1%	⑤ Dry blend to make gel powder.
300 Bloom gelatin	4 g	2.5%	
LM pectin (Genupectin LM 104 AS, CP Kelco brand)	2 g	1.25%	
Agar (Texturas brand)	0.7 g	0.56%	
Mineral water	120 g	75%	⑥ Whisk gel powder into water. ⑦ Bring mixture to boil.
Pregelatinized starch paste, from above	80 g	50%	⑧ Blend starch paste into warm gel solution. ⑨ Remove from heat, and blend by hand over ice until completely cool and fluid. ⑩ Slowly blend in warmed olive oil until fully emulsified to form olive oil noodle base.
Olive oil, chilled but still fluid	as needed		⑪ Transfer noodle base to pastry bag. ⑫ Extrude noodles 1 mm / 1⁄32 in thick into chilled olive oil bath. ⑬ Refrigerate, and allow to set for at least for 4 h before serving. ⑭ Garnish with flaky salt and herbs as desired.

(original 2005, adapted 2010)



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These noodles are a fun alternative to the traditional butter or oil that accompanies bread. They can also be used as a garnish in fish and shellfish dishes. Any other oil or fat can be used in place of olive oil.

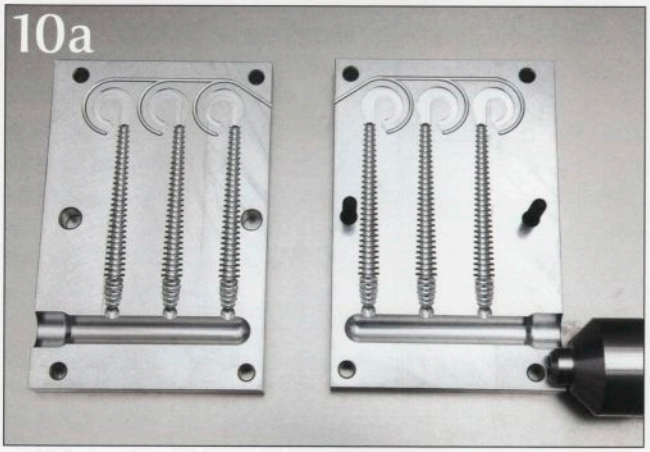
EXAMPLE RECIPE

OLIVE OIL GUMMY WORMS

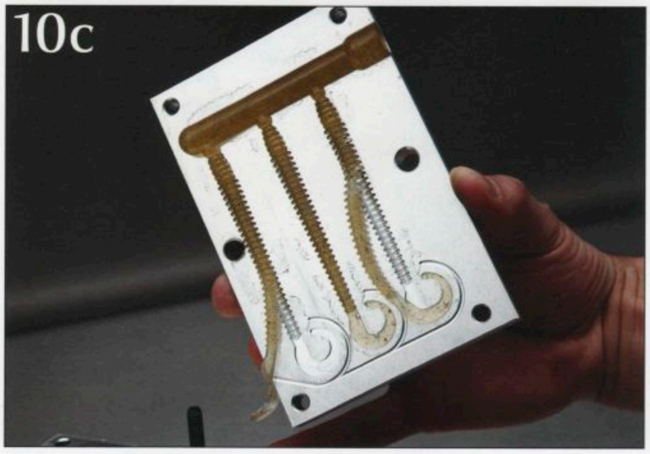
Yields 445 g

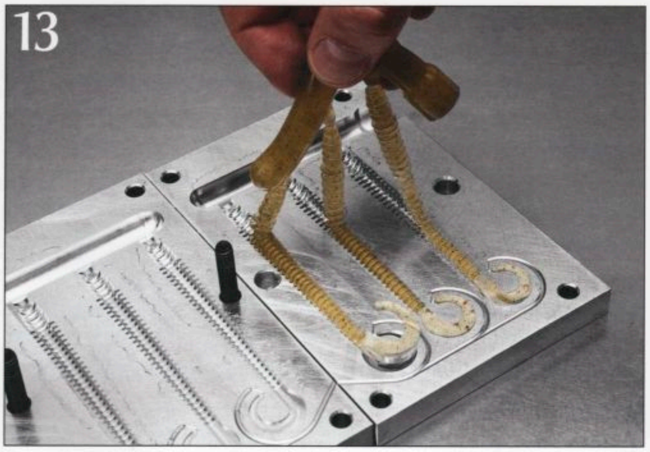
INGREDIENT	QUANTITY	SCALING	PROCEDURE
200 Bloom gelatin	20 g	27%	① Disperse gelatin into cold water.
Water	40 g	53%	② Vacuum seal gelatin mixture.
			③ Hydrate in 60 °C / 140 °F bath for 30 min.
			④ Set aside gelatin mixture.
Water	110 g	147%	⑤ Combine.
Isomalt	100 g	133%	⑥ Bring to boil.
Clear honey	55 g	73%	⑦ Whisk in gelatin mixture.
Glucose syrup DE 40	25 g	33%	
Gum arabic	20 g	27%	
Olive oil	75 g	100%	⑧ Whisk in; emulsify fully to form gummy worm base.
Vanilla seeds and pulp	1 g	1.3%	⑨ Whisk into gummy worm base.
Thyme essential oil	0.1 g	0.13%	⑩ Cast base into worm-shaped molds.
			⑪ Cool.
			⑫ Refrigerate for at least 4 h to set.
			⑬ Remove from molds.

(2010)



Fishermen use metal mold systems to create artificial lures from liquid plastic (we found them for sale online). These molds come in many shapes and sizes, and are perfect for casting gels. Like all molds, they work best if sprayed or wiped with a very light film of cooking oil.





SUNNY-SIDE UP "EGGS" ADAPTED FROM WYLIE DUFRESNE

Yields 800 g (about 25 "eggs")

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the egg whites:			
Coconut milk	500 g	100%	① Combine.
Sugar	20 g	4%	② Steep milk mixture for 20 min in refrigerator.
Cardamom, cracked	9 g	1.8%	③ Strain.
Guar gum (8/22A Powder, TIC Gums brand)	0.8 g	0.16%	④ Blend to fully incorporate into milk mixture. ⑤ Heat to 80 °C / 176 °F.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.8 g	0.16%	⑥ Pour 20 g of mixture directly from pot onto each of 25 plates to create egg white shapes. Work quickly; gel mixture sets rapidly.
Xanthan gum (Keltrol T)	0.8 g	0.16%	⑦ Refrigerate "egg" whites.
For the egg yolks:			
Carrot juice	250 g (from about 500 g of carrots)	50%	⑧ Blend until fully incorporated.
Glucose syrup DE 40	25 g	5%	
Xanthan gum (Keltrol T)	1.5 g	0.3%	
Smoked maple syrup	to taste		⑨ Season juice mixture.
Salt	to taste		⑩ Pour into silicone hemisphere molds 5 cm / 2 in. in diameter. ⑪ Freeze completely, about 2 h, to form yolks.
For assembly:			
Water	250 g	50%	⑫ Blend in pot.
Kappa carrageenan (Genugel CHP2, CP Kelco brand)	1 g	0.2%	⑬ Heat gum mixture to 80 °C / 180 °F. ⑭ Cool to 45 °C / 113 °F, and hold at temperature.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	1 g	0.2%	⑮ Remove frozen yolks from molds with toothpick or skewer. ⑯ Dip yolks into cooled gum mixture.
Potassium chloride	0.12 g	0.024%	⑰ Place one coated yolk in center of each "egg" white. ⑱ Allow yolks to thaw at least 30 min before serving.
Black pepper, coarsely ground	to taste		⑲ Season.
Coarse salt	to taste		
Olive oil	to taste		

(original 2005)

Part of the trick in creating a faux egg is to mimic the irregular shape of a fried egg.

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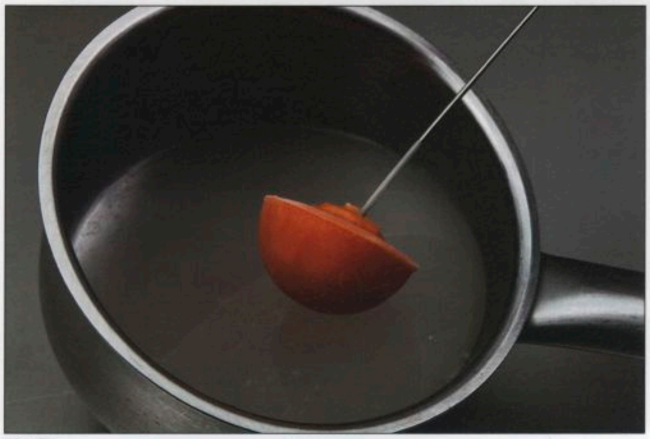

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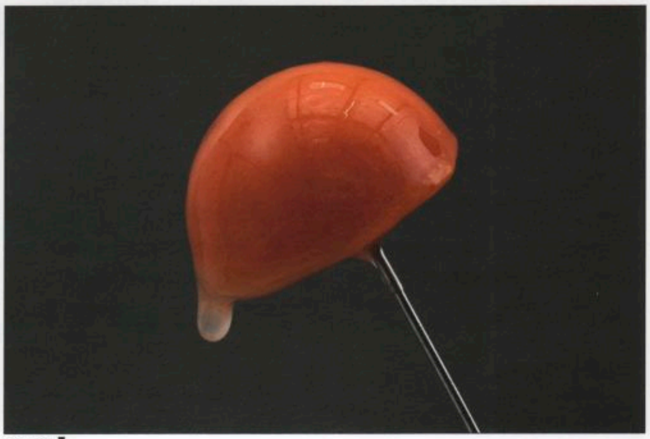

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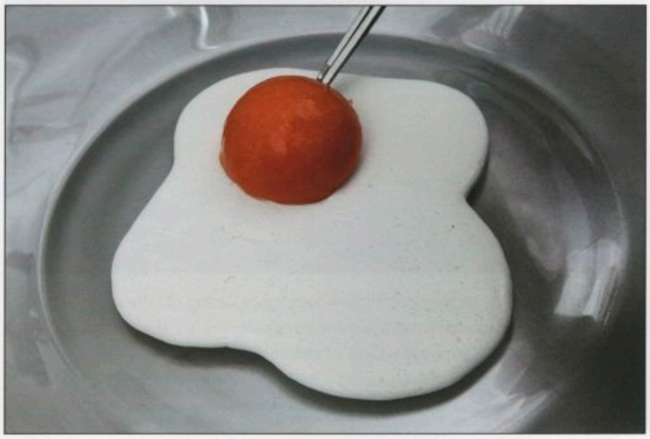

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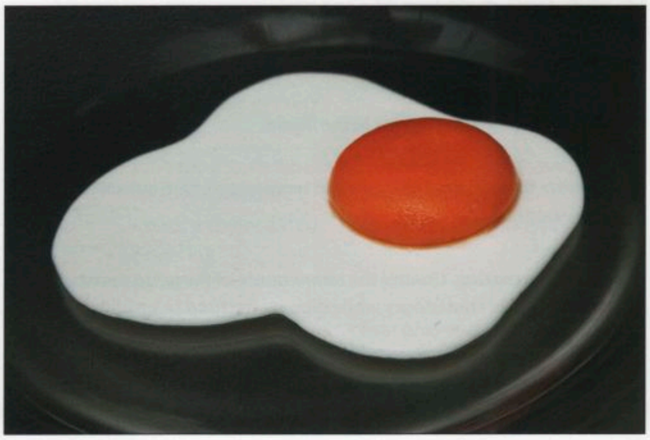

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PARAMETRIC RECIPE

COATING GELS

The classic coating gel is known as a chaudfroid. Translated from French, the term means hot–cold and describes an elaborate presentation of ingredients that mimic all the richness of a hot dish but that are encapsulated in a cold, shiny gelatin.

To make a traditional chaudfroid, a cook would render the gelatin, concentrate and clarify it, and then layer the finished sauces and gel over chilled meats and seafood in thin strata while suspending intricate decorations. The antique art of chaudfroid is still taught in traditional culinary schools and practiced occasionally, but its heyday passed a century ago.

Recently, however, the emergence of modern gelling agents has revived and expanded the art of chaudfroid. A new spin on the technique uses hot gels on hot foods. We call it chaud-chaud. With it, for example, you can suspend halibut in a gel perfumed with makrud lime (aka kaffir lime), and then cook it sous vide to the perfect temperature. Marc Veyrat and other modern chefs have advanced the use of coating gels to form beautiful and aromatic cooking vessels from the gels. Like a crust of salt or clay, a firm coating gel creates an attractive case that the diner can crack open and explore. Gels excel at carrying aromas that expand the sensory experience of eating.

To make a coating gel, use the same technique used when making a cold or hot gel. When the gel is nearly set, spoon it onto the food, or dip the food into the coating. Liquid nitrogen offers an excellent way to quickly and briefly cool the surface of the food, enabling the preparation of especially thin coatings.

MIXING A GEL FOR COATING

1 **Select a temperature and texture.** If the food will be coated hot, fewer options are available, but the table Best Bets for Firm Coating Gels on the next page presents good formulas that yield textures ranging from elastic and tender to brittle and firm.

2 **Choose the gelling agent.** We give several options for hot and cold coating gels in the table of formulas. Some options use a mixture of two or more gelling agents.

3 **Measure and mix the gelling agents.** Set the weight of the liquid to 100%. For example, to make a smooth licorice coating gel for cold food, use 0.7 g of low-acyl gellan and 0.2 g of high-acyl gellan for every 100 g of licorice infusion.

4 **Disperse the gelling agents in the liquid.**

5 **Hydrate fully.** Hydration times and temperatures are indicated in the table.

6 **Apply the coating.** Control the temperature of the gel to maintain a barely liquid consistency while dipping the food or brushing on the coating.

One problem with coating gels is their tendency to slip off the surface rather than coating it. A way to avoid this problem is to prepare the surface by scoring or pricking it (see page 158). Another method to help adherence is to get the surface very cold. Dousing it in liquid nitrogen helps with this.

This sole has been coated in gel and garnished in the style of a classic haute cuisine chaudfroid, like one Escoffier might have served.

Best Bets for Firm Coating Gels

Temperature	Texture	Firmness	Gelling agent	(scaling)*	Hydrate (°C)	(°F)	(min)	Coat	Example use	See page
cold	elastic	tender	160 Bloom gelatin	2.3%	60	140	5	cool over ice until syrupy, about 15 min, before applying to food	traditional chaudfroid, sous vide chicken breast with truffle jus coating, cured salmon loin with watercress juice coating	
			xanthan gum	0.2%						
		firm	160 Bloom gelatin	3%	60	140	5			
	brittle	tender	iota carrageenan	0.45%	75	167	3	keep gel base warm while applying coating; the gel sets quickly	crimini in amber	154
			kappa carrageenan	0.35%						
hot or cold	elastic	tender	sorbitol	3.00%	95	203	3	chill food with liquid nitrogen before coating to get a thin covering	modern chaud-chaud, warm oysters with seaweed vinegar gelée	
			agar	0.60%						
			xanthan gum	0.25%						
			low-acyl gellan	0.35%	95	203	3			
			xanthan gum	0.20%						
		firm	sorbitol	2%	95	203	3	prechill food with liquid nitrogen to coat thinly	foie gras with beet and hibiscus glaze	158
			160 Bloom gelatin	1%						
			agar	1%						
	brittle	firm	low-acyl gellan	0.7%	95	203	3	dip food in bath of gel solution to coat evenly	salmon with licorice	155
			high-acyl gellan	0.2%						

*(*set weight of liquid to 100%*)

FOIE GRAS PARFAIT SPHERES

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Raw duck foie gras	425 g	100%	① Cook sous vide in 57 °C / 135 °F bath to core temperature of 56 °C / 133 °F, about 20 min.
White duck stock see page 2·301	170 g	40%	② Disperse gelatin in small amount of cold stock, and heat until fully dissolved. ③ Whisk gelatin mixture into remaining stock.
160 Bloom gelatin	10 g	2.4%	④ Blend warm foie gras with gelatin mixture and remaining ingredients.
Insta Cure No. 1	6 g	1.4%	⑤ Pipe 12 g of mixture into each of 36 silicone hemisphere molds, each 2.5 cm / 1 in. in diameter.
Salt	6 g	1.4%	
Sugar	3 g	0.7%	⑥ Refrigerate for at least 4 h to set. ⑦ If using kernel "pit," scoop 1 cm / ⅜ in hemisphere from center of molded foie gras.
Hazelnuts or apricot kernels, roasted and peeled (optional)	18 whole		⑧ Melt flat surface of each hemisphere with blowtorch, and press kernel into center divot. ⑨ Join pairs of hemispheres to form spheres. ⑩ Insert 10 cm / 4 in skewer into each foie gras sphere, and freeze. ⑪ Using metal skewer dipped in very hot water, indent top of each sphere to mimic dimple that holds stem, and sculpt side of sphere to mimic natural crevasse of cherry. ⑫ Dip sphere into hot water and then into liquid nitrogen. Refrigerate until cool.

(2009)

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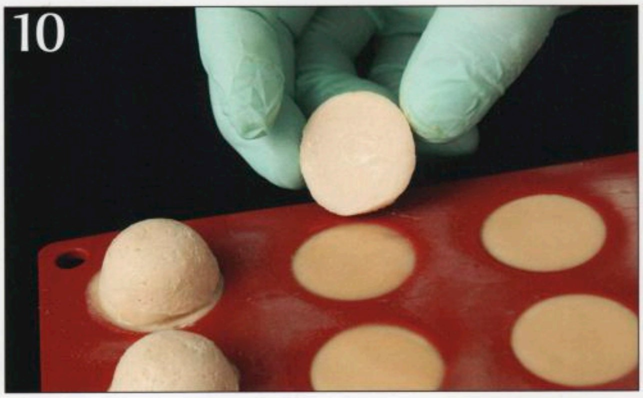

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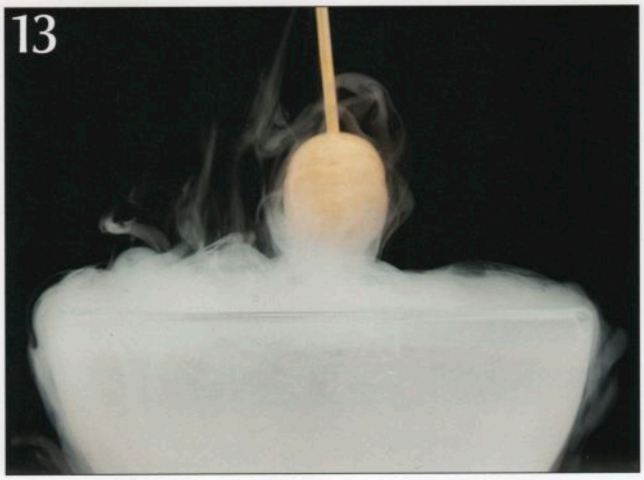


Carving the indentation in the cherry before it is dipped into the gelée coating is a nice touch that adds to the realistic look. The final effect is quite dramatic.

This recipe calls for a high percentage of gelatin, which makes it easier to manipulate the parfait. The gel breaks when it freezes however, so once it thaws, the gel will not set again.

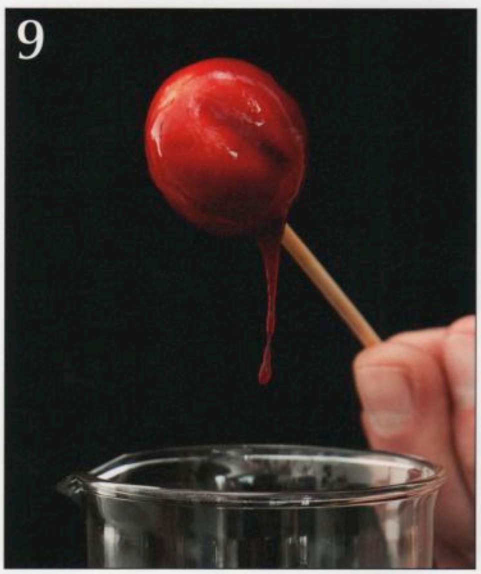
FOIE GRAS CHERRIES

Yields 18 cherries

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sour cherry juice	150 g	100%	① Disperse gellan into juice, and bring to boil.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	1.5 g	1% (*0.26%*)*	② Pour liquid into beaker set in ice-water bath. ③ Blend mixture with immersion blender as it sets to form sour cherry fluid gel.
Cherry pickling brine see page 5·268	85 g	57%	④ Disperse gelatin in small amount of brine. ⑤ Heat mixture until gelatin is fully dissolved.
160 Bloom gelatin	14 g	9.3% (*2.4%*)*	⑥ Blend in remaining ingredients. ⑦ Whisk in sour cherry fluid gel.
Black cherry puree	200 g	133%	⑧ Vacuum seal to remove accumulated air bubbles.
Amarena cherry syrup	150 g	100%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.6 g	0.4% (*0.07%*)*	
Foie gras parfait spheres, see previous page	100 g (four spheres)	67%	⑨ Dip frozen foie gras spheres into cherry liquid, coating evenly. ⑩ Refrigerate until set, about 1 h. To serve, temper at room temperature for 10 min.

(2009)

(% of total weight of all other ingredients except foie gras*)



CRIMINI IN AMBER INSPIRED BY FERRAN ADRIÀ

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Crimini mushrooms, stem on, peeled	50 g	100%	① Clean. ② Cut into at least 20 slices 1 mm / 1⁄32 in thick. ③ Cover with damp paper towel, and refrigerate.
Dried porcini	30 g	60%	④ Rinse. ⑤ Soak for 5 min. ⑥ Strain.
Water	400 g	800%	⑦ Add to rinsed and soaked porcinis. ⑧ Simmer for 10 min.
Salt	7.5 g	15%	⑨ Mix into porcini mixture. ⑩ Simmer for 10 min.
Kombu	5 g	10%	
Koji-Aji (Ajinomoto brand)	2 g	4%	
Bonito flakes	1 g	2%	⑪ Add to porcini mixture. ⑫ Remove from heat. ⑬ Infuse for 1 min. ⑭ Strain; measure 200 g of stock.
Iota carrageenan (Texturas brand)	0.9 g	1.8% *(0.45%)**	⑮ Combine with reserved porcini stock. ⑯ Bring to boil to dissolve completely. ⑰ Remove from heat. ⑱ Skim off any accumulated foam. ⑲ Dip chilled crimini slices in hot gel mixture; coat slices completely. ⑳ Transfer to nonstick baking sheet or lightly oiled plastic wrap; ensure slices remain coated.
Kappa carrageenan (Texturas brand)	0.7 g	1.4% *(0.35%)**	
Aged Parmesan, small dice	20 pieces		㉑ Garnish gel-encased crimini slices.
Breakfast radish, small dice	20 pieces		
Pickled dried fig, small dice see page 5·137	20 pieces		
Pressure-cooked sesame seeds see page 3·303	30 g	60%	㉒ Dab evenly on finished crimini.

(original 2004, adapted 2010)

*(% of total weight of reserved porcini stock)

19

20a

20b

EXAMPLE RECIPE

SALMON POACHED IN LICORICE ADAPTED FROM HESTON BLUMENTHAL

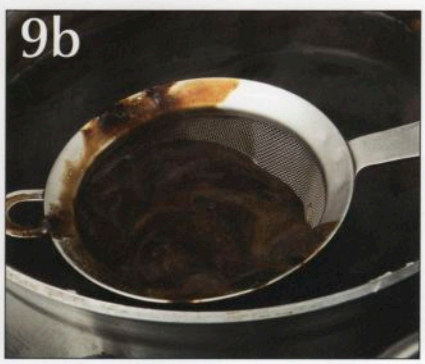
Yields 280 g

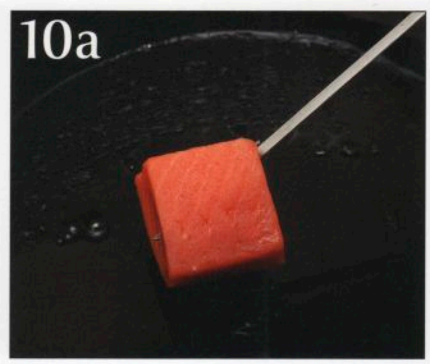
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Distilled water	2.4 kg	150%	① Combine while bringing to simmer.
Hard, glassy black licorice sticks (store-bought), crushed into small pieces	125 g	7.8%	② Cool for 5 min. ③ Process mixture in food processor for 5 min or until licorice is fully dissolved. ④ Strain licorice stock through fine sieve. ⑤ Reserve 1.6 kg of stock, refrigerated.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	11.2 g	0.46% *(0.7%)**	⑥ Dry blend.
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	3.2 g	0.13% *(0.2%)**	
Licorice stock, from above	1.6 kg	100%	⑦ Disperse gellan gum mixture into cold stock. ⑧ Heat mixture to 95 °C / 203 °F until gellans are hydrated, about 2 min. ⑨ Skim any foam from surface using small sieve.
Salmon fillet, skinned and cut evenly into squares	200 g (four squares, 50 g each)	12.5%	⑩ Insert wooden skewer into side of each fish square and, holding skewer, dip squares individually into stock. ⑪ Place coated salmon on plates to cool until set, about 5 min. ⑫ Dip fish into stock again to apply second coat. ⑬ Transfer fish to chilled tray lined with silicone mat. ⑭ Set at room temperature, about 5 min. ⑮ Wrap each coated square tightly in plastic wrap. ⑯ Vacuum seal individually, and cook sous vide in 44 °C / 111 °F bath to core temperature of 43 °C / 109 °F, about 25 min.

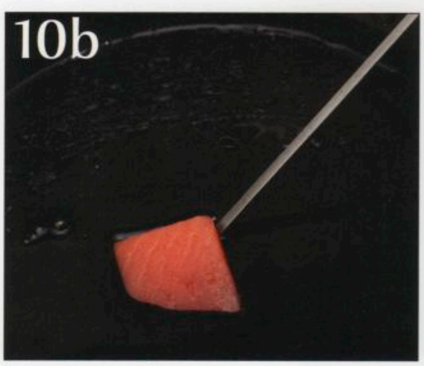
(original 2003, adapted 2010)

(% of total weight of licorice stock*)

At The Fat Duck, this dish is served with vanilla mayonnaise, asparagus, and pink grapefruit.







HALIBUT IN VERBENA BUBBLE INSPIRED BY MARC VEYRAT

Yields 180 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Halibut fillet, skinless	100 g	100%	① Cut into four equal rectangles. ② Set aside.
Coconut cream (store-bought)	100 g	100%	③ Combine.
240 Bloom gelatin	2 g	2%	④ Heat to dissolve gelatin.
Xanthan gum (Keltrol T, CP Kelco brand)	0.5 g	0.5%	⑤ Pour in layer 1 mm / ⅓₂ in thick into rectangular mold on baking sheet lined with plastic wrap. ⑥ Refrigerate for 2 h to set. ⑦ Place halibut rectangle on coconut gel; align width of rectangle with edge of gel sheet. ⑧ Cut long rectangle of gel equal in width to halibut rectangle and long enough to wrap completely around fish. ⑨ Roll halibut tightly in long gel rectangle. ⑩ Cut and roll gel around remaining halibut portions.
For lemon verbena encasement:			
Water	400 g	400%	⑪ Blanch mint leaves for 2 min in boiling water
Lemongrass, thinly sliced	40 g	40%	⑫ Cool quickly in ice water.
Mint leaves	20 g	20%	⑬ Blend blanched mint with remaining ingredients until smooth.
Lemon verbena essential oil	0.2 g	0.2%	⑭ Strain.
Agar (Texturas brand)	10 g	10% *(2.5%)**	⑮ Disperse in mint mixture. ⑯ Heat to 95 °C / 203 °F for 3 min to hydrate.
Sorbitol	2 g	2% *(0.5%)**	⑰ Remove from heat, and pour enough gel mixture to make layer 2 mm / 1/16 in thick in bottom of four deep rectangular molds that are larger than halibut rectangles. ⑱ Let gel set in molds for 2 min. ⑲ Place rolled halibut on top of gel in each mold. ⑳ Pour remaining gel mixture quickly over each rolled halibut to form airtight seal around fish. ㉑ Refrigerate until set, about 10 min.
For fish sauce condiment:			
Fish sauce	30 g	30%	㉒ Blend together until dissolved, and reserve.
Honey	20 g	20%	㉓ Remove encased halibut portions from molds.
Lime juice	20 g	20%	㉔ Vacuum seal portions together.
Rice vinegar	10 g	10%	㉕ Cook sous vide in 48 °C / 118 °F bath or steam oven to core temperature of 47 °C / 117 °F, about 25 min.
Xanthan gum (Keltrol T, CP Kelco brand)	0.15 g	0.15%	㉖ Transfer portions from bag to plates. ㉗ To serve, break verbena gel casing at table to reveal steamed fish and liquefied coconut gel. Remove verbena gel casing, and discard. ㉘ Serve with fish sauce condiment.

(original 2006, adapted 2010)

(% of total weight of water in verbena bubble encasement*)

The verbena gel encasement is intended only as an aromatic cooking vessel for the fish; it should not be consumed. It imbues the fish with the scent of the essential oil and makes for a dramatic presentation.

The coconut cream is solidified with gelatin for assembly but melts into a liquid when served hot.

Marc Veyrat used a hot gel casing as a cooking vessel, in the same way that parchment, salt, clay, and pig bladders have been used in the past. The original version of this dish was a piece of turbot encased in lemongrass with white chocolate. Veyrat's insight presents a huge range of possibilities, both aesthetic and aromatic, for the Modernist chef. Imagine a steamed pigeon encased with suspended rose petals in a clear, rose-scented gel. Or a black gel that is broken open at the table to reveal a suspended whole egg.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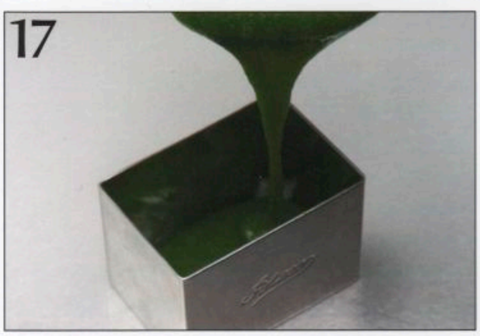
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FOIE GRAS TORCHON WITH BEET AND HIBISCUS GLAZE

Yields 600 g

ADAPTED FROM PAUL LIEBRANDT

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beet juice see page 2·344	800 g (from 1 kg of beets, about five large)	320%	① Reduce over medium heat until syrupy, about 30 min. ② Cool at room temperature. ③ Measure 250 g of reduced juice.
Reduced beet juice, from above	250 g	100%	④ Bring juice to boil, and remove from heat. Add hibiscus and orange peel, and steep at room temperature for 15 min.
Dried hibiscus flowers	20 g	8%	⑤ Strain, and cool completely.
Dried orange peel	5 g	2%	
Sorbitol	12.5 g	5%	⑥ Combine, and disperse in infused juice.
160 Bloom gelatin	5 g	2%	⑦ Boil for 2 min to fully hydrate, and keep warm.
Agar (Texturas brand)	2 g	0.8%	
Salt	to taste		⑧ Season. ⑨ Cool mixture to 65 °C / 149 °F, and hold at temperature.
Foie gras torchon see page 3·176	500 g	200%	⑩ Center foie gras terrine on cooling rack. ⑪ Prick evenly across surface with fine skewer so that gel will adhere more easily.
Liquid nitrogen	as needed		⑫ Ladle over liquid nitrogen to freeze terrine surface. ⑬ Pour warm glaze directly from pot over terrine in one fluid motion to coat evenly; repeat. ⑭ Refrigerate glazed terrine for at least 8 h before serving. Pigment from glaze will permeate terrine.

(original 2008, adapted 2010)

Be sure to work quickly with the hot gel because it begins to set below 45 °C / 113 °F. Warming the ladle will prevent the gel from setting on the surface of the ladle.

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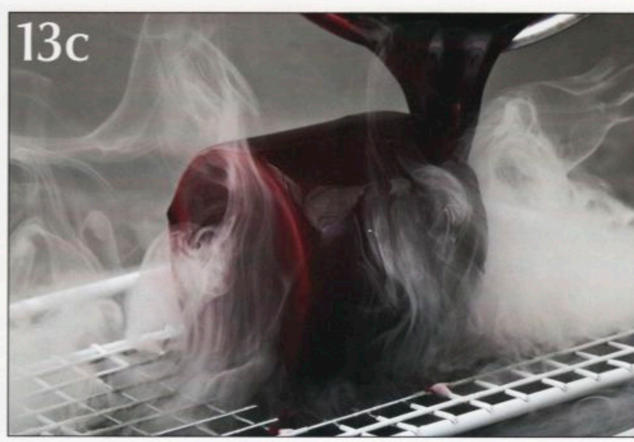

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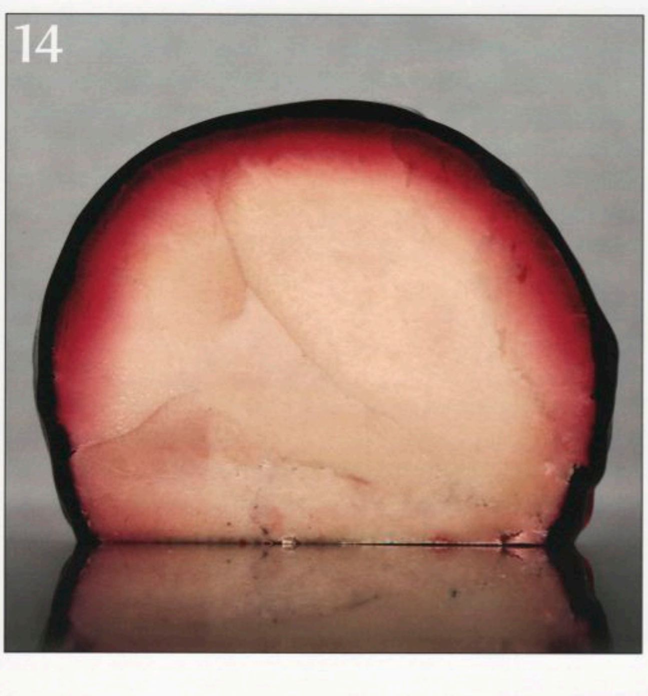
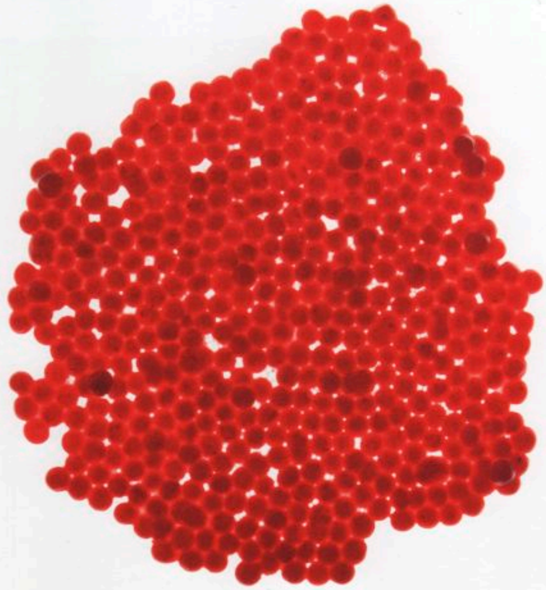


If liquid nitrogen is not available, then chill the torchon in a freezer or blast chiller. Ice water will make the surface wet, which interferes with gel adhesion.

This elegant preparation is a Modernist version of the classic foie gras terrine in aspic. Here, the hibiscus adds both flavor and color, some of which penetrates the foie gras.

PARAMETRIC RECIPE

HOT GELS



In many ways, hot gels embody the Modernist cooking movement. They are whimsical, counterintuitive, dramatic, and a child of both scientific exploration and artistic creativity. Yet these unfamiliar foods are also refined, painstakingly flavored, and historically and gastronomically relevant.

Agar, carrageenans, LM pectins, and gellans all yield excellent hot gels with good flavor release. Combine them with gums and other gelling agents to expand the range of textures and melting points.

Best Bets for Hot Gels

Texture	Gelling agents	(scaling)*	Hydrate (°C)	Hydrate (°F)	Cast or mold	Note	Example	See page
tender, very elastic	xanthan gum low-acyl gellan	0.25% 0.10%	95	203	cast directly into serving vessel	bone marrow-like texture	warm aspic	163
	sorbitol high-acyl gellan agar	5.00% 0.20% 0.10%	95	203	cast directly into serving vessel	opaque, so not suited to clear gels	warm panna cotta, eggless crème brûlée	
	high-acyl gellan xanthan gum low-acyl gellan	0.20% 0.15% 0.10%	95	203	cast directly into serving vessel	creamy mouthfeel	warm panna cotta, eggless crème brûlée	
tender, elastic	xanthan gum locust bean gum low-acyl gellan	0.15% 0.15% 0.10%	95	203	cast into serving vessel or mold			
	high-acyl gellan low-acyl gellan	0.20% 0.10%	95	203	cast into serving vessel or mold		eggless flan, custard	
firm, elastic	locust bean gum agar	0.25% 0.20%	85	185	best molded; cut with care	best with nondairy gels; add 5% sorbitol for tender texture	gel noodles	
	high-acyl gellan low-acyl gellan xanthan gum	0.25% 0.20% 0.10%	85	185	best molded; cut with care	pâte de fruit-like texture	hot eggless flan	
firm, semibrittle	agar guar gum	0.4% 0.2%	85	185	best suited for cutting and shaping		hot terrine	
	high-acyl gellan agar	0.40% 0.25%	95	203	best suited for cutting and shaping			
very firm, brittle	agar	0.5%	85	185	best suited for cutting and shaping	tends to weep over time	gel seasoning cubes	5·267
	low-acyl gellan high-acyl gellan	0.30% 0.15%	95	203	best suited for cutting and shaping		gel seasoning cubes	

*(*set weight of liquid to 100%*)

MAKING A HOT GEL

1 **Select a texture.** Possibilities range from tender to firm and from elastic to brittle.

2 **Choose the gelling agents.** The table Best Bets for Hot Gels on the previous page gives at least two options for each texture. Most formulas use a mixture of two or more gelling agents.

3 **Scale and mix the gelling agents.** All quantities indicated in the table are proportional to the weight of the puree or juice. For example, to make a brittle, firm gel with consommé, use 0.5 g of agar for every 100 g of consommé.

4 **Dry blend the gelling agents, and disperse them in the flavorful liquid.**

5 **Hydrate fully.** Blend while heating to ensure that the gelling agents are evenly distributed during hydration. Usually 2–3 min at **95** °C / **203** °F is sufficient to hydrate the gelling agents.

6 **Cast.** See the table for casting directions and references to example recipes. See page 132 for illustrated, step-by-step instructions.

Most hot gels can also be served cold. Methycellulose gels are the one exception: they set when hot and melt when cold—see page 170.

EXAMPLE RECIPE

AGAR CARBONARA ADAPTED FROM FERRAN ADRIÀ

Yields 1 kg (about 20 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Consommé madrilène see page 2·374	500 g	100%	① Blend, and bring to boil.
			② Cast onto tray measuring 60 cm by 40 cm / 24 in by 16 in to form layer 1 mm / 1⁄32 in thick.
Agar (Texturas brand)	3 g	0.6%	③ Refrigerate for 2 h.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	1.25 g	0.25%	④ Cut into noodles 2 mm / 1⁄16 in wide.
			⑤ Arrange in even layer on silicone mat.
Unsalted butter, cut into small cubes	100 g	20%	⑥ Vacuum seal.
Bacon scraps	50 g	10%	⑦ Cook sous vide in **70** °C / **158** °F bath for 2 h.
			⑧ Strain, and reserve butter.
Heavy cream	250 g	50%	⑨ Reduce cream by half over medium heat.
			⑩ Reserve in squeeze bottle.
Egg yolks, pasteurized see page 78	40 g	8%	⑪ Strain.
			⑫ Reserve in squeeze bottle.
Smoked bacon, cut into 5 mm / ¼ in cubes	80 g	16%	⑬ Heat noodles in **200** °C / **390** °F oven until just warmed through, about 4 min.
			⑭ Warm bacon cubes in reserved bacon-infused butter over medium heat, about 4 min.
			⑮ Divide noodles equally among eight plates.
Parmigiano Reggiano, cut into 5 mm / ¼ in cubes	100 g	20%	⑯ Garnish each serving with bacon and Parmesan cubes, reduced cream, egg yolks, and truffle oil.
Truffle oil	10 g	2%	

(original 1999, adapted 2010)

SHELLFISH CUSTARD HOMAGE TO JOËL ROBUCHON

Yields 1.2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Heavy cream	300 g	100%	① Combine in pot.
Whole milk	140 g	47%	② Simmer for 5 min.
Mushroom jus see page 2·348	90 g	30%	③ Remove from heat.
Salt	5 g	1.7%	
Chervil, leaves	30 g	10%	④ Add to warm milk, and infuse for 20 min at room temperature.
Tarragon, leaves	6 g	2%	⑤ Strain and cool.
Shellfish stock see page 2·296	280 g	93%	⑥ Combine with cold milk mixture.
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	1.6 g	0.53% *(0.2%)**	⑦ Dry blend, and disperse into shellfish stock mixture. ⑧ Heat to 90 °C / 194 °F, and hold at temperature for 3 min.
Xanthan gum (Keltrol T, CP Kelco brand)	1.2 g	0.4% *(0.15%)**	⑨ Remove from heat. ⑩ Cast into desired molds to make custards of about 80 g each.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.57 g	0.2% *(0.07%)**	
Sodium hexametaphosphate	0.4 g	0.14% *(0.05%)**	
Cauliflower fluid gel foam base see page 5·283	300 g	100%	⑪ To serve, transfer cauliflower foam base to 1 l siphon. ⑫ Charge with one cartridge of nitrous oxide. ⑬ Reheat custards, and warm siphon to 80 °C / 176 °F.
Sea urchin	100 g (24 tongues)	33%	⑭ Garnish each custard with three tongues. ⑮ Shake warmed siphon vigorously, and top each custard with cauliflower foam.
Coffee butter, melted see page 371	40 g	13.3%	⑯ Drizzle over custards.

(published 1996, adapted 2010)

(% of total weight of first four liquid ingredients*)

Joël Robuchon is one of the world's most influential chefs. His original version of this dish consisted of a spoonful of oscietra caviar topped with layers of delicate shellfish gelée, cauliflower cream, and chlorophyl puree. It inspired many interpretations, from Ferran Adrià's hot version of the original to Thomas Keller's Cauliflower Panna Cotta (see page 142). We created this dish in homage to Robuchon and to the creative lineage that has followed it.

It can be hard to hydrate gellan in a liquid that contains calcium. Fortunately, the calcium in milk and cream is naturally sequestered. It poses no problem as long as sufficient heat is used during hydration. When using gellan with other liquids that contain calcium, a sequestrant may be necessary (see page 129).

EXAMPLE RECIPE

BOEUF EN GELÉE INSPIRED BY DANIEL BOULUD

Yields 1.5 kg (eight portions)

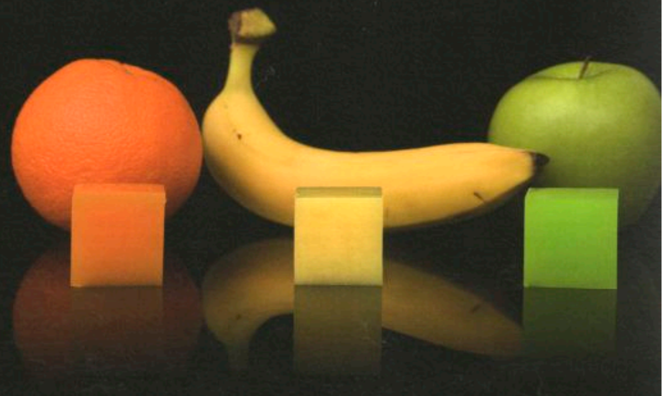
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Carrots, brunoise	50 g	5%	① Sauté together until tender, about 5 min.
Parsnips, brunoise	50 g	5%	② Cool.
Shallots, brunoise	50 g	5%	
Neutral oil	15 g	1.5%	
Oxtail meat, cooked sous vide and shredded see page 5·50	300 g	30%	③ Fold into vegetable mixture.
Tomato confit, finely minced	40 g	4%	
Grain mustard	to taste		④ Season meat and vegetable mixture.
Salt	to taste		⑤ Divide into 50 g servings, and spoon evenly into bottom of eight small bowls.
Xanthan gum (Keltrol T, CP Kelco brand)	2.5 g	0.25%	⑥ Blend.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	1.25 g	0.1%	
Oxtail consommé see page 2·376	1 kg	100%	⑦ Disperse gum mixture into cold consommé. ⑧ Heat to 95 °C / 203 °F, and hold for 3 min. ⑨ Pour hot gel into bowls of meat and vegetables until mixture is submerged 2.5 cm / 1 in below surface of gel. ⑩ Refrigerate bowls.
Horseradish foam see page 284	120 g	12%	⑪ To serve, reheat bowls in 70 °C / 158 °F bath or steam oven until just warmed through, about 10 min.
Fresh wasabi, peeled	20 g	2%	⑫ Garnish evenly with horseradish foam and grated fresh wasabi as desired.

(original 2000, adapted 2010)

Beef in aspic is a classic haute cuisine dish that is normally served cold so that the aspic doesn't melt. Here we serve boeuf en gelée hot by using a gel mix that can be heated.

PARAMETRIC RECIPE

HOT FRUIT AND VEGETABLE GELS



Modern gelling agents allow us to fine-tune the texture of fruit jellies in ways not possible when using traditional gelling ingredients. For example, a blend of high-acyl and low-acyl gellan gums (such as Kelcogel F and Kelcogel LT 100) can be used to produce a soft yet brittle texture, a very firm yet elastic gel—or nearly any combination in between. Dissolved solids from the fruit and added sugars affect the texture; the more dissolved solids, the harder the gel.

Fruit and Vegetable Acidities

Low acidity (pH ≥ 4.6)	(pH)		(pH)	Medium acidity (pH 3–4.6)	(pH)	High acidity (pH ≤ 3)	(pH)
artichoke	6	peas	6	apple	4.0	cherry	3
asparagus	6	persimmon	6	apricot	3.7	cranberry	3
avocado	7	pumpkin	7	blackberry	3.5	gooseberry	3
banana	5	radish	7	black currant	3.3	lemon	2
beans	6	red cabbage	6	blueberry	3.7	lime	3
beets	6	red onion	6	elderberry	3.8		
bell pepper	5	russet potato	6	grape	3.8		
broccoli	7	rutabaga	6	grapefruit	3.7		
Brussels sprout	6	mushroom	7	greengage	3.4		
button mushroom	7	spaghetti squash	6	guava	4.1		
carrot	6	spinach	7	kiwi	3.6		
cauliflower	7	spring onion	6	mango	4.0		
celery	6	sweet onion	6	mulberry	3.5		
cucumber	6	sweet potato	7	nectarine	3.0		
eggplant	6	taro	6	orange	3.9		
fennel	6	tomato	5	passion fruit	3.5		
fig	6	turnip	6	peach	3.7		
jicama	7	watermelon	5	pineapple	3.5		
leek	6	yellow squash	6	plum	3.6		
lettuce	7	zucchini	7	pomegranate	4.0		
lychee	6			quince	3.7		
melon	5			raspberry	3.3		
napa cabbage	6			red currant	3.1		
papaya	6			rhubarb	3.4		
parsnip	6			strawberry	3.8		
pear	5			tangerine	4.1		

The acidity found in fruits and vegetables is the primary issue with making gels with them. Calcium content can also be an issue, which is why, in general, we recommend using sodium hexametaphosphate as a sequestrant if gellan is in the gel mixture. In some cases, however, you may need to add extra calcium to gel (see page 129).

We took pains to measure and calculate the average pH's of these various fruits and vegetables because this information is useful for far more than making hot fruit gels. Whether you are seasoning broths and sauces, creating brines and marinades, or making preserves, pH plays a huge role in the final qualities of these preparations. Note that the pH can vary with ripeness and variety, so you may want to use a pH meter to measure it yourself.

For more on the role of pH in fruit and vegetables see page 3·274.

For more on how to measure pH, see page 2·316.

MAKING A HOT FRUIT GEL

1. **Prepare and puree the fruit or vegetable.** The gels can also be made with juice, but that approach yields a very different gel texture.

2. **Find the acidity of the puree or juice.** Use the table of fruit and vegetable acidities, or measure the pH directly by using a pH meter.

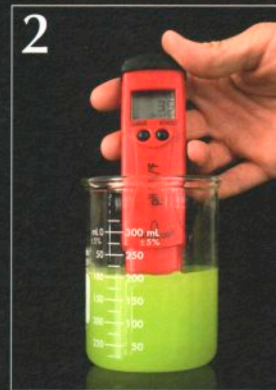
3. **Select a texture.** Possibilities range from brittle to very elastic and soft.

4. **Choose the gelling agent.** We give two options for each texture in the table Best Bets for Hot Fruit Gels below. Some options use more than one agent.

5. **Mix the gelling agents.** Set the weight of the puree or juice to 100%, and measure each gelling agent proportionally. The amount of sodium hexametaphosphate, if any, varies according to the pH of the food. Dissolve it in the juice before adding the gelling agent or agents.

6. **Disperse the gelling agents into the cold juice or puree, and hydrate fully.** A few minutes at 90 °C / 194 °F is usually sufficient to hydrate the gelling agents. Use a high-shear mixer, such as a blender, immersion blender, or rotor-stator homogenizer. You may need to add calcium when using low-acyl gellan. While still hot, shear in calcium lactate or another calcium salt after hydration, stirring well until dissolved. For more details on calcium salts, see page 129.

7. **Cast into a mold, and then cut to size when set.** Allow 5–10 min at room temperature, or 2–4 min in the refrigerator, for the gel to set to moderate firmness. The locust bean/xanthan gum formula will set after being frozen and thawed. A methocellulose/gelatin gel will set when heated to 90 °C / 194 °F.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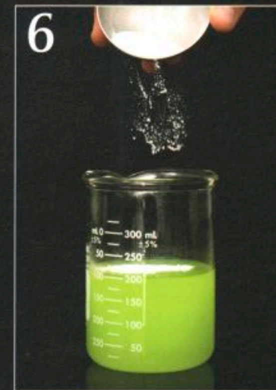
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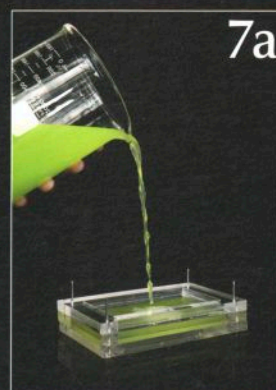
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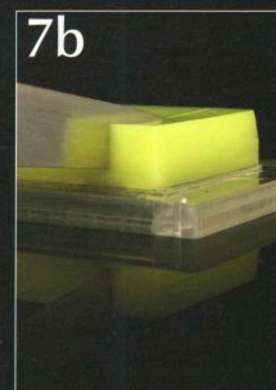
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Best Bets for Hot Fruit Gels

Texture	Gelling agent	Low acidity (scaling)*	Medium acidity (scaling)*	High acidity (scaling)*
brittle	high-acyl gellan	0.30%	0.3%	0.3%
	sodium hexametaphosphate	0.05%	0.1%	0.2%
	agar	0.5%	0.5%	0.5%
semibrittle	high-acyl gellan	0.20%	0.2%	0.2%
	low-acyl gellan	0.10%	0.1%	0.1%
	sodium hexametaphosphate	0.05%	0.1%	0.2%
	agar	0.4%	0.4%	0.4%
	locust bean gum	0.3%	0.3%	0.3%
elastic	high-acyl gellan	0.20%	0.20%	0.20%
	low-acyl gellan	0.10%	0.10%	0.10%
	xanthan gum	0.15%	0.15%	0.15%
	sodium hexametaphosphate	0.05%	0.10%	0.20%
	locust bean gum	0.8%	0.8%	0.8%
	xanthan gum	0.2%	0.2%	0.2%
very elastic	methylcellulose E4M	1.5%	1.5%	1.5%
	160 Bloom gelatin	3.0%	3.0%	3.0%
	agar	0.4%	0.4%	0.4%
	locust bean gum	0.3%	0.3%	0.3%
	sorbitol	5.0%	5.0%	5.0%

*(*set weight of fruit or vegetable to 100%*)

For details on how to disperse and hydrate methylcellulose, see page 170.

Banana is problematic to work with because its polyphenol oxidase enzyme causes the flesh, once peeled, to brown very quickly. In order to neutralize the enzyme, we cook (heat-treat) the whole banana in its skin sous vide at 88 °C / 190 °F for 12 min. This method can be applied to similarly susceptible fruit such as avocados and persimmons, particularly if you don't want to add acid.

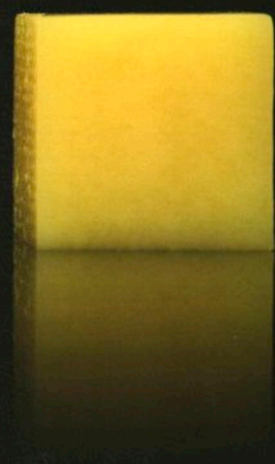
EXAMPLE RECIPE

HOT BANANA GEL

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Banana, unpeeled	100 g	100%	① Cook sous vide in 88 °C / 190 °F bath for 12 min. ② Peel. ③ Sieve.
Water	175 g	175%	④ Blend all ingredients with banana flesh, and bring to simmer to hydrate locust bean gum.
Fructose	25 g	25%	⑤ Cast into mold, and cool.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	2.2 g	2.2%	⑥ Freeze completely, and store until needed.
Xanthan gum (Keltrol T, CP Kelco brand)	0.55 g	0.55%	⑦ Thaw gel to serve.

(2009)



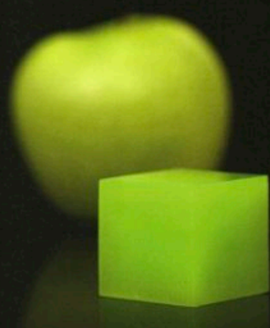
EXAMPLE RECIPE

HOT GREEN APPLE GEL

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Green apple, peeled and thinly sliced	100 g	100%	① Cook sous vide in 90 °C / 194 °F bath for 30 min. ② Puree until smooth, and reserve.
Malic acid	4 g	4%	③ Dissolve acid into fresh juice to preserve juice color.
Green apple juice (or water)	175 g	175%	
Fructose	25 g	25%	④ Dry blend powders.
Calcium gluconate	1.25 g	1.25%	⑤ Disperse into juice mixture.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.55 g	0.55%	⑥ Blend with reserved puree. ⑦ Heat to at least 85 °C / 185 °F to hydrate.
Xanthan gum (Keltrol T)	0.42 g	0.42%	⑧ Cast into mold, and refrigerate until set, about 5 min.
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	0.275 g	0.275%	
Sodium hexametaphosphate	0.2 g	0.2%	

(2009)



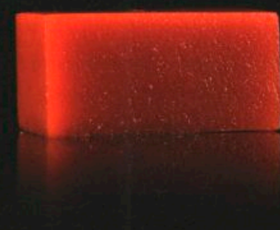
EXAMPLE RECIPE

HOT QUINCE GEL

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fragrant quince, halved, cored, and peeled, peels reserved	100 g	100%	① Pressure-cook with reserved peels at a gauge pressure of 1 bar / 15 psi for 45 min on full pressure.
Water	127 g	127%	② Puree.
Sugar	63 g	63%	③ Cool completely.
Citric acid	1.8 g	1.8%	④ Dry blend powders.
Calcium gluconate	0.82 g	0.82%	⑤ Disperse into cold puree.
Sodium hexametaphosphate	0.2 g	0.2%	⑥ Mix into puree.
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	0.3 g	0.3%	
Low-acyl gellan (Kelcogel F)	0.6 g	0.6%	
Malic acid	as needed		⑦ Add acid as needed to pH 4.5 or to taste.
			⑧ Heat to at least 85 °C / 185 °F.
			⑨ Cast into mold, and allow to set.

(2008)



The distinctive ruby color of cooked quince is created by tannic acid's reaction with heat. Pressure-cooking most fully develops this ruby color. Tannic acid also inhibits the gelling of gellan gums. It can be made soluble by adding glycerol.

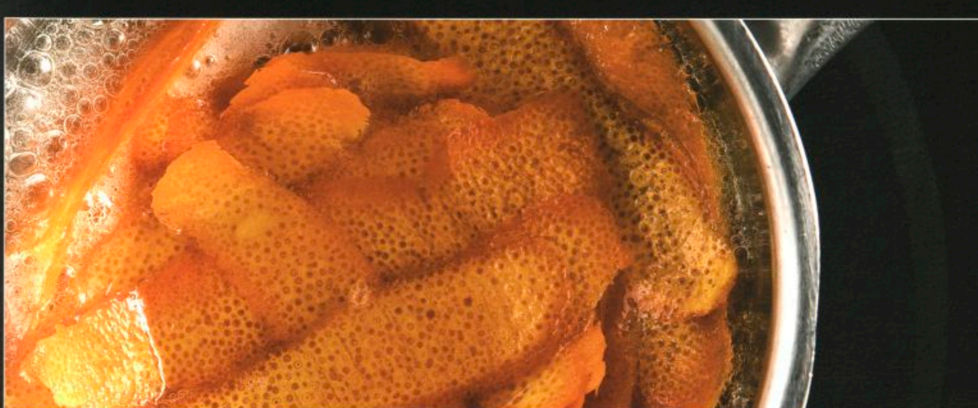
EXAMPLE RECIPE

HOT ORANGE GEL

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	75 g	60%	① Mix to dissolve, and warm to make syrup.
Fructose	75 g	60%	② Vacuum seal with syrup, cook sous vide in 88 °C / 190 °F bath for 4 h.
Orange zest, blanched three times	50 g	40%	③ Puree, pass through fine sieve, measure 175 g of puree, and reserve.
Citric acid	2 g	1.6%	④ Dry blend powders.
Agar (Texturas brand)	1.2 g	0.96%	
Locust bean gum (TIC Gums brand)	0.9 g	0.72%	
Orange juice, sieved	125 g	100%	⑤ Mix 50 g (40%) of orange juice into puree.
			⑥ Disperse powder blend into cold mixture.
			⑦ Boil until fully hydrated, about 2 min.
Sorbitol	15 g	12%	⑧ Combine with remaining 75 g (60%) of juice, and blend into hot puree.
			⑨ Cast immediately into mold, and allow to set.

(2009)



The flavor of fresh citrus is quickly destroyed by heat. To preserve the flavor, we hydrate the agar with a small portion of the juice, and then add the remaining juice right before casting the jelly.

GEL FILMS AND VEILS

For centuries, cooks have used very thin layers of highly concentrated gels to glaze and seal both baked goods and cold dishes. Modernist cooks have started asking "Why stop there?" With the vast array of gelling agents now available, you can readily make both cold and hot gels in endless variety. Classic chaudfroid combinations, such as meat jellies with cream, can be draped on nontraditional foods such as grains or vegetables. Clear sheets might mimic pasta; perhaps an opaque gel of coconut could masquerade as a slice of cheese. You can challenge your artistry and technique by applying customized textures to create lacy veils, delicate tangles, or films of complex fruit and vegetable gels that are as colorful as stained glass. To make gel films, create a hot or cold gel as described earlier in this chapter, and then cast the gel solution into a thin film on an acetate sheet, a silicone mat, or a petri dish.

EXAMPLE RECIPE

QUINOA AND IDIAZÁBAL WITH BONITO STOCK VEIL

ADAPTED FROM ANDONI LUIS ADURIZ

Yields 800 g (eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White vegetable stock see page 2·296	700 g	233%	① Blend together. ② Heat to 70 °C / 158 °F.
Idiazábal cheese, finely grated	300 g	100%	③ Rest for 10 min. ④ Strain; reserve 700 g of cheese-infused stock.
Quinoa	200 g	67%	⑤ Combine with reserved stock. ⑥ Simmer until quinoa is just cooked through, about 30 min. ⑦ Cool completely.
Salt	to taste		⑧ Season quinoa, and reserve 470 g, refrigerated.
White vegetable stock see page 2·296	375 g	125%	⑨ Heat to 70 °C / 158 °F.
Bonito flakes	60 g	20%	⑩ Stir into vegetable stock. ⑪ Remove from heat, and cover pot tightly with plastic wrap. ⑫ Rest for 30 min. ⑬ Strain. ⑭ Cool completely, and reserve 300 g of bonito stock.
Bonito stock, from above	300 g	100%	⑮ Disperse into reserved bonito stock while cold.
160 Bloom gelatin	3 g	1%	⑯ Bring stock to boil, and simmer for 2 min.
Agar (Texturas brand)	1.2 g	0.4%	⑰ Cast onto tray lined with plastic wrap to form layer 1 mm / 1⁄32 in thick. ⑱ Refrigerate until fully set, about 4 h. ⑲ Cut circles 7.5 cm / 3 in. in diameter from bonito gel. ⑳ Spoon quinoa into mounds on center of eight plates slightly smaller in diameter than gel circles. ㉑ Cover each quinoa mound with gel circle. ㉒ Heat plates in 80 °C / 175 °F oven for about 8 min.
Rosemary blossoms	32 blossoms		㉓ Garnish at table.
Creamed honey	to taste		

(original 2002, adapted 2010)

EXAMPLE RECIPE

DUNGENESS CRAB AND APPLE ROULADE INSPIRED BY SCOTT CARSBERG

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Apple juice	200 g	100%	① Season juice.
Malic acid	to taste		
Fructose	to taste		
Agar (Texturas brand)	0.8 g	0.4%	② Disperse into juice.
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	0.6 g	0.3%	③ Bring juice to boil, and simmer for 2 min. ④ Cast onto nonstick baking sheet to form layer 1 mm / 1⁄32 in thick. ⑤ Refrigerate until set, about 5 min. ⑥ Cut into circles 7 cm / 3 in. in diameter.
Dungeness crab meat or other fresh crab meat	300 g	150%	⑦ Fold together to make crab salad.
Basic mayonnaise see page 226 (or store-bought)	50 g	25%	
Scallions, fine julienne	30 g	15%	
Sweet almond oil	24 g	12%	
Lemon balm, fine julienne	3 g	1.5%	
Vanilla seeds and pulp	1.5 g (from half a bean)	0.75%	
Lime juice	to taste		⑧ Season crab salad.
Salt	to taste		⑨ Place apple gel circle flat across large flat plate or cutting board.
Seasonal herbs	to taste		⑩ Spoon salad thinly and evenly across surface of each circle. ⑪ Roll each circle to form tight roulade. ⑫ Garnish with seasonal herbs.

(original 2005, adapted 2010)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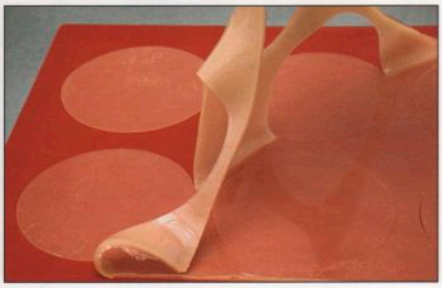
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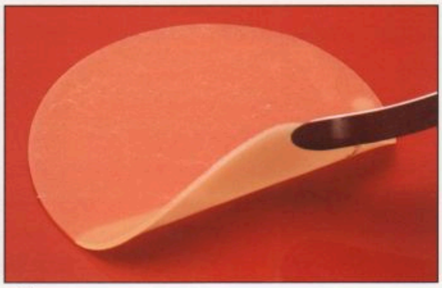
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Scott Carsberg's original and elegant presentation featured paper-thin slices of apple, cut with a mandoline, as the wrapping for a crab mixture. We have substituted a thin apple gel. Both approaches work well.

PARAMETRIC RECIPE

CELLULOSE GUM GELS

Cellulose gums, such as methylcellulose, deserve special attention because they are the contrarians among gelling agents: they set when heated and melt when chilled. That odd behavior makes these modern gums uniquely useful in many situations. For example, cellulose gums play key roles in commercial baking as stabilizers that hold food together in the high heat of the oven.

Pie and cobbler fillings will not boil over when gelled with methylcellulose. Onion rings are made from chopped or ground onions mixed with methylcellulose before being formed so that they maintain their shape in the fryer and don't rupture the coating.

Cellulose gums also make excellent foaming agents (see page 244), or they can be used to create warm jellied terrines and instant noodles like those made famous by Wylie Dufresne at wd~50 in New York City.

Cellulose gums are sold as flavorless, white powders, each formulated for specific uses. The gums are divided into three categories: methylcellulose (MC), hydroxypropyl methylcellulose (HPMC), and super methylcellulose (SMC). Each product has a different chemical structure and thus different viscosities, gelling strengths, gelling temperatures, and melting temperatures.

Properties and Applications of Cellulose Gums

Gel firmness	Category	Gelling agent	Viscosity (mPa · s)	Quantity (scaling)*	Hydrate (°C)	Hydrate (°F)	Gels (°C)	Gels (°F)	Melts (°C)	Melts (°F)	Example uses
soft	HPMC	K99	80–120	0.4%–4%	<30	<86	70–90	158–194	<50	<122	formation of films, fried products, tender gels
		K4M	2,700–5,040								
		K100	75,000–140,000								
semifirm	HPMC	E15	12–18	1.0%–3%	<25	<77	58–64	136–147	<50	<122	custards, noodles
		E50	40–60								
		E4M	2,700–5,040								
	HPMC	F50	40–60	0.2%–2.5%	<25	<77	62–68	144–154	<35	<95	foams, whipped toppings, puddings
		F450	360–540								
		F4M	2,700–5,040								
firm	MC	A15	12–18	0.1%–2%	<13	<55	50–55	122–131	<25	<77	baked goods, set foams, formation of films
		A4M	2,700–5,600								
		A40M	7,500–14,000								
very firm	Super MC	SGA 150	150–450	1.0%–3.5%	<10	<50	38–44	100–111	<15	<59	liquid coatings, firm-set gels
		SGA A7C	700–980								
		SGA A50M	50,000–120,000								

*(*set weight of liquid to 100%*)

The gelling agents listed in the tables above refer to Dow brand products. For the names of comparable products made by other manufacturers, see the Hydrocolloid Product Guide on page II near the end of this volume.

MAKING A METHYLCELLULOSE GEL

1 **Select a texture.** Several options are listed in the table Best Bets for Methylcellulose Gels below.

2 **Make a methylcellulose stock solution.** Measure the methylcellulose, and whisk it into hot water equal to about one-third of the weight of the fluid you want to gel. Avoid using cold water because it causes the powder to hydrate too quickly and clump. Quantities in the table are given as a percentage of the water used. For example, mix in 1.2 g of SGA 150 for every 100 g of water to produce a stock solution for firm, custard-like gels.

3 **Hydrate fully in the refrigerator for 6–12 h.** The mixture will become a clear liquid.

4 **Add to the product to be set.** The table suggests a number of uses. In general, add one part methylcellulose stock solution to every two parts flavored fluid. For example, to make 300 g of apple jelly, add 100 g of methylcellulose stock to 200 g of concentrated apple juice.

5 **Cast the product into a container, and heat it to set.** Heat it at least to the gelling temperature given in the table, and hold it above the melting temperature until ready to serve.

Best Bets for Methylcellulose Gels

Texture	Firmness	Gelling agent	Quantity (scaling)*	Gels (°C)	Gels (°F)	Melts (°C)	Melts (°F)	Example use	See page
very elastic	tender	K100M	1.5%	90	194	50	122	tender pudding, instant crème brûlée	
elastic	tender	A15C	1.5%	55	131	25	77	gel sheets, instant noodles	172
elastic	firm	E4M	1.5%	64	147	50	122	gel pancakes	
		F450	2.5%	68	154	35	95	dumplings, gnocchi	
semibrittle	firm	SGA 150	1.2%	44	111	15	59	firm custard, scrambled corn	
brittle	firm	SGA 7C	1.0%	44	111	15	59	hot sliceable terrine	

*(*set weight of liquid to 100%*)

Photo courtesy of José Luis López de Zubiría—Mugaritz

Andoni Luis Aduriz serves his Green Pea Pods at Mugaritz with a Citrus Infusion and Walnut Oil.

INSTANT TOFU NOODLES ADAPTED FROM WYLIE DUFRESNE

Yields 1.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	150 g	44%	① Disperse.
Methocel A 15C (Dow brand)	7.5 g	2.2% (*1.5%*)*	② Bring to boil.
Tofu, firm	340 g	100%	③ Blend into boiling water to form puree.
Salt	to taste		④ Season tofu puree.
Toasted sesame oil	to taste		⑤ Cool to 50 °C / 122 °F.
			⑥ Refrigerate until hydrated, at least 6 h.
			⑦ Transfer to squeeze bottle with tip 5 mm / 3⁄16 in. in diameter.
			⑧ Set aside.
Hon dashi see page 2·306	900 g	265%	⑨ Blend dashi with miso.
			⑩ Centrifuge at 27,500*g* for 1 h to make consommé.
Aka miso	25 g	7.4%	
Shiro miso	20 g	6%	
Salt	to taste		⑪ Season miso consommé.
			⑫ Bring to boil, and ladle into bowls.
Golden enoki mushrooms, tops only	50 g	15%	⑬ Garnish soup.
			⑭ Extrude tofu puree into hot soup to form instant noodles.
Fresh sea lettuce, thick julienne	17 g	5%	
Scallions, green parts only, thinly sliced	7 g	2%	

(original 2003, adapted 2010)

(% of total weight of tofu and water*)

12

14

Part of the fun in Wylie Dufresne's original presentation is that the guests squirts the noodle mix into the hot broth at the table, thus making their own instant noodles.

For more on alternative clarification methods to clarify the miso broth, see page 2·351.

EXAMPLE RECIPE

SWEET PEA CLUSTERS INSPIRED BY FERRAN ADRIÀ AND ANDONI LUIS ADURIZ

Yields 375 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pea juice (or vegetable stock) see page 2·367 (or page 2·296)	200 g	100%	① Bring juice to boil.
			② Disperse methylcellulose into boiling juice.
Methocel E4M (Dow brand)	4 g	2%	③ Simmer for 3 min.
			④ Refrigerate until hydrated, at least 6 h.
			⑤ Measure 20 g of E4M solution to coat peas.
Sweet peas, shelled	130 g	65%	⑥ Blend xanthan gum into methocel solution.
E4M solution, from above	20 g	10%	⑦ Mix peas with reserved solution; stir to coat peas evenly.
Xanthan gum	0.03 g	0.015%	⑧ Form 16 clusters of 9 g each.
			⑨ Arrange clusters, well separated, on baking sheet lined with plastic wrap, and refrigerate.
Water	1 kg	500%	⑩ To serve, transfer clusters carefully to salted 90 °C / 194 °F bath.
Salt	20 g	10%	⑪ Remove from bath when gel on clusters has fully set, about 1 min.
Ham broth see page 2·304	200 g	100%	⑫ Bring broth to simmer, and check seasoning.
			⑬ Divide broth equally among four bowls.
			⑭ Place two pea clusters in each bowl.
Walnut oil	20 g	10%	⑮ Season broth.
Mint leaves	8 g	4%	

(original 2003, adapted 2010)

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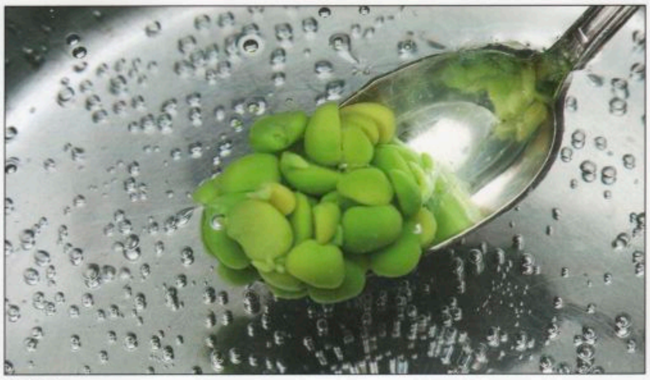

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POTATO BEIGNETS WITH CAVIAR

Yields 700 g (about 25 beignets)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Baked potato stock see pages 2·309 and 3·302	100 g	80%	① Bring water to a boil. ② Shear Methocel into boiling stock.
Methocel E4M (Dow brand)	5.5 g	4.4% *(0.77%)**	③ Simmer for 3 min. ④ Place pot in ice-water bath, and stir until cold and thickened. ⑤ Vacuum seal, and refrigerate Methocel mixture for at least 8 h to hydrate.
Baked potato stock see pages 2·309 and 3·302	125 g	100%	⑥ Blend together until smooth.
Cultured buttermilk (stabilizer-free)	125 g	100%	
Eggs	50 g	40%	
Crème fraîche	90 g	72%	
Methocel mixture, from above	45 g	36%	
All-purpose flour	120 g	96%	⑦ Dry-blend, and sift together.
Instant potato flakes (store-bought)	30 g	24%	⑧ Pour wet mixture in, and stir until completely incorporated. Do not overwork the batter.
Salt	5 g	4%	
Baking powder	5 g	4%	
Baking soda	2.5 g	2%	
Clarified butter	20 g	16%	⑨ Drizzle into batter while stirring; mix to distribute evenly.
Neutral oil	as needed		⑩ Roll 30 ml / 2 T portions gently in gloved hands until round and smooth. Do not completely deflate mixture. ⑪ Drop balls into 190 °C / 375 °F oil until golden brown and slightly puffed, about 3 min. ⑫ Drain on paper towels.
Caviar (best quality available)	as desired		⑬ Serve with warm beignets.
Crème fraîche	as desired		

(2010)

(% of total weight of all other batter ingredients*)

EXAMPLE RECIPE

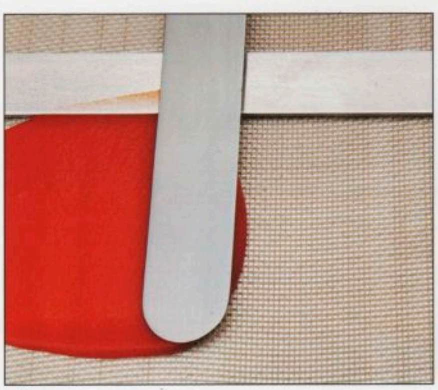
MACKEREL WITH SPICY TOMATO SKIN INSPIRED BY HESTON BLUMENTHAL

Yields 800 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	225 g	100%	① Puree until smooth.
Tomato confit see page 5·62	150 g	67%	② Pass through fine sieve.
Red bell pepper, roasted and peeled	75 g	33%	
Cayenne pepper	2 g	0.9%	
Salt	to taste		③ Season puree.
160 Bloom gelatin	4.5 g	2% *(1%)**	④ Disperse into puree. ⑤ Heat to 90 °C / 194 °F.
Methocel F50 (Dow brand)	5.7 g	2.5% *(1.27%)**	⑥ Blend into hot puree until fully dispersed, and continue blending for 1 min. ⑦ Vacuum seal, and refrigerate until fully hydrated, at least 6 h. ⑧ Spread puree on tray lined with plastic wrap to form layer 1 mm / 1/32 in thick. ⑨ Dehydrate in oven at 110 °C / 230 °F for 15 min. ⑩ Cool resulting tomato skin to room temperature.
Mackerel fillets, cleaned, pin bones and skin removed	320 g (four fillets)	142%	⑪ Cut tomato skin to match dimensions of each fillet. ⑫ Press cut tomato skins onto fillets.
Olive oil	40 g	18%	⑬ Vacuum seal fillets individually. ⑭ Refrigerate until set, at least 30 min. ⑮ Remove fillets and skins from bags, and vacuum seal again individually with 10 g of olive oil in each bag. ⑯ Cook fillets sous vide in 46 °C / 115 °F bath to core temperature of 45 °C / 113 °F, about 15 min. ⑰ Remove fillets from bags.
Bouillabaisse broth see page 2·308	300 g	133%	⑱ Warm, and adjust seasoning.
Blood orange segments	40 g	18%	⑲ Toss together to make salad.
Fennel, thinly shaved	40 g	18%	⑳ Season salad.
Radish, thinly shaved	20 g	9%	㉑ Place each fillet covered in tomato skin in individual serving dish.
Thai basil leaves	5 g	2%	㉒ Garnish with salad.
Olive oil	to taste		㉓ Pour bouillabaisse broth around fillets at table.
Salt	to taste		

(published 2007, adapted 2010)

(% of total weight of first three ingredients*)



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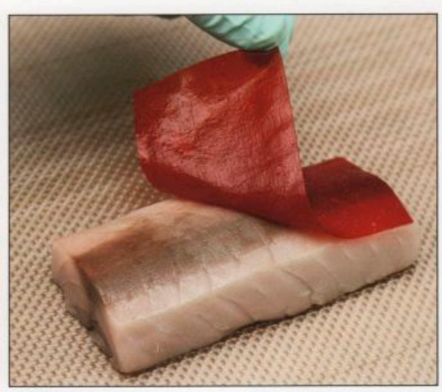

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The remarkable thing about this methocel skin is that it can be placed on the raw fish fillet and vacuum-sealed with oil without compromising its texture. The skin's texture will be quite leathery when it comes out of the dehydrator but will become tender and delicate once cooked with the fish.

FLUID GELS

In 2000, Ferran Adrià started serving at elBulli a liquid that was both hot and cold. His pea soup contained horizontal layers, some at 4 °C / 39 °F and others at 60 °C / 140 °F. Adrià devised careful techniques and used xanthan gum as a thickener to make the soup. Five years later, Heston Blumenthal started serving a hot-and-cold tea at The Fat Duck. The tea was made from fluid gels, with the hot side separated vertically from the cold side.

For a recipe for Hot and Cold Tea, see page 182.

Gels form from a network of molecules, and usually that strong mesh creates a stable, solid structure. Some gels, however, act like a solid only when at rest, undisturbed. When these gels are subjected to shear forces, however, they flow as if they were liquid. Gels with this property are called **fluid gels**. As **shear-thinning fluids**, they can act sometimes as solids and sometimes as liquids—or, in weaker form, as liquids whose viscosity varies with the amount of force applied.

A common example is ketchup, which can sit stubbornly in the bottle until shaking applies enough force that the flow starts, at which point the ketchup pours like a liquid. Because fluid gels are often consumed by diners as liquids, one might argue that they should be discussed along with thickening techniques. Fluid gels often start out as solids, however, and the techniques and gelling agents used to make them have more to do with gels than with thickened fluids, so we cover them here.

Fluid gels have many applications in cooking. They can help maintain a colloidal suspension by keeping the particles in it from settling. Commercial chocolate milk is one example. In homemade chocolate milk, some chocolate particles settle to the bottom of the glass before the drink is finished. Commercially made chocolate milk must sit on the shelf for weeks or months, so it is important to maintain the suspension of the chocolate. This is achieved by the addition of hydrocolloids that create a lightweight fluid gel. You could accomplish the same task with a thickening agent, but that would make the milk highly viscous all the time. As a fluid gel, the hydrocolloid-enhanced mix is thick enough to suspend the particles when it is sitting in the fridge but becomes thin enough to drink when you tilt the glass and impose shear forces on the gel.

Chefs have exploited fluid gels to serve hot and cold liquids in the same container, a trick that has been featured in the cuisine of The Fat Duck, where you can get hot and cold tea in the same cup. The idea is simple. First, prepare two very thin fluid gels, one hot and one cold. Carefully pour the two gels into opposite sides of a container, separated by a card. Finally, remove the card carefully. The fluid gels retain their high viscosity as long as they are kept still, thus allowing the server to bring the cup to the table without mixing them. When you tilt the cup to drink, enough shear forces are generated to convert the fluid gels to drinkable liquids.

Most gelling agents can be used to form fluid gels, but several of them stand out because their gel networks are particularly prone to fluid gel formation. Agar and gellan both form excellent fluid gels, for example, and these are the hydrocolloids most commonly used to form them.

Surprisingly, eggs are also an excellent choice for making fluid gels. Egg whites, yolks, or a mixture of the two can be set as a gel (typically by heating), and then turned into a fluid gel by shearing. If the egg fully sets (as a hard-boiled egg does, for example), then it won't fluidize. But softer cooked egg gels—even those that can appear to be quite solid—can be turned into fluid gels.

Fluid gels are most often made in one of two ways. The simplest is to prepare a solid gel and then shear it with a blender or rotor-stator homogenizer. Alternatively, you can shear the gel as it cools and sets so that it never gets a chance to form a solid gel. Either method works, but it is important that the shearing method you choose is not so vigorous that it creates enough heat from friction to affect the gel.

An oyster with passion fruit fluid gel, horseradish cream, lavender, and lindi pepper tuile is a signature dish of Heston Blumenthal at The Fat Duck (see page 180).

PARAMETRIC RECIPE

FLUID GELS

In a fluid gel, the network of gel molecules has been disrupted by the action of pureeing. Once this occurs, the gel puree displays some properties of a liquid and some of a solid.

As a result, a thick fluid gel mimics some of the texture and mouthfeel of a puree. It can seem solid until it undergoes shearing, at which point it flows like a liquid. You can exploit this unusual behavior to make a wide variety of interesting textures, ranging from a very thick paste to a light soup. No particles get in the way of the flavor. You could make a carrot puree with the same texture as a carrot juice fluid gel for example, although the juice version will have a brighter flavor.

Very light fluid gels are useful for suspending particles to keep them from settling to the bottom—to keep spices afloat in a consommé, for example, or to hold the fruit pulp in a fruit juice. Even more dramatically, a fluid gel can suspend spherified liquid drops or swirls of a garnish, like squid ink (see page 131).

One can even use fluid gels to serve hot and cold tea from the same cup (see page 182). For instructions on using the table below, see the next page.

Best Bets for Fluid Gels

Temperature	Viscosity	Gelling agents	(scaling)**	Hydrate or cook (min)	(°C)	(°F)	Note	Example use	See page
cold	thin	160 Bloom gelatin	0.8%	2–5	60	140	stir or sieve before serving; gel will continue to set	thickened consommé, broth	
		egg yolk	250%	35	65	149	select quantity to obtain amount of egg flavor desired	savory crème anglaise, lemon egg yolk sauce	83, 180
			84%	35	69	156			
			25%	35	80	176			
		iota carrageenan	0.1%	3	75	167	higher viscosity with dairy	light cream sauce	
	medium-thick	160 Bloom gelatin	1.5%	2–5	60	140	stir or sieve before serving; gel will continue to heal	passion fruit jelly, coating gel for terrines	180
		egg yolk	150%	35	80	176		mustard sauce for cold cuts, smooth salad dressing	
		whole egg	100%	35	78	172			
		kappa carrageenan	0.4%	3	95	203	higher viscosity with dairy	light pudding	
	thick	160 Bloom gelatin	2.5%	2–5	60	140	stir or sieve before serving; gel will continue to set	vegetable or fruit juice puree, dense pudding	
		whole egg	250%	35	78	172		low-fat mayonnaise, aioli	
		iota carrageenan	0.35%	3	75	167	higher viscosity if used with dairy	traditional pudding	
		kappa carrageenan	0.20%						
hot	thin	agar	0.25%	3	95	203	slightly cloudy	broth	
		low-acyl gellan*	0.1%	3	95	203	acidic liquids may require a sequestrant to hydrate	consommé	
	medium-thick	egg yolk	80%	35	69	156	do not reheat above cooking temperature	rich egg-yolk sauce	
		agar	0.40%	3	95	203		gravy, cream-style sauce	
		xanthan gum	0.15%						
		low-acyl gellan*	0.5%	3	95	203	acidic liquids may require a sequestrant to hydrate	gravy, cream-style sauce	
	thick	agar	0.9%	3	95	203		fluid gel puree	
		xanthan gum	0.2%						
		egg yolk	150%	35	69	156		egg-only mayonnaise	
		low-acyl gellan*	0.8%	3	95	203	acidic liquids may require a sequestrant to hydrate	fizzy grape fluid gel	183

*(*add 0.15% calcium lactate for low calcium solutions; allow 3 h to fully set*); **(*set weight of liquid to 100%*)

MAKING A BASIC FLUID GEL

1 **Select the temperature and desired viscosity.** The table Best Bets for Fluid Gels on the previous page lists several options for both hot and cold gels.

2 **For egg fluid gels, cook eggs.** The table suggests cooking times and temperatures.

3 **For hydrocolloid fluid gels, scale and mix the gelling agents.** The table offers two or more options for each combination of service temperature and viscosity. Quantities in the table are scaled relative to the weight of the principal liquid. For example, to make a thick, hot onion gel, use 0.8 g of low-acyl gellan for every 100 g of onion puree.

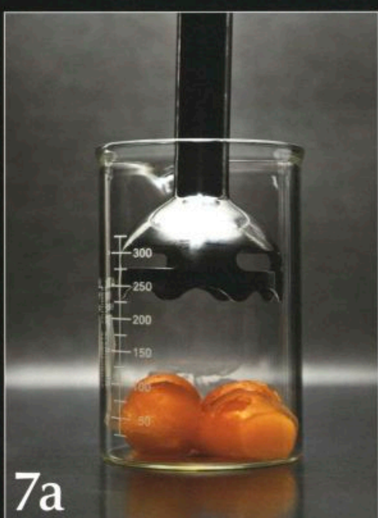
4 **Disperse the gelling agents into the liquid.** A sequestrant may be necessary if using gellan (see page 129).

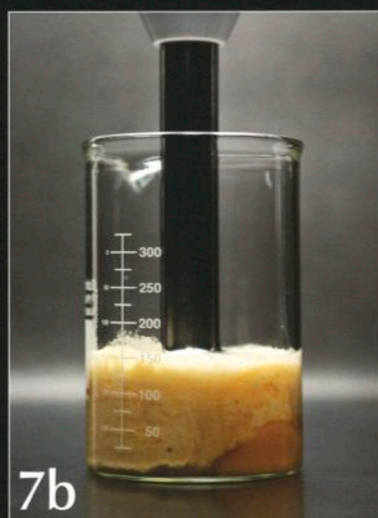
5 **Hydrate fully.** Hydration times and temperatures are indicated in the table. If you use a sequestrant, or if the food has low calcium content, then you may need to add calcium after hydration (see page 129).

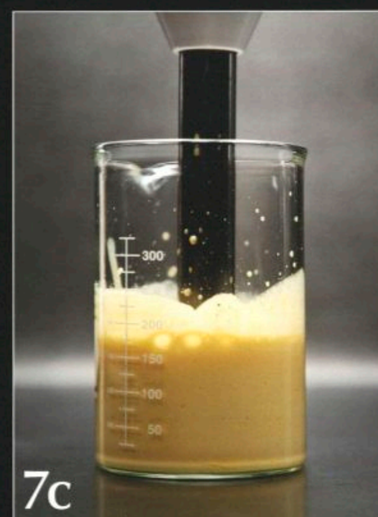
6 **Cast the gel, and let it set.**

7 **Puree the gel to the preferred consistency.** Additional liquid may be added as needed to thin the gel.

8 **Sieve the fluid gel to produce a gel having a finer consistency (optional).**







Cooked egg yolks can be pureed to make a fluid gel (7a–7c). Sieving a gelatin fluid gel (8a, 8b) yields a finer consistency, but such gels will eventually re-set, so sieve or puree them no more than 1 h before serving.

VARIATION: Quick-Setting a Fluid Gel

1 **Follow steps 1–5 on the previous page.**

6 **Set the gel in a beaker immersed in ice water.**

7 **Puree the gel with a hand blender as the gel sets.**

VARIATION: Using a Concentrated Premade Stock Gel

1 **Follow steps 1–6 on the previous page to make and cast a stock gel.** A convenient choice is to make a standard concentration, such as 1% low-acyl gellan or agar. If they contain more than a threshold of 1.3% gellan or agar, the stock gels will not return to a completely fluid state.

7 **Combine the liquid with the premade cubes, and puree.** If you want a 0.25% fluid gel, and you have a 1% pre-made gel, then set the weight of the liquid to 100%, and add 33% premade gel. See page 183 for an example.

8 **Adjust the consistency by adding stock gel or liquid (optional).**

Premade gel is very convenient for making fluid gel sauces to order and also for making fluid gels from liquids that you wouldn't want to heat to a typical hydration temperature, such as an herb puree. Gel cubes keep in the refrigerator for at least a week, and they can be made with a liquid base of water, stock, or cream. If the concentration of the premade gel is P%, and the final concentration of the fluid gel is F%, then you can calculate the scaling for the premade gel using this formula: scaling (%) = F ÷ (P − F).

VARIATION: Making a Coarse Fluid Gel

1 **Follow steps 1–6 on the previous page to make and cast a gel.**

7 **Run the gel through a food mill, potato ricer, or stand mixer to break up the gel into coarse pieces—or simply break up with a fork to make a coarse fluid gel.** Use this method to make faux ricotta, polenta (see page 181), or porridge.

Steak and eggs are a classic combination, and the best part is the runny yolk. Here, we used the recipe below to make an egg-based fluid gel. After cooking sous vide, it appears to be solid, but, once blended, its fluid nature becomes apparent. To make a thicker sauce, add up to twice as much cooked egg yolk as indicated in the recipe.

EXAMPLE RECIPE

LEMON EGG-YOLK FLUID GEL

Yields 200 g of fluid gel

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Strip steak	one steak		① Vacuum seal, and cook sous vide in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 40 min.
Egg yolks	120 g	100% (*84%*)*	② Blend egg yolks, and vacuum seal. ③ Cook sous vide in 69 °C / 156 °F bath for 35 min. Yolks will solidify ④ Remove from bag.
White beef stock see page 2·296	130 g	108%	⑤ Blend cold stock and lemon juice with yolk mixture until completely fluid. ⑥ Pass through fine sieve.
Lemon juice	12 g	10%	
Salt	to taste		⑦ Season, and reheat to 60 °C / 140 °F. Keep temperature below 69 °C / 156 °F, otherwise sauce will thicken.

(original 2004, adapted 2010)

(% of total weight of stock and juice*)

EXAMPLE RECIPE

PASSION FRUIT JELLY ADAPTED FROM HESTON BLUMENTHAL

Yields 580 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Passion fruit puree (Boiron brand)	150 g	40%	① Disperse gelatin in cold water. ② Whisk together puree and fructose.
Fructose	45 g	12%	③ Warm sweetened puree until fructose is completely dissolved.
160 Bloom gelatin	10.5 g	2.8% (*2%*)*	④ Add hydrated gelatin to warm puree, and stir together until dissolved.
Fresh oyster juice	375 g	100%	⑤ Whisk into warm liquid mixture. ⑥ Refrigerate for 1 h to set. ⑦ Press set gel through sieve to make it fluid. ⑧ Spoon onto fresh oysters in cleaned shells, and serve immediately.

(original 2001)

(% of total weight of passion fruit puree and oyster juice*)

EXAMPLE RECIPE

POPCORN PUDDING ADAPTED FROM WYLIE DUFRESNE

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Organic microwavable popcorn	75 g (one bag)	19%	① Microwave popcorn.
Whole milk	2.5 kg	625%	② Blend with popped popcorn.
Freeze-dried corn see page 3·372 (or store-bought)	200 g	50%	③ Pass corn milk through fine sieve twice; measure 400 g of corn milk.
Corn milk (from above)	400 g	100%	④ Combine corn milk and water.
Water	45 g	11%	⑤ Disperse gums into liquid.
Iota carrageenan (Genuvisco J, CP Kelco brand)	2.7 g	0.68% *(0.6%)**	⑥ Bring mixture to boil, and remove from heat. ⑦ Cool until set.
Kappa carrageenan (Genugel CHP2, CP Kelco brand)	1.8 g	0.45% *(0.4%)**	⑧ Blend to fine puree. ⑨ Pass pudding through fine sieve.
Salt	to taste		⑩ Season.

(original 2004)

(% of total weight of corn milk and water*)

Popcorn Pudding

Parmesan "Polenta"

EXAMPLE RECIPE

PARMESAN "POLENTA" INPIRED BY DAVE ARNOLD AND NILS NORÉN

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White chicken stock see page 2·296	100 g	100%	① Shear powders into cold stock with immersion blender. ② Bring mixture to boil.
Parmesan water see page 2·310	100 g	100%	③ Place mixture in pan, and place over ice-cold water bath to set.
Corn juice see page 2·336	100 g	100%	④ Pulse set gel with hand blender—or press through potato ricer—to create an irregular, coarse-grained mixture.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	3 g	3% *(1%)**	⑤ Refrigerate until use.
Unsalted butter, cubed	50 g	50%	⑥ To serve, reheat polenta, and whisk in butter until melted.
Parmesan, finely grated	50 g	50%	⑦ Whisk in Parmesan.
Salt	to taste		⑧ Season.

(original 2009, adapted 2010)

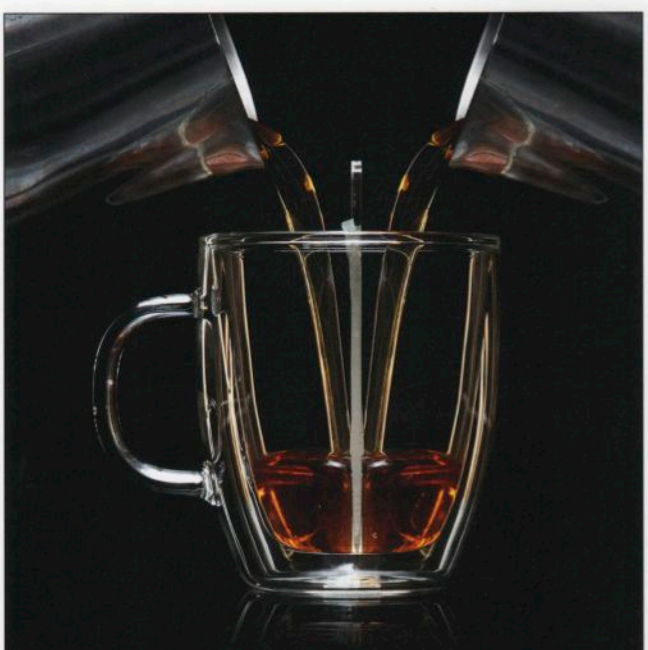
(% of total weight of chicken stock and corn juice*)

HOT AND COLD TEA ADAPTED FROM HESTON BLUMENTHAL

Yields 1.73 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Distilled water	1.8 kg	209%	① Stir together.
Earl Grey tea leaves	40 g	4.6%	② Vacuum seal, and infuse at room temperature for 1 h.
			③ Strain tea through fine sieve, and measure 1.73 kg.
			④ Divide reserved tea into two 860 g and two 5 g portions for hot and cold tea components.
For cold tea:			
Earl Grey tea, from above	860 g	100%	⑤ Dry blend, and whisk into 860 g of reserved tea.
Unrefined caster sugar	80 g	9.3%	⑥ Bring mixture to simmer.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.6 g	0.07%	⑦ Blend until completely dissolved, and reserve gellan mixture.
			⑧ Combine with 5 g of reserved tea.
Sodium citrate	0.6 g	0.07%	⑨ Whisk into gellan mixture to hydrate and thicken.
Malic acid	1 g	0.12%	⑩ Cool over ice-water bath, and then refrigerate for 24 h.
Calcium chloride	0.25 g	0.03%	⑪ Pass tea mixture through fine sieve.
			⑫ Refrigerate until needed.
For hot tea:			
Earl Grey tea, from above	860 g	100%	⑬ Follow steps 5–11 above.
Unrefined caster sugar	80 g	9.3%	⑭ Warm fluid gel in 72 °C / 162 °F bath.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.6 g	0.07%	⑮ Place tight-fitting vertical dividers down centers of four small glasses, aligning dividers perpendicular to handles.
Sodium citrate	0.6 g	0.07%	⑯ Remove cold tea gel from refrigerator.
Malic acid	3.5 g	0.4%	⑰ Pour hot tea and cold tea gels individually into separate halves of each glass, filling both sections to same height.
Calcium chloride	0.25 g	0.03%	⑱ Remove divider, and serve immediately without jostling or tipping. Align dividing lines with lips of drinkers so that they experience hot and cold teas simultaneously.

(original 2005)



17a

17b

EXAMPLE RECIPE

UMAMI SEASONING FLUID GEL INSPIRED BY GRANT ACHATZ

Yields 625 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Brown beef stock or water see page 2·296	300 g	100%	① Blend liquids, and disperse agar into cold mixture. ② Bring mixture to 95 °C / 203 °F, and hold for 3 min to hydrate fully. ③ Remove from heat, and cast into mold. ④ Refrigerate until set, about 5 min. ⑤ Break gel into small pieces for easier blending.
Tomato ketchup (Heinz brand)	80 g	26.7%	
Clear honey	60 g	20%	
Fish sauce	30 g	10%	
Sherry vinegar	20 g	6.7%	
Agar (Texturas brand)	6 g	2%	
Dark soy sauce	150 g	50%	⑥ Puree soy sauce with set gel until very smooth, and pass through fine sieve. ⑦ Serve as seasoning for grilled mushrooms with shaved jalapeño peppers and avocado.

(original 2007, adapted 2009)

EXAMPLE RECIPE

FIZZY GRAPE FLUID GEL ADAPTED FROM HESTON BLUMENTHAL

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White grape juice	720 g	100%	① Blend in pot.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	6.4 g	0.89% *(0.8%)**	② Heat to 95 °C / 203 °F to fully hydrate, and hold for 3 min. ③ Remove from heat, and strain through fine sieve. ④ Cool over ice-water bath, blending continuously, until gel mixture is chilled and completely fluid.
Muscat wine (dry)	80 g	11%	⑤ Add to fluid gel, and blend. ⑥ Pass through fine sieve, and cool.
Champagne	15 g	2%	⑦ Fold gently into fluid gel, and pour fluid gel into 1 l whipping siphon. ⑧ Vent head space with one cartridge of carbon dioxide (see page 2·468). Charge with two cartridges of carbon dioxide, and shake siphon vigorously. ⑨ Refrigerate for at least 2 h to carbonate.

(original 2005, adapted 2010)

(% of total weight of white grape juice, muscat wine, and Champagne*)

EXAMPLE RECIPE

ONION FLUID GEL ADAPTED FROM HESTON BLUMENTHAL

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Onions, thinly sliced	250 g	62.5%	① Combine in pot. ② Sauté onions until soft and translucent.
Unsalted butter	30 g	7.5%	
Thyme, sprig	1 g	0.25%	
Low-fat milk	200 g	50%	③ Add to cooked onions, and simmer mixture for 5 min. ④ Remove from heat, and discard thyme. ⑤ Blend mixture fully. ⑥ Press through fine sieve, and reserve 400 g of infused milk.
White chicken stock see page 2·296	150 g	37.5%	
Heavy cream	95 g	23.8%	
Salt	to taste		⑦ Season infused milk, and let cool.
Infused onion milk, from above	400 g	100%	⑧ Disperse into cold infused milk. ⑨ Bring milk to 93 °C / 199 °F, and hold for 3 min to fully hydrate gellan. ⑩ Transfer to container, and cool over ice-water bath. ⑪ Blend by hand until cold and completely fluid. ⑫ Pass through fine sieve, and refrigerate.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	2.7 g	0.68%	

(original 2007)

SPHERIFICATION

The term "spherification" was coined by Ferran Adrià and refers to the fact that the small droplets tend to be spherical. This shape occurs for the same reason that bubbles and balloons are round: the spherical geometry minimizes the surface-tension energy.

Spherification was patented in the UK in 1942 (see page 1·38) and has been widely used in industry since then. Sergi Estragues and Joachim Vives, representatives of a Spanish food company, initially demonstrated the technique to Ferran Adrià.

Spherification is used in the pharmaceutical industry to encapsulate drugs for time release. It is known as "ionotropic gelation."

We classify spherification as a hydrocolloid-ion reaction that can result in a solid droplet with a liquid center. Other methods, such as dropping a hot hydrocolloid mixture into cold oil or liquid nitrogen, can make spherical gel beads that are fully solid; see page 145 for an example. Even though the results look superficially similar, we do not consider these to be examples of spherification.

Spherification is the process of encapsulating liquid in gel spheres. It is one of the most dramatic techniques in Modernist cuisine because the outcome is so unusual in appearance. Small-scale spheres look a bit like caviar, while large spheres often look like marbles or some other nonfood item. They hardly look like things you can easily whip up in a kitchen. Yet you can, and that is part of the appeal of the technique.

Spherification was first used for fine dining in 2003 by Ferran Adrià at elBulli, and many chefs have since begun experimenting with it. Spherification exploits the gelling that occurs when a hydrocolloid such as alginate encounters a calcium ion coagulant.

The original spherification technique uses alginate mixed with a food that has no free calcium in it (usually achieved with a sequestrant) as one component. Drops of this liquid fall into a setting bath made of a dilute calcium solution (usually calcium chloride or calcium lactate). The surface of the drops start to gel as soon as they enter the bath.

Remove the spheres from the calcium setting bath quickly enough, and you can get droplets of liquid surrounded by a skin of gel. Leave the spheres in the bath for longer, or hold them longer afterward, and the beads solidify. Heating the beads to 85 °C / 185 °F for 10 minutes or more stops the setting process and keeps the centers liquid. A trick to force the drops into spherical shapes is to add just enough sugar (up to 22%) to the setting bath to match the density of the liquid being spherified. Without this addition, the droplets sink to the bottom and become lopsided.

Newer methods of spherification have been invented, mostly at elBulli, that improve on the original approach. Reverse spherification starts with a bath of pure water and hydrocolloid rather than with a bath of calcium. The calcium is in the liquid to be spherified; the bath is the gelling solution. Many foods naturally contain sufficient calcium; for others, you must add calcium to the food. When the liquid drops into the gel bath, a coating of gel forms around the droplet as the calcium interacts with the alginate. One great thing about this technique is that it can't possibly gel all the way to the center because there is no hydrocolloid present there. The center can thus remain liquid indefinitely if you so choose.

In a third spherification approach, which we call **cryospherification** or molded spherification, you freeze the liquid that is to be spherified in a mold, and then drop frozen pieces into a hydrocolloid bath. As the pieces thaw, their outer layers start to gel. This procedure can be accomplished using either direct or reverse spherification methods, although cooks most often use it with the reverse approach. Reverse cryospherification provides you with much more precise control over the shape and size of the resulting flavor beads.

The results of chefs' first attempts at spherification were quite small—a faux salmon caviar with an average diameter of about 6 mm / ¼ in. One can, however, produce many sizes, including the famous elBulli olives and even an egg yolk doppelgänger (see pages 193 and 194). Pioneering cooks originally used alginate hydrocolloids for spherification, but similar results can be achieved with gellan, LM pectin, and carrageenan.

Spherification is an almost magical technique that lets a chef make what appear to be berries, caviar, or other impossible creations that encase liquid in a solid shell. It is easy to see that the faux olives on the next page have been made using reverse spherification—they have a thin, clear gel coating around them.

PARAMETRIC RECIPE

SPHERIFICATION

Spherification is a great trick. This quintessentially Modernist process transforms a liquid into an orb enveloped by a gelled skin. The result looks interesting, and there is a certain child-like joy in spooning into your mouth beads that instantly burst and saturate your palate with, say, fresh and flavorful melon juice.

The secret to spherification is to first create a gel mixture that cannot set due to lack of coagulating ions. The mixture is then put into a setting bath that contains the missing component. When the two solutions meet, gelling begins. Surface tension gives the beads their distinctive spherical shape.

The time that the gelled skin spends in the bath determines its strength and depth. A short dip yields a tissue-thin skin; a long soak produces chewy beads. Rinsing finished gels twice slows the gelling process and eliminates any bitter flavor left from the bath. Heating the beads to 85°C / 185°F for 10 min stops the gelling process.

An alternative approach, called reverse spherification, puts the calcium in the edible liquid (or puree) instead of in the bath water. The bath now contains unset gel made with deionized or distilled water, so it has no calcium. Reverse spherification, because of its many advantages, is usually the method of choice. Once the spheres are made, you can store them in fresh water, infusions, or flavored oil for up to three days. Serve them hot or cold.

DIRECT SPHERIFICATION

1 **Select a spherification method from the table Best Bets for Spherification on the next page.** To gel a liquid that naturally contains calcium, we recommend using reverse spherification, described in the variation on the next page.

2 **Scale and mix the gelling agents.** Weigh the ingredients relative to the amount of liquid you will be gelling. For example, when making cranberry gel spheres, add 2 g of iota carrageenan for every 100 g of cranberry juice.

3 **Disperse the gelling solution.** Add sequestrants as needed (see page 129).

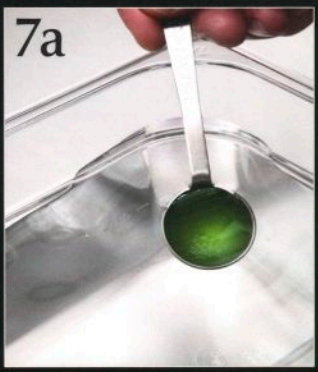
4 **Hydrate fully.** See the table of hydrocolloid properties on page 42 for hydration times and temperatures.

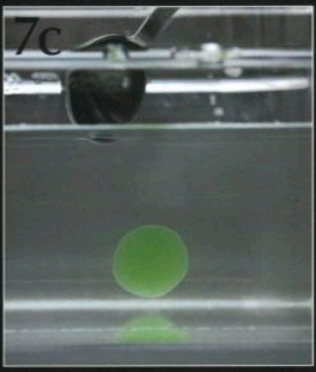
5 **Vacuum seal (optional), and chill for 2 h.** Vacuum sealing removes air from the solution and helps prevent bubbles from altering the shape and texture of the spheres as they form.

6 **Prepare the setting bath.** Stir the setting agent into clean water, and allow 1 h for it to dissolve fully. Optionally, add sugar syrup (up to 22% sugar concentration) or corn syrup to the bath so that its density matches that of the liquid to be gelled. This prevents the droplets from falling to the bottom of the setting bath.

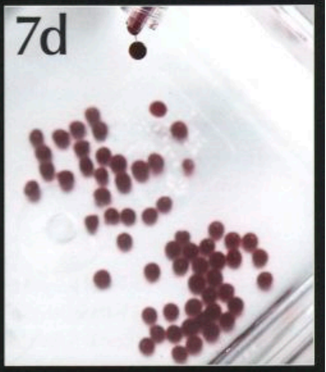
7 **Introduce drops of gelling solution into the bath.** A common technique when making large spheres is to slide tablespoonfuls of gelling fluid gently into the bath water. A peristaltic pump (see page 139) can be set up to drip the droplets continuously. If you are making small spheres, use a syringe to dispense the solution. Allow the skin to form for 1–3 min; beads will grow increasingly firm as they soak.

8 **Rinse the spheres with clear water.** Rinsing slows the gelling process and washes away any lingering flavors from the setting solution. Rinse the spheres at least twice. Remove with a perforated spoon. Optionally, heat to 85 °C / 185 °F for 10 min to stop further solidification. Store the spheres in water or oil until needed.





Large sphere gel



Small sphere gel

Best Bets for Spherification

Method	For the sphere base	(scaling)*	For the setting bath	(scaling)*	Note	See page
alginate (direct)	sodium alginate xanthan gum (optional)	1% 0.2%–0.5%	calcium chloride	0.5%	xanthan gum thickens liquid and yields more even orbs	189
	sodium alginate xanthan gum (optional)	1% 0.2%–0.5%	calcium gluconate	2.5%	see note above	
alginate (reverse)	calcium lactate xanthan gum (optional)	3% 0.2%–0.5%	sodium alginate sodium citrate (optional)	0.5% 1.2%	see note above use sodium citrate when liquid is acidic or high in calcium	next
carrageenan (direct)	iota carrageenan	2%	potassium phosphate	5%	hydrate carrageenan cold for at least 5 h; can also be made reverse	
gellan (direct)	low-acyl gellan sodium hexametaphosphate	0.2% 0.1%	calcium gluconate lactic acid	6% 0.1%	best made with low acid, moderate calcium liquids; make frozen hemispheres and set in 80 °C / 176 °F calcium bath; can also be made reverse	
LM pectin (reverse)	calcium lactate	5%	LM pectin	2%	can also be made direct	190

**(set weight of liquid to 100%)*

VARIATION: Suspending a Solid in a Gelled Sphere

1 **Follow steps 1-6 on the previous page.** If you are using reverse spherification, see the variation below.

7 **Add a solid to the center of the liquid or puree.** The solid must be fully encased in the solution; if any part protrudes, an intact membrane will not form around the sphere. Continue with step 7 on the previous page for direct spherification, or see below for reverse spherification.

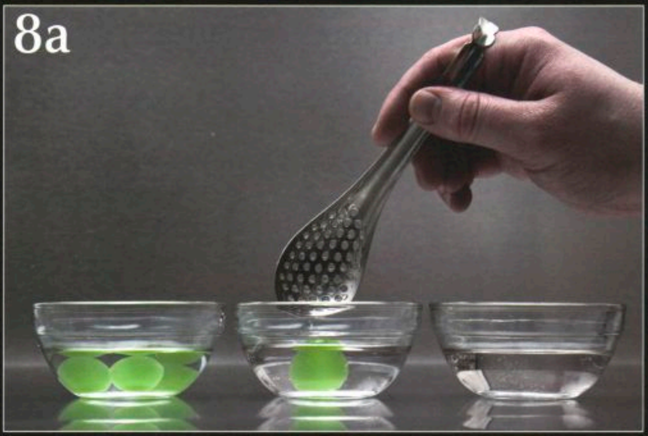
In either direct or reverse spherification, you can freeze the droplets ahead of time. To use, put them into a warm bath and, as they defrost, spherification occurs.

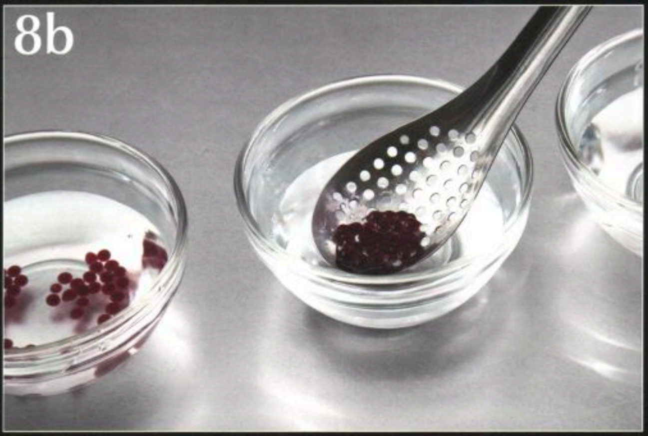
VARIATION: Reverse Spherification

In reverse spherification, the edible liquid is mixed with calcium lactate or another salt, and the gelling agent (such as alginate) is dispersed into the bath.

When the edible liquid enters the bath, a skin of gel forms around it, encapsulating the liquid. Unlike direct spherification, the edible liquid itself does not set, although the skin does grow increasingly firm the longer the bead remains in the bath. Adding xanthan gum to the liquid thickens it and yields smoother spheres. Because the bath contains no salts, it is not necessary to rinse the beads.

The edible liquid should not be so thin that it will dissolve in the bath or fail to hold a distinct shape. Nor should it be so thick that it resists rounding into a sphere. The ideal viscosity is that of thick cream. Xanthan gum can be added to control the viscosity.



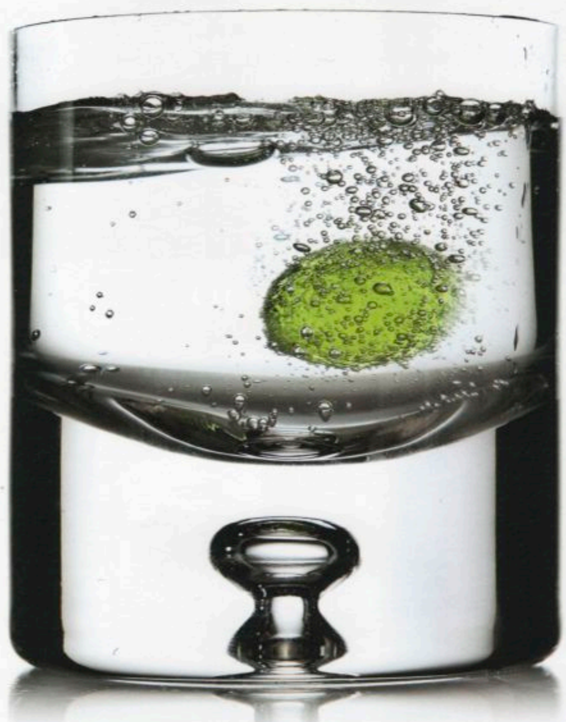


CARBONATED MOJITO SPHERES ADAPTED FROM JOSÉ ANDRÉS

Yields 480 g (about 40 spheres)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water, distilled	450 g	86%	① Blend until completely dissolved.
Lime juice	120 g	34.5%	
Sugar	120 g	34.5%	
Mint leaves, julienne	80 g	23%	② Blend into juice mixture.
Lime zest, grated	12 g	3.4%	③ Steep, refrigerated, for 1 h. ④ Strain, and reserve 350 g of juice solution to make spheres. Reserve remainder to store spheres.
Lime juice mixture, from above	350 g	100%	⑤ Blend with reserved juice solution until incorporated.
White rum	130 g	37%	
Calcium lactate	6.7 g	1.9%	
Xanthan gum (Keltrol T, CP Kelco brand)	1.7 g	0.5%	
Ascorbic acid	0.3 g	0.08%	
Sodium alginate (Algin, Texturas brand)	5 g	1.43%	⑥ Blend water and sodium alginate until completely dissolved. ⑦ Refrigerate bath for 1 h.
Water	1 kg	286%	⑧ Fill two whipping siphons with 100 g each of reserved juice mixture. ⑨ Fill tablespoon with mixture, tip gently into alginate bath, and release contents. ⑩ Set for 7 min; skin will form. ⑪ Remove from bath with perforated spoon, and rinse sphere twice in fresh water. ⑫ Place sphere gently into whipping siphon containing juice mixture. ⑬ Repeat procedure with remaining mixture; fill each siphon only half full with spheres. ⑭ Vent head space with one cartridge of carbon dioxide, and then charge each siphon with two cartridges of carbon dioxide at least 5 h before serving. Refrigerate siphons to carbonate spheres.
Lime zest, finely grated	to taste		⑮ Remove spheres from whipping siphons with perforated spoon, and place in cocktails. ⑯ Garnish.

(original 2008, adapted 2010)



In this recipe from José Andrés, the spherifed liquid is carbonated to create a spectacular cocktail effect.

EXAMPLE RECIPE

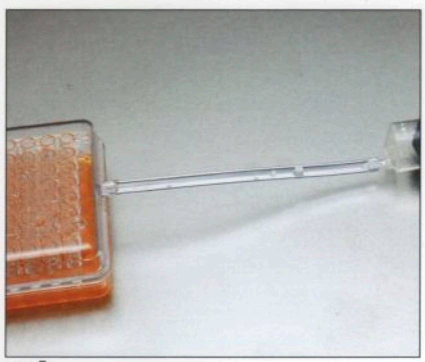
MELON CAVIAR ADAPTED FROM FERRAN ADRIÀ

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sodium alginate (Algin, Texturas brand)	2 g	0.8%	① Combine sodium alginate with 50 g of melon juice.
Melon juice see page 2·340	250 g	100%	② Blend until dissolved. ③ Mix in remaining melon juice. ④ Strain. ⑤ Vacuum seal; remove excess air.
Water	500 g	200%	⑥ Blend calcium chloride in water until dissolved.
Calcium chloride	2.5 g	1%	⑦ Set up three baths: one filled with calcium chloride solution to set spheres, two filled with cold water to rinse spheres. ⑧ Fill syringes or droplet maker with melon juice mixture. ⑨ Expel droplets one at a time into calcium chloride bath. ⑩ Remove each droplet from bath after 1 min. ⑪ Strain melon caviar. ⑫ Rinse caviar twice in cold water baths.

(original 2003)

8a



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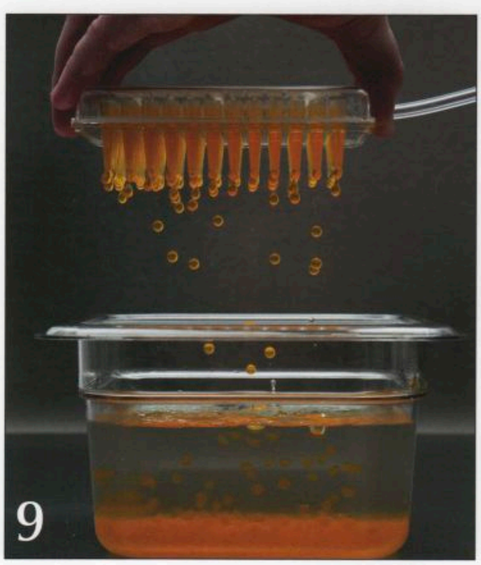

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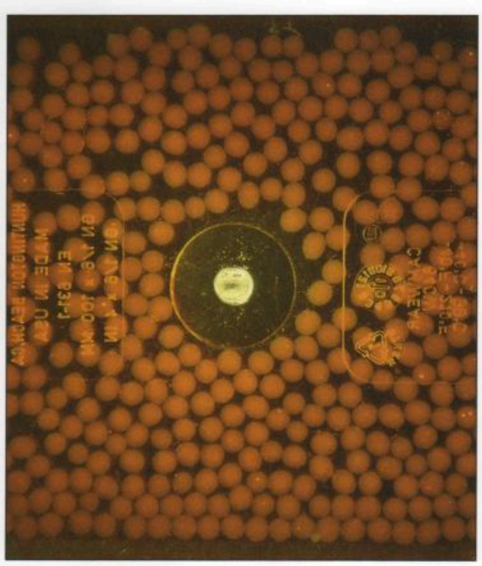


One problem with direct spherification is that the gel continues to set over time, eventually creating a firm gel rather than a gel membrane surrounding a fluid. You can neutralize this chemical reaction by heat-treating the spheres, just after setting them, in an 85 °C / 185 °F bath for 10 min. The water should have the same viscosity as the sphere cores so that they don't leach liquid during the heating. Add xanthan gum or sugar as necessary.

Another challenge for a chef is how to make enough of the little spherified beads to serve a group. Arrays of 96 nozzles, originally designed for biology laboratories, can help. For a more elaborate setup, feed the gel by using a peristaltic pump, as illustrated on page 139.

GRUYÈRE SPHERES ADAPTED FROM WYLIE DUFRESNE

Yields 2 kg (about 24 spheres)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Gruyère cheese, finely grated	250 g	100%	① Spread on tray lined with silicone mat. ② Bake in 175 °C / 350 °F oven until golden, about 12 min.
Whole milk	1 kg	400%	③ Blend with cheese until fully incorporated.
Propylene glycol alginate (Protanal Ester BV, FMC BioPolymer brand)	7.5 g	3%	④ Refrigerate overnight. ⑤ Strain through fine sieve.
Salt	to taste		⑥ Season, and pipe into silicone hemisphere molds 3 cm / 1¼ in. in diameter. ⑦ Freeze completely, about 2 h.
Water, room temperature	500 g	200%	⑧ Blend until completely dissolved.
LM pectin (Genupectin LM 104 AS, CP Kelco brand)	20 g	8%	⑨ Remove frozen cheese hemispheres from molds, and drop into pectin bath. ⑩ Soak until coated with pectin, about 1½ min.
Water, room temperature	500 g	200%	⑪ Blend until completely dissolved to make setting bath.
Calcium lactate	2.5 g	1%	⑫ Drop pectin-coated spheres into setting bath. ⑬ Allow membrane to form, at least 90 s, and then remove from bath; hold in cold water.
Yellow onions, thinly sliced	200 g	80%	⑭ Sauté onions until very tender and deep golden, about 35 min.
Unsalted butter	50 g	20%	⑮ Puree.
Xanthan gum (Keltrol T, CP Kelco brand)	0.8 g	0.32%	⑯ Blend into onion puree.
Salt	to taste		⑰ Season onion puree.
Rye bread, frozen, crusts removed	100 g	40%	⑱ Cut into slices 3 mm / ⅛ in thick with meat slicer. ⑲ Roll slices through pasta machine to compress. ⑳ Bake slices at 95 °C / 205 °F between two silicone mats for 45 min.
Oxtail consommé see page 2·376	500 g	200%	㉑ Combine, and bring to simmer. ㉒ Season soup.
Salt	to taste		㉓ Drop cheese spheres into soup, and warm through.
Sherry vinegar	to taste		㉔ Serve spheres in hot consommé with rye bread slice smeared with onion puree.
Lemon thyme leaves	10 g	4%	㉕ Garnish.

(original 2007, adapted 2010)

Photo courtesy of Takahiko Marumoto

Modernist raviolo al'uovo

Spheres can be made more versatile by making their membrane stronger. Leave the spheres in the setting bath for 8–10 min to form a stronger membrane. They can then be delicately breaded and fried, or carefully placed in the center of a raviolo filling for a Modernist raviolo al'uovo. Dana Tough and Brian McCracken exploit this process and serve a deep-fried béarnaise sphere with beef carpaccio at Spur in Seattle, in homage to Wylie Dufresne.

EXAMPLE RECIPE

MUSSELS IN MUSSEL JUICE SPHERES ADAPTED FROM FERRAN ADRIÀ

Yields 200 g (about 20 spheres)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Mussel jus see page 2·344	100 g	100%	① Blend until completely dissolved.
			② Vacuum seal solution to remove excess air.
Calcium gluconate	2.5 g	2.5%	③ Refrigerate until needed.
Xanthan gum (Texturas brand)	0.5 g	0.5%	
Rock mussels	20 mussels		④ Steam for 3 min until just opened.
			⑤ Shuck.
			⑥ Refrigerate to cool quickly.
Water	1 kg	1,000%	⑦ Blend to dissolve completely.
Sodium alginate (Algin, Texturas brand)	5 g	5%	⑧ Vacuum seal to remove excess air.
			⑨ Set up three baths: fill one with sodium alginate solution, and fill two with cold water.
			⑩ Place one mussel at a time onto spoon 2.5 cm / 1 in. in diameter.
			⑪ Pour 4 g of reserved mussel juice solution onto mussel.
			⑫ Tip spoon carefully into sodium alginate bath to gently release contents.
			⑬ Set in bath until membrane has fully formed, about 5 min.
			⑭ Remove sphere from bath with perforated spoon.
			⑮ Repeat procedure with remaining mussels and mussel juice solution.
			⑯ Rinse spheres in two cold water baths.
Salt	7 g	7%	⑰ Dissolve salt in water to make brine.
Water	400 g	400%	⑱ Immerse mussel spheres in brine.
			⑲ Refrigerate until needed.
			⑳ To serve, warm spheres in 60 °C / 140 °F bath for 3 min.

(original 2005)

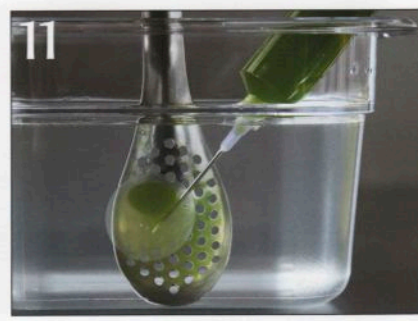
EXAMPLE RECIPE

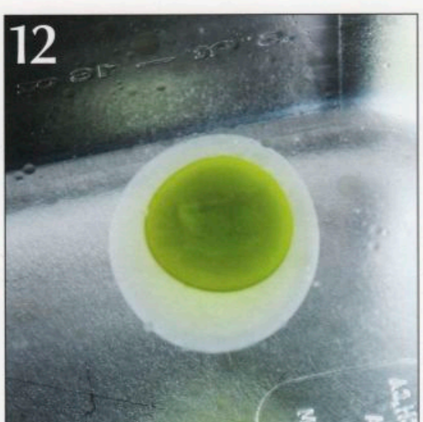
TOMATO SPHERES WITH BASIL OIL

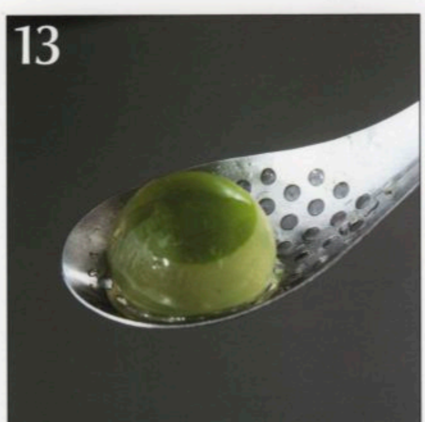
Yields 300 g (about 12 spheres)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tomato water see page 2·366	250 g	50%	① Blend until homogenized. ② Press through fine sieve, and reserve refrigerated.
Sodium alginate (Algin, Texturas brand)	2 g	0.4%	
Grapeseed oil	200 g	40%	③ Puree in blender for 3 min.
Basil, blanched and shocked	100 g	20%	④ Press through fine sieve. ⑤ Decant basil oil, and reserve in syringe.
Water	500 g	100%	⑥ Blend to dissolve completely.
Calcium lactate	2.5 g	0.5%	⑦ Set up four baths: fill one with calcium lactate solution, and fill three with cold water. ⑧ Fill tablespoon with reserved tomato water solution. ⑨ Tip spoon into calcium lactate bath to gently release contents. ⑩ Set in bath until membrane has fully formed around tomato sphere, about 30 s. ⑪ Inject approximately 3 ml / 0.1 oz of basil oil into submerged sphere. ⑫ Remove syringe; wait for membrane puncture to heal and sphere to reshape, about 15 s. ⑬ Remove sphere from bath with perforated spoon. ⑭ Repeat procedures with remaining tomato water solution and basil oil. ⑮ Rinse spheres in each of three cold water baths. ⑯ Refrigerate until needed.

(2010)







Injecting the spheres underneath the surface of the gel solution is important, as the hole can then repair itself after the needle is withdrawn.

To suspend oil droplets within a sphere, you can make the sphere base an unstable emulsion, and break the emulsion after spherification. First, make a fluid gel with 100 g of flavorful liquid, 10 g of oil or fat, 3 g of calcium lactate, and 0.5 g of kappa carrageenan. Cast into silicone hemispheres, freeze, and then place in a gel bath (see next page). Once set, heat the spheres in simmering water for a few minutes to break the emulsion. This approach does not yield liquid as clear as the injection method does.

EXAMPLE RECIPE

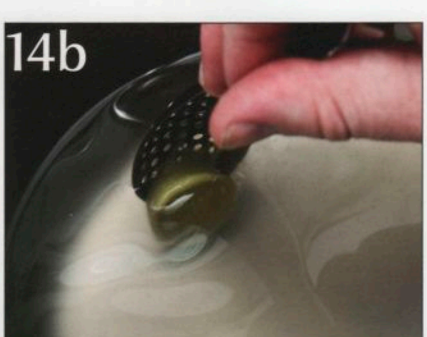
LIQUID PIMENTO OLIVE ADAPTED FROM FERRAN ADRIÀ

Yields 480 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Extra-virgin olive oil	500 g	100%	① Combine to make aromatic olive oil.
Thyme	20 g	4%	② Reserve for later use.
Orange peel, julienne	15 g	3%	
Green olives, pitted	500 g	100%	③ Blend in food processor to fine paste.
Olive brine, from olives	200 g	40%	④ Press through fine sieve, and reserve 450 g of olive puree.
Calcium lactate	13.5 g	2.7% *(3%)**	⑤ Blend by hand with olive puree until completely dissolved.
Xanthan gum (Texturas brand)	1.6 g	0.32% *(0.36%)**	⑥ Blend gradually with olive puree. ⑦ Cast into hemisphere molds.
Piquillo pepper, cut in thin strips (store-bought)	15 g	3%	⑧ Place pepper strip on top, and carefully push into each hemisphere. ⑨ Freeze.
Sodium alginate (Algin, Texturas brand)	5 g	1%	⑩ Disperse with hand blender, and refrigerate until needed. ⑪ Before use, blend until sodium alginate is completely incorporated.
Water	1 kg	200%	⑫ Vacuum seal to remove accumulated bubbles. ⑬ Pour into bowl to make bath for setting olives. ⑭ Bring bath to simmer. ⑮ Remove each frozen hemisphere from mold, place on spoon, and tip gently into bath. ⑯ Set in bath for 3 min. Hemispheres will thaw into spheres, and skin will form. ⑰ Remove olive sphere from bath with perforated spoon. ⑱ Rinse sphere twice in cold water. ⑲ Repeat with remaining olive hemispheres. ⑳ Store spherified olives, refrigerated, in reserved aromatic olive oil.

(original 2005, adapted 2010)

(% of weight of reserved olive puree*)



PROSCIUTTO AND MELON "RAW EGG"

Yields five eggs

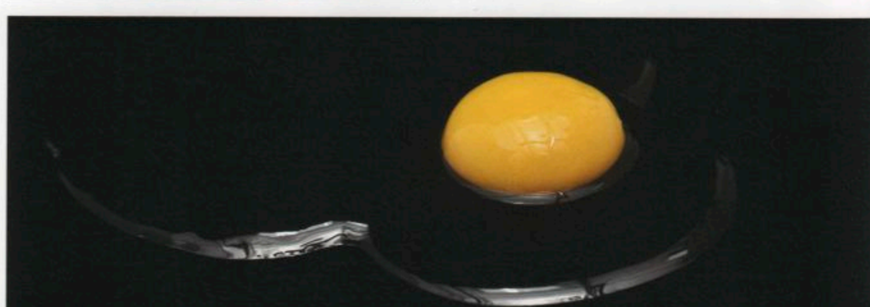
INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the setting bath:			
Water	2 kg	400%	① Whisk together.
Sodium alginate (TICA-algin 400 Powder, TIC Gums brand)	10 g	2%	② Vacuum seal to remove excess air, and refrigerate for 2 h.
For the egg-yolk base:			
Sugar	20 g	4%	③ Sift together.
Calcium lactate	9 g	1.8%	
Xanthan gum	2.5 g	0.5%	
Salt	1.7 g	0.3%	
Malic acid	1.1 g	0.2%	
Melon juice	500 g (from about 900 g of melon)	100%	④ Blend juice into calcium lactate mixture, taking care to incorporate as little air as possible. ⑤ Dispense with sauce gun into 2 cm / ¾ in hemisphere molds. ⑥ Freeze. ⑦ Heat sodium alginate solution until fluid is **60–65** °C / **140–149** °F. ⑧ Remove from heat, and carefully drop in frozen hemispheres. ⑨ Leave for 2 min, turn spheres over, and leave for 1 min longer. ⑩ Fill three bowls with water: heat two to **75–80** °C / **167–176** °F; fill third with cold water. ⑪ Transfer spheres with slotted spoon to first bowl of warm water to rinse for 1 min. ⑫ Rinse spheres again in second bowl of warm water, and reserve in cold water.
For the "raw" egg-white base:			
Ham broth, gelatin-clarified see pages 2·304 and 2·370	500 g	100%	⑬ Mix, and bring to boil. ⑭ Pour into sauce gun, and rest at room temperature until about **60** °C / **140** °F.
Xanthan gum	1.25 g	0.25%	⑮ Dispense "egg" white into one half of plastic eggshell.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.032 g	0.006%	⑯ Place yolk sphere in center of white, and cap with other half of plastic shell. ⑰ Dispense remaining white into sealed shell through drilled hole until overflowing. ⑱ Chill over ice.

(2010)

Many chefs have made faux hard-boiled eggs. This is the first faux raw egg that we have seen.

The eggshell molds we used are store-bought plastic Easter eggs with a vertical seam. It is also important to freeze-filter the ham stock to remove its natural gelatin so that the egg-white base takes on the correct texture.

We drilled a 6 mm / ¼ in hole into the top right corner of each mold to finish filling it.



EXAMPLE RECIPE

"POACHED" EGG

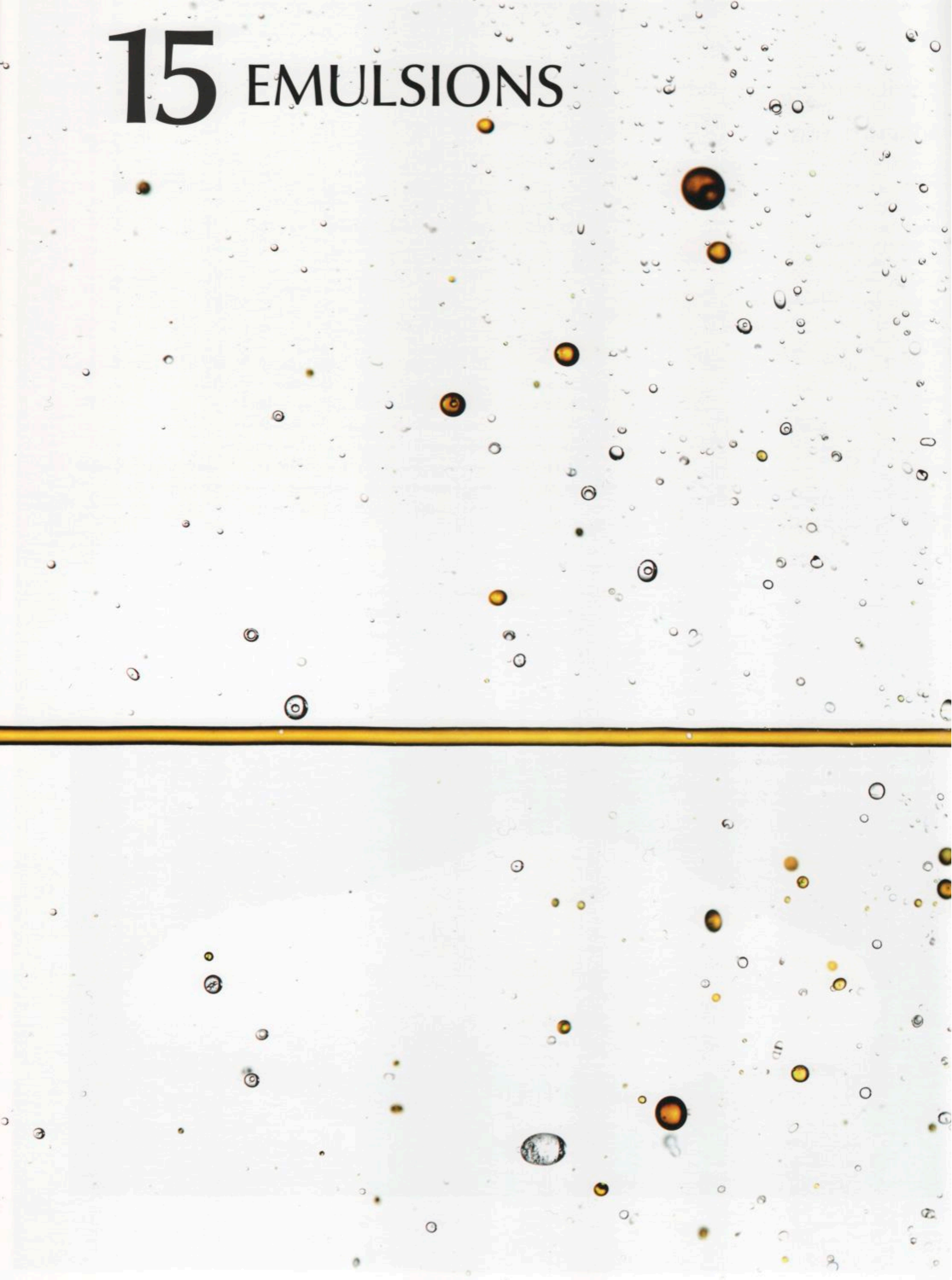
Yields five "eggs"

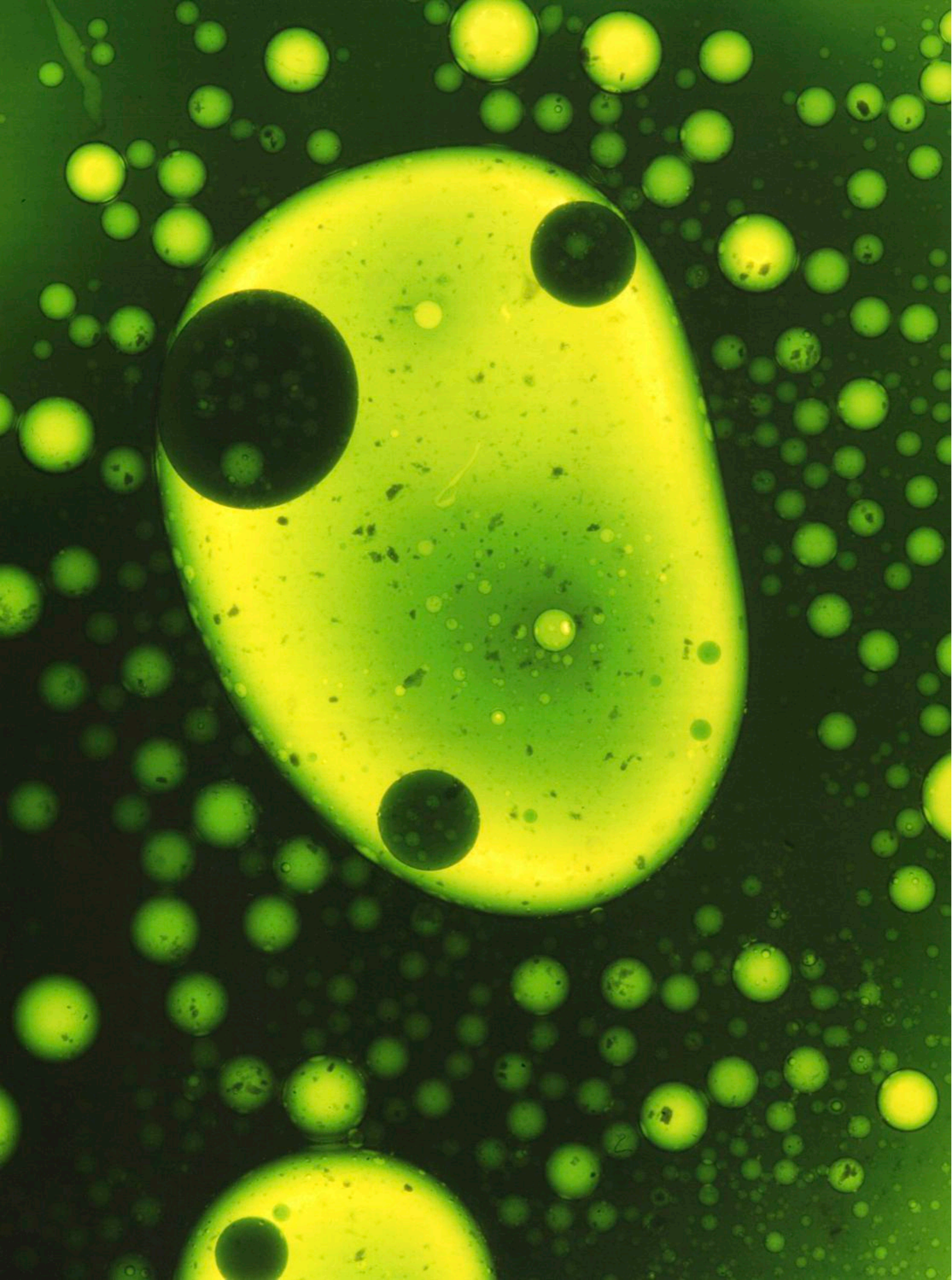
INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the setting bath:			
Water	2 kg	333%	① Whisk together.
Sodium alginate (TICA-algin 400 Powder, TIC Gums brand)	10 g	1.7%	② Vacuum seal to remove excess air, and refrigerate for 2 h.
For the egg-yolk base:			
Calcium lactate	4 g	0.7%	③ Sift together.
Sugar	3 g	0.5%	
Salt	2 g	0.3%	
Egg yolks, pasteurized see page 78	150 g	25%	④ Blend into calcium lactate mixture, taking care to incorporate as little air as possible.
			⑤ Dispense with sauce gun into 2 cm / ¾ in hemisphere molds. Freeze.
Rendered bacon fat	50 g	8.5%	⑥ Heat sodium alginate solution until fluid is 60–65 °C / 140–149 °F.
			⑦ Remove from heat, and carefully drop in frozen hemispheres.
			⑧ Leave for 2 min, turn spheres over, and leave for 1 min longer.
			⑨ Fill three bowls with water: heat two to 75–80 °C / 167–176 °F; fill the third with cold water.
			⑩ Transfer spheres with slotted spoon to first bowl of warm water to rinse for 1 min.
			⑪ Rinse spheres again in second bowl of warm water, and reserve in cold water.
For the "cooked" egg-white base:			
Gruyère water see page 2·310	600 g	100%	⑫ Mix, and bring to boil.
			⑬ Pour into sauce gun, and rest at room temperature until about 60 °C / 140 °F.
Heavy cream	100 g	16.5%	⑭ Dispense "egg" white into one half of plastic eggshell.
Iota carrageenan (Texturas brand)	4.2 g	0.7%	⑮ Place yolk sphere in center of white, and cap with top half of plastic shell.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.44 g	0.07%	⑯ Dispense remaining white into sealed shell through drilled hole until overflowing.
			⑰ Chill over ice.

(2010)

Faux hard-boiled eggs are common, but here is a faux poached egg.

15 EMULSIONS





EMULSIONS

Oil and water don't mix, as every cook knows. Less commonly known is the reason for this mutual repulsion, which is, fundamentally, electrical. Water molecules are electrically unbalanced, or **polar**: each has a slight positive charge around the oxygen atom and partial negative charges around the two hydrogen atoms. Water molecules thus tend to stick together because the negative end of one attracts the positive end of another. But oil molecules, being **nonpolar**, don't interact nearly as well with water as water mingles with itself. In fact, scientists refer to fats as being **hydrophobic**—water-fearing.

If you try to overcome this natural repulsion by stirring very hard, you will divide the oil into finer and finer droplets. But those globules won't ever truly dissolve in the water. To the naked eye, it may look as though they mix because the suspended droplets can become microscopic. If you create a milky liquid of this kind, you've made an **emulsion**.

Cooks prize emulsions for their creamy texture and often unusual flavor impact. But they can be tricky to make and to store. Emulsions are **metastable,** which means that, given enough time, they eventually separate into their component liquids. In this chapter, we explain why this happens and what you can do to bind emulsions together longer.

Under magnification, oil droplets or air bubbles suspended in a liquid look and act much like solid particles. All of these influence the water's ability to move about and thus give the mixture distinctive properties.

Oil (yellow) segregates into large, visible droplets when poorly mixed with parsley water (dark green). More forceful stirring would shrink the oil droplets to microscopic size, transforming this amalgamation into a true emulsion.

In any emulsion, two elements must always be in place: oil (or liquid fat) and water (or any water-based liquid). One of these elements plays the role of the **continuous phase** (also known as the bulk phase), which is the portion that suspends droplets of the other element, known as the **dispersed phase**.

If the continuous phase is water and the dispersed phase is oil, this is called an oil-in-water, or **O/W,** emulsion. Milk, in its natural state, is an O/W emulsion with particles of milk fat dispersed throughout the watery continuous phase. Cream and mayonnaise are also O/W emulsions.

On the flip side, butter is an example of a water-in-oil, or **W/O,** emulsion. Here an oil element (butterfat) suspends a dispersed state of the water from the original liquid cream. Some of the butterfat is solidified into tiny crystals that help stabilize the emulsion.

So far emulsions might sound relatively simple, but unfortunately they aren't. Some books about food emulsification contain hundreds of pages of equations describing how those tiny droplets keep from grouping back together. The details rapidly become intimidating to nonexperts.

Given such complexity in the theory, emulsions in the kitchen remain a largely empirical exercise. You can't always predict what's going to work best (or at all); often you just have to experiment to discover the best method. Nevertheless, we offer some guidelines that will help you achieve good results fairly consistently.

For more on the molecular properties of water, see chapter 6 on The Physics of Food and Water, page 1·292.

For more on air bubbles in liquids, see chapter 16 on Foams, page 240.

For more on how solid particles affect the behavior of liquids, see chapter 13 on Thickeners, page 2.

The technical name for a droplet in an emulsion covered with surfactant molecules is a micelle.

Although the vast majority of culinary emulsions fall into either the O/W or W/O category, there are other types, including complex double emulsions such as O/W/O and W/O/W. In these cases, droplets are nestled within droplets inside a continuous phase.

HOW EMULSIFICATION WORKS

Not only are the physics of emulsions complicated, but their chemistry is, too. Making an emulsion is only the beginning; making it stable is another story. It helps to reduce the droplets to the smallest possible size, which creates an emulsion that's relatively stable by its nature. But to make that emulsion last for a long time, you need to add an **emulsifier**, an agent that helps make—or break—an emulsion.

Beyond that simple description of what an emulsifier does, there is no single definition of what it *is*, nor is there a simple explanation that covers how all emulsifiers work. Thankfully, you don't need to know precisely why an emulsifier works in order to benefit from using it. There are a great many types of emulsifiers, and they all work in different ways. In fact, in many cases the best option may be to use multiple emulsifiers. As a general rule, mixtures of emulsifiers work better than a single emulsifier does to improve the stability of emulsions.

Because emulsifiers work in so many different ways, it's harder to lay down general principles and rules for making emulsions than it is for other aspects of culinary science. For example, HLB values and the Bancroft rule (see pages 204 and 202) apply well to simple emulsions but not to those that involve proteins, complex sugars, or starches. If you try to stabilize an emulsion such as mayonnaise by adding a thickener such as xanthan gum, often only a certain amount will do the job right; just a hair more or less, and the emulsion can actually become *less* stable. Tests are the best way to determine how a specific emulsifier will perform in a particular circumstance.

We're lucky, however, that advances in food science—driven in large part by companies that want to make shelf-stable salad dressings and mayonnaise—have eliminated much of the guesswork for us. So there are some recipes and insights that we can begin with. For instance, a general rule of thumb is that the volume of an O/W emulsifier should be about 5% of the volume of the oil phase. This rule has significant exceptions, but it is a starting point for potential functional applications.

One proven emulsifier most people already have at home is the versatile egg yolk. It serves as the emulsifier in mayonnaise and hollandaise, for example. If you've made these emulsions, you probably have an intuitive understanding of how egg yolks work to bind them, but the chemistry of how the emulsification happens is actually quite complex.

Commercial mayonnaise smeared on a glass slide and viewed through a microscope reveals oil droplets that are relatively uniform in size. This uniformity is necessary to ensure a long shelf life.

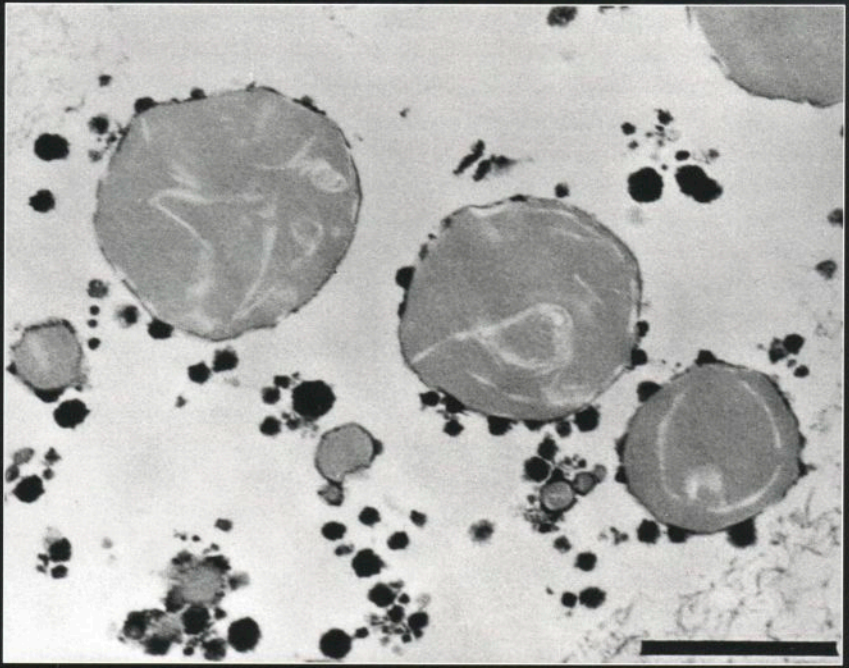
Common Emulsions

Many of the foods you see on the street every day are emulsions: hot dogs and Mountain Dew, chocolate and ice cream, mayonnaise and milk. Each of these foods contains a fat mixed with a water-based solution in such a way that the two mingle without separating.

The process of making emulsions is tricky, and historically it has been the subject of kitchen mysticism and folklore. Not long ago, teachers explained that a proper hollandaise would form only when butter dropped naturally into the sauce from the heat of a clenched hand. Mayonnaise was said to be impossible to make in a thunderstorm or under even sillier conditions.

Thankfully, modern science, tools, and ingredients have dispensed with the hocus-pocus. These days, culinary students don't have to add oil drop by drop to a sauce as they emulsify it; they simply whiz all the ingredients together with a hand blender. Mastery over the mysteries of emulsions has made many of the staple treats of modern life possible.

Food	Emulsifier or stabilizer	Note
beurre blanc	casein from butter	very fragile without an additional emulsifier
butter	casein from dairy	less fragile than beurre blanc
chocolate	lecithin and/or casein (from milk powder), sometimes polyglycerol polyricinoleate	ganache and milk chocolate include sodium caseinate, but lecithin is traditionally added to chocolate
Mountain Dew and other sodas	gum arabic	emulsifies flavor compounds in many soft drinks
espresso crema	coffee polysaccharides	lipids and colloids in coffee are forced into emulsion under pressure and stabilized by polysaccharides extracted from the coffee
frankfurter	myosin protein from meat	when overcooked, proteins denature, and emulsion breaks down
hollandaise	lecithin from egg yolk	stability depends on droplet size
ice cream	casein, egg yolk, semisolid fat droplets	complex emulsion and foam stabilized by dairy proteins, lecithin from egg yolks, and semisolid droplets of fat that trap air bubbles
mayonnaise	lecithin from egg yolk	stability depends on droplet size
milk and cream	casein	homogenization reduces particle size
vinaigrette	polysaccharides and proteins from mustard	fragile



The intricate structure of cream is apparent in this image made by using a transmission electron microscope. The large, medium-gray blobs are droplets of butterfat. White lines inside some butterfat droplets show those that have crystallized. The small black dots surrounding the butterfat droplets are complexes of milk protein molecules. The background is the water phase of cream, which is essentially the same as skim milk.

Photo by Douglas Goff, University of Guelph

Cow's milk is "white" owing to light scattering, but it also has a yellowish tone contributed by the butterfat. This hue comes from carotenoid compounds (such as those that give carrots their color) in the feedstock eaten by the cow; these compounds are then retained in the butterfat.

Goat's milk and products like the cheese and the butter made from it are much whiter than cow's milk. The principle reason is that goats metabolize carotenoids better than cows do, so goat's milk butterfat is clear or nearly so. A second contributing factor is that the fat droplets or globules in goat's milk are much smaller, which causes more light scattering.

Broader and more modern uses often rely on **surfactants**, an important class of emulsifiers that influence the stability of an emulsion by stabilizing the individual droplets in suspension.

Surfactants (a contraction of "surface active agents") are molecules that act as an interface between oil and water. They are typically somewhat long molecules in which one end is **hydrophilic** (it "likes" water, as polar molecules do) and the other end is hydrophobic (it "fears" water, as oil molecules do). As a result, surfactant molecules tend to line themselves up at the edge of a droplet so that one end of the molecule interacts with the water and the other end with the oil, effectively knitting them together and stabilizing the emulsion.

One of the most common types of surfactants is soap or detergent. Soap makes things clean through the process of emulsification. When you have a cooking apron spotted with grease, for example, laundry detergent attacks the grease and emulsifies it with the water, creating an emulsion that is then drained away. In fact, some surfactants taste soapy because they are actually soaps; the same properties that allow them to wash away grease interact in our mouths to leave a soapy taste. Not all surfactants have this characteristic, but it's important to be careful about the type and amount used to avoid this problem.

Another class of emulsifiers is milk proteins, primarily caseins, which act at the junction of water and oil to help stabilize the dispersion of one in the other. Caseins affect the surface of the dispersed droplet, making that surface layer thicker and more stable within the continuous phase of the emulsion. In a sense, caseins could be called surfactants because they act at the surface, but most experts classify them separately.

A very different way to influence the stability of an emulsion is to give the continuous phase greater viscosity by adding a thickener. This adds stability by making it harder for the droplets of the dispersed phase to move. In general terms, you can influence the effectiveness of an emulsifier by

THE SCIENCE OF

Bancroft's Rule

What makes some mixtures O/W emulsions and others W/O? You might think the ratio of oil to water is the determining factor, but that isn't the case. Milk, an O/W emulsion, is only about 3.25% oil (milk fat) by weight. Heavy whipping cream is a very similar O/W emulsion, but it contains about 36% oil. Mayonnaise is typically more than 80% oil, yet it, too, is an O/W emulsion. But then there is butter, which is at least 80% oil. What makes butter a W/O emulsion and mayonnaise an O/W?

Bancroft's rule gives us part of the answer. First proposed by chemist Wilder Dwight Bancroft in 1913, the rule states that the nature of an emulsion is primarily determined by whether its emulsifier is more soluble in oil or in water.

Most surfactant emulsifiers are soluble in both oil and water, but to different degrees. Bancroft argued that if you want to make an O/W emulsion, you should start with an emulsifier that is more soluble in water than in oil. Conversely, when making W/O emulsions, use emulsifiers that are more soluble in oil than in water. Since Bancroft developed this rule, it has been systematized to yield HLB values (see page 204)—numbers that describe the relative solubility of a given surfactant in oil and in water.

Bancroft's rule also suggests the order for mixing the ingredients—first, mix the emulsifier into the bulk phase; the emulsifier is more soluble in that component. Once those two are mixed, add the dispersed phase while blending. This method is the way a traditional mayonnaise is made—lemon juice (the bulk phase) is mixed with egg yolk (lecithin is the primary emulsifier here), which is soluble in water. Then oil is beaten in slowly. Even if we reversed that order, we would tend to wind up with the same end result. But Bancroft's rule tells us that it usually works better to mix in the order of solubility.

Unfortunately, this is "Bancroft's rule" rather than "Bancroft's law" for a reason: it is a general rule of thumb that doesn't always hold true, and it can be overridden by a number of factors. Because the solubility of many emulsifiers depends on temperature, Bancroft's rule does too—as well as on other variables, such as the presence of dissolved salt, sugars, or proteins, all of which can occur in food emulsions.

THE PHYSICS OF

The Optics of Emulsions

Think of all the emulsion examples we've discussed or that you've made in the past, and consider what they look like. With the exception of microemulsions (see page 205), all emulsions are opaque because of their fundamental nature as a mixture of water and oil. This opacity is particularly interesting because, separately, the water and oil elements may be clear before the emulsion is made. When you melt butter, for example, and separate the butterfat, the result is clear even though unmelted butter is opaque. So why is milk white and cream whiter?

It has to do with something called an **index of refraction.** Light is scattered whenever it crosses the interface between substances that have different indices of refraction. It is similar to the visual effect of a spoon in a glass of water; the spoon can look broken because water has a different index of refraction than air, and at the interface, the light is bent, and it distorts the image of the spoon.

It sounds a bit surprising at first, but if you pass light through a large enough number of clear objects, the resultant scattering makes the collection of clear objects look white.

This phenomenon explains why fog and clouds are white, even though the water in the suspended droplets is clear and the air itself is clear. Light is bent at the point of interface between the droplets, and this deflection happens millions of times across a large area of cloud or fog. A glass of water still looks clear because you only have one glass in front of you, so you can see how the light bent by the glass distorts the spoon, and things behind the glass. If you placed thousands of glasses of water on a table and stepped back, you would see that the bending of light through the glasses scatters the light so much your eye couldn't trace all of the bending as light passes through one glass after another. Physicists call this process **Mie scattering.** When the scattering objects are large compared with the size of the wavelength of light, Mie scattering makes the collection of scattering particles appear opaque white.

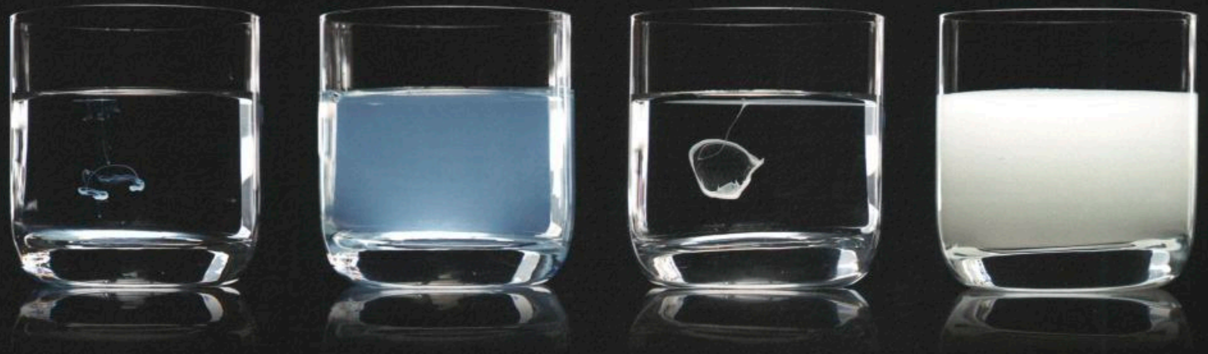
You can see this effect in glass beads or marbles. Pick up an individual bead, and you can see that it is clear. But a bucketful of them looks white. The same thing occurs for salt and sugar—the individual salt crystals or sugar crystals are clear, but a pile of them Mie scatters to white.

In emulsions; the individual droplets similarly create Mie scattering and thus a milky or opaque look. Emulsions aren't always white because the oil and water phases are not perfectly clear—many oils have a yellow cast, and the water phase often includes ingredients that are colored. Microemulsions are not milky because their droplets are too small and too few to scatter much light.

By way of a very simple experiment, you can see the difference in Mie scattering relative to the size of particles in the emulsion. Start with two glasses or beakers of water. Into one, add some nonfat milk. Into the other, add the same volume of heavy cream. In the first glass, even after just a few drops of milk have been added, the water begins to take on a bluish cast. When cream is added to the second glass, however, the liquid turns a milky white.

Cream contains a much higher concentration of fat droplets, which scatter all frequencies of light in the same way, hence the very white appearance. Nonfat milk, in contrast, has had virtually all of its fat droplets removed, leaving a dilute continuous phase that contains milk proteins and other particles that refract the light to some degree, but only enough to make it appear bluish rather than white. The bluish cast occurs because of another type of scattering, called Rayleigh scattering (also known as the **Tyndall effect**). When the scattering particles are so small that they become comparable in size to the wavelengths of visible light, and they then scatter some colors preferentially. This effect makes nonfat milk bluish because the milk protein particles are very small. It is also why the sky is blue.

Nonfat milk is, essentially, the continuous phase of cream. If you added butterfat and emulsified the two, you'd return the milk to its creamy, emulsified state and distinct white color.



THE CHEMISTRY OF

HLB Values

Surfactant molecules have a hydrophilic (water-loving, polar) portion and a **lipophilic** (oil-loving, aka hydrophobic or water-loathing, nonpolar) portion. The ratio of the masses of these two portions is called the **hydrophilic-lipophilic balance, or HLB.** It is a numeric value from 0 to 20 that helps classify what a surfactant does. When Bancroft's rule holds, the HLB helps us pick the emulsifier (surfactant) necessary to create different types of emulsions.

The HLB isn't perfect in this regard because surfactant chemistry varies greatly with temperature, the ionic charge of the surfactant, the presence of complex molecules like sugars or proteins, and various other factors. These nuances aren't captured in the HLB, which reflects only the masses of each portion of the surfactant molecule. Nevertheless, it is a useful measure.

Many emulsifiers can be modified to create different HLB values. Soy lecithin has an HLB value of 8.0, but modified lecithins can take a wide range of values. Mono- and diglycerides can have HLB values ranging from 1-10. Like hydrocolloids and other high-tech food ingredients, emulsifiers made by different manufacturers have different trade names and formulas.

Surfactant Type	HLB Range	Example
antifoaming agent	0-3	oleic acid (1.0)
W/O emulsifier	4-6	mono- and diglycerides sorbitan monostearate (4.7)
wetting agent	7-9	sorbitan monolaurate/Span 20 (8.6)
O/W emulsifier	8-18	soy lecithin (8.0) polysorbate 60/Tween 60 (14.9) sucrose monolaurate (15.0)
detergents	13-15	Octoxynol-9
solubilizer/hydrotrope	10-18	sodium xylene sulfonate

Instead of reducing a sauce with cream, you could simply add butterfat to the sauce. This is exactly what happens with a beurre blanc or other sauces finished with butter. If the butterfat is added without an emulsifier, the sauce tends to be unstable. One can remedy this by adding an emulsifier (see page 219). This addition isn't necessary with cream because it is effectively a combination of emulsifier (milk proteins) and fat that come together.

taking care to combine the emulsifier, oil phase, and water phase in the proper order while using the right equipment to make small droplets.

A very different approach to stability is to add a weighting agent. Part of what makes mixing oil and water so challenging is not only their polar differences but also their differences in density. Water, the heavier molecule, will always want to push oil, the lighter molecule, to the surface. But if you add an oil-soluble weighting agent, such as brominated vegetable oil, to the oil to make it heavier, you can temper its natural tendency to float to the top. The technique really only works in that direction (making oil heavier); attempting to make the water lighter and more compatible with oil would be a much tougher task.

Viscosity and Emulsions

They say that blood is thicker than water. And it is—it has about three times the **viscosity** of water, in large part because blood is a colloidal suspension of many blood cells. The mechanical properties of those blood cells as they flow past each other give blood its viscosity. The same thing happens in emulsions, which typically have a higher viscosity than the oil and the water they are made of.

The classic example is mayonnaise. Its continuous phase—such as lemon juice—has roughly the viscosity of water. As you begin dispersing oil into that liquid phase, the viscosity starts to change. The more oil you add, the thicker the emulsion becomes. A mayonnaise can be made so thick that a knife will stand upright in it. The resulting emulsion is much thicker than either the continuous phase or the dispersed phase alone. In fact, most emulsions are non-Newtonian, **shear-thinning fluids** (see page 5). At a high viscosity with low shear forces, emulsions appear solid. Give them a foreceful push, and they begin to flow.

Cream is another example of an emulsion in which droplet interactions cause thickening. It is clearly thicker than milk because of the mechanical properties of the droplets of fat that are suspended within the continuous phase of the cream. Just as mayonnaise becomes thicker with more oil in it, milk with more butterfat (i.e., cream) also becomes thicker.

This effect can be used to thicken other liquids. A common technique is to add cream to a liquid and then boil the mixture to reduce it to a thickened sauce. The thickening is caused by the emulsified butterfat in the cream. As the water evaporates away during reduction, the fat in the cream remains. The concentration of fat droplets increases, and so does the emulsion's viscosity. *Voilà*, a thickened sauce with luxurious mouthfeel.

In most cooking emulsions, the ratio of the dispersed phase to the continuous phase is nowhere near the maximum possible. You can start with one tablespoon of water or lemon juice and a teaspoon of egg yolk and create an enormous amount of mayonnaise if you keep adding oil; to a large extent, it's up to you when you stop. Eventually, however, if you add enough oil, there will not be enough lecithin from the egg yolk left to stabilize the emulsion, and if the temperature and other conditions are right, your emulsion will break—or could even undergo phase inversion and turn from O/W to W/O.

Because of the high proportion of oil in traditional mayonnaise, low-fat mayonnaise might seem unlikely. But it's actually easily made by adding thickeners such as xanthan gum. A small amount of oil establishes a thin base emulsion, which is then thickened to the traditional texture of mayonnaise. If you add an appropriate thickener to the continuous phase before you start emulsifying, you can produce a flavorful mayonnaise by using much less oil than usual.

Thickening a sauce via emulsification tends to produce a very high-calorie result because you need a high ratio of oil to thicken an O/W emulsion. It also produces a dominant oil taste. This is desirable in some contexts, but modern thickeners let you control thickness without using as much oil.

For more on Nouvelle cuisine, see page 1·24.

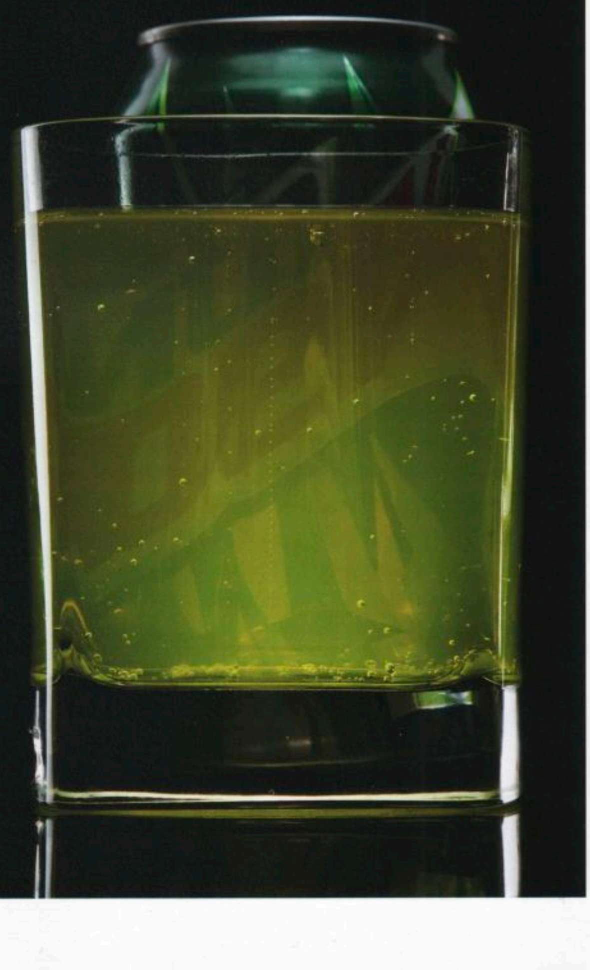
THE SCIENCE OF

Microemulsions and Nanoemulsions

Most food emulsions are technically macroemulsions, which means that they have droplet sizes ranging from 0.1 to 100 microns (µm). Because they are thermodynamically unstable, these emulsions will eventually separate. But if they are properly made, that is a moot point because they can remain stable long enough to be served. Indeed, well-made emulsions can be stable as long as you want keep them in that form.

Macroemulsions are optically opaque or turbid (see page 203). If the droplet size becomes small enough, however—typically 20–100 nanometers (nm) / 0.02–0.1 µm—then the emulsion can be transparent, a so-called nanoemulsion. Familiar examples include Mountain Dew and other soft drinks. These drinks have flavor oils suspended in a nanoemulsion with the help of emulsifiers such as gum arabic. Although nanoemulsions are thermodynamically unstable, they can last long enough to do their job.

A third category is microemulsions, which have droplet sizes of 5–50 nm (0.005–0.05 µm). They are also transparent, but they are thermodynamically stable. Microemulsions form spontaneously under certain conditions. They are not common in food applications, although microemulsions are used to encapsulate oil-soluble vitamins in some nutritional food products.



METHODS OF EMULSIFYING

No emulsion will ever have a perfectly uniform droplet size; some droplets will be smaller and some will be larger, following some statistical distribution. The droplet sizes we mention refer to the average diameter.

For more on rotor-stator homogenizers, see page (2·420). Ultrasonic homogenizers are discussed in more detail on page (2·415), and high-pressure homogenizers on page (2·422).

To prevent overheating an emulsion with friction, start with very cold ingredients, or add some of the water phase as ice. You can also process the emulsion in bursts and allow the mixture to cool before the next burst.

To make an emulsion, you almost always have to apply mechanical force to break the dispersed phase into small droplets that become suspended within the continuous phase. It can take a surprising amount of force to make this happen.

There are two stages of emulsification. The first stage, when you first disperse oil in water (or vice versa) to homogenize the two, is called a **primary emulsion**. In this stage the droplets are fairly coarse. The next stage, when an existing emulsion is beaten to further decrease the size of the dispersed droplets, is called a **secondary emulsion**. Every rule about emulsions has its exceptions, but, if you have enough emulsifier, generally the smaller you make the droplets, the more stable the emulsion becomes, and the longer it lasts.

A primary emulsion can be made with a whisk, but you'll have pretty large droplets that won't hold up very long. That is just fine for à la minute preparations, but to make a longer-lasting secondary emulsion, you'll need a lot more energy behind the effort.

A typical blender creates an emulsion with droplets as small as about 10 microns / 0.0004 in. It will feel smooth and less greasy on your tongue and be perfectly acceptable for many cooking purposes. A food processor is another common tool for emulsifying, although it produces slightly coarser emulsions than a blender does because the food processor has larger blades and a slower rotation speed. A hand or immersion blender is roughly as effective for emulsifying as a classic blender is.

Producing finer emulsions requires moving beyond standard kitchen tools to specialized implements. A rotor-stator homogenizer (see page 2·420) is more effective than a blender in part because it has two blades—one stationary (the stator) and one spinning (the rotor). These precision blades travel very close to each other, as close as 25 microns / 0.001 in apart, generating powerful shear forces. A rotor-stator homogenizer reduces most emulsion droplets to a diameter of three microns. The countertop variety is just as convenient to use as a blender; you can start with oil and water to create a primary emulsion, and then go all the way to a secondary emulsion in one sequence. To produce the finest droplets, however, you may need to process the mixture for several minutes or more.

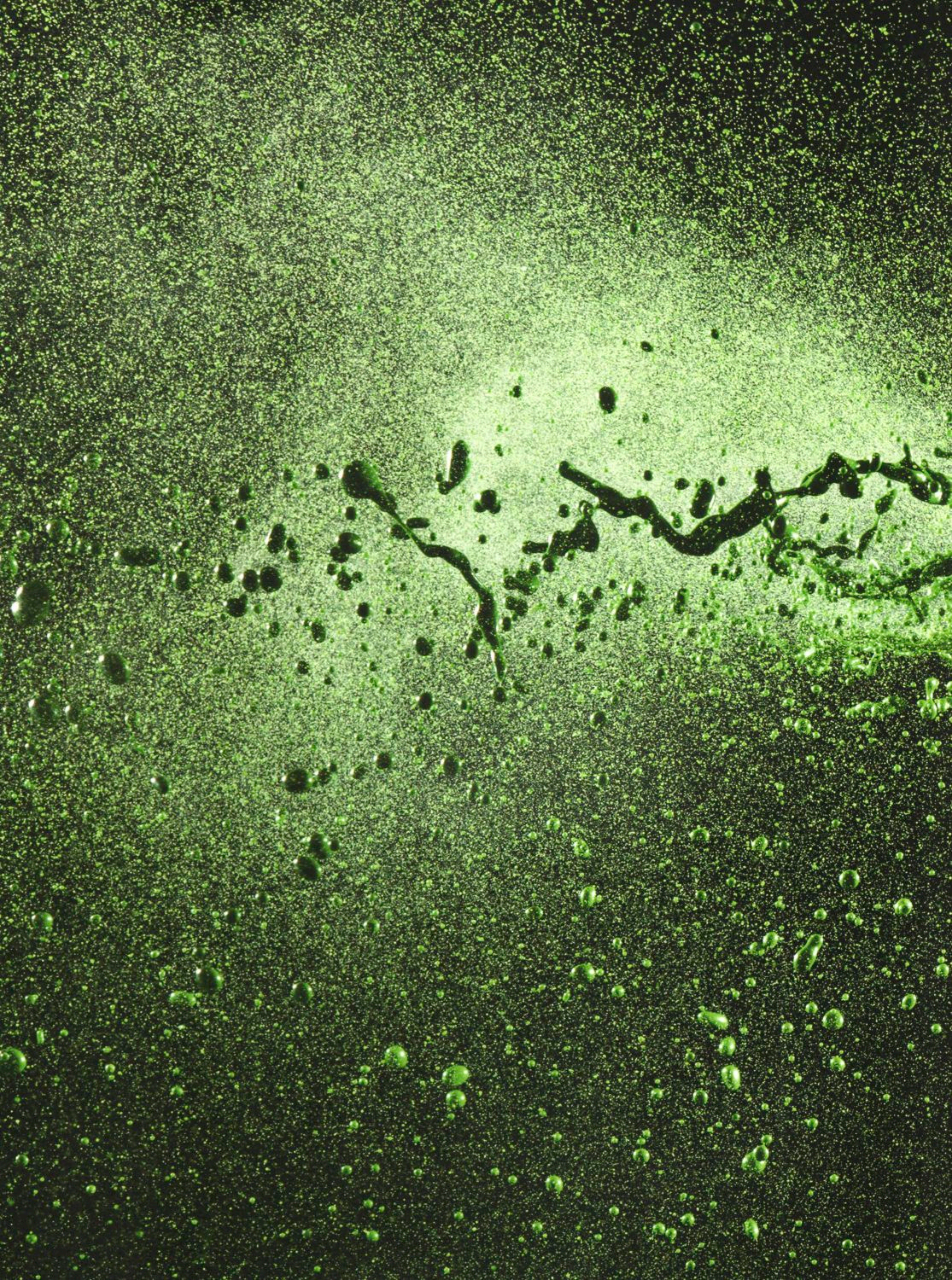
Be careful not to let the emulsion get too warm. The mechanical energy used to break up the droplets also produces friction—and thus heat. It can be all too easy to overheat the ingredients, leading to a broken or overcooked emulsion.

Another tool that can create a very fine emulsion is an ultrasonic homogenizer, which produces mechanical vibrations and transmits them into a liquid via a probe. The vibrations create millions of microscopic bubbles in the liquid. You can use an ultrasonic homogenizer to make a primary emulsion, but the tool really excels at applying extra force to an existing emulsion in order to create a secondary emulsion. With an ultrasonic homogenizer, overheating is a greater risk. In addition, the part of the mixture that gets the most force is near the end of the probe, so you need to stir to make sure all parts of the mixture are evenly emulsified.

The ultimate tool for making an emulsion is a high-pressure homogenizer. It uses very high pressure to create the finest possible emulsions, having droplets that average less than 0.1 micron in diameter. An emulsion processed in a high-pressure homogenizer is finer, smoother, and richer than an emulsion made almost any other way, and you can run an emulsion through the tool multiple times to reduce droplet sizes further. In practice, a high-pressure homogenizer can be used only for secondary emulsions.

Cream becomes butter through a process called phase inversion. With right amount of mechanical agitation and at a suitable temperature, an O/W emulsion (in this case, cream) can flip and become a W/O emulsion (butter). This transformation is one of the rare examples of phase inversion in traditional cooking, but controlled phase inversion is used in some advanced processes for making emulsions.

Even more complicated processes are used for making the double emulsions W/O/W or O/W/O. These are used in the cosmetics industry but, so far, not for food.



TOOLS FOR MAKING EMULSIONS

The whisk was probably a mind-blowing invention when it first became available to household kitchens. Imagine what an improvement it offered over wooden paddles and spoons. The egg beater was another technological step up, and then motorized blenders and food processors came along and revolutionized cooking again. Interestingly, none of these tools completely replaced its predecessors: all still do an adequate job of dispersing and suspending droplets of oil and water. They all can create emulsions, in other words. But they aren't all equally efficient.

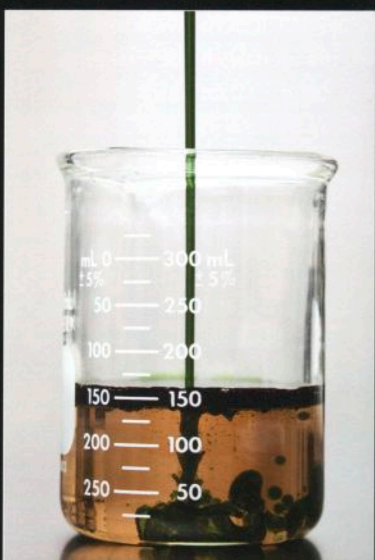
We predict that the next must-have mixer will be the countertop rotor-stator homogenizer—our favorite tool for making fine emulsions. These gadgets produce consistent, refined, ultrastable, and fast results when used for nearly any emulsifying task. Even higher-tech than the rotor-stator homogenizer are tools such as high-pressure homogenizers and ultrasonic homogenizers. These devices create amazingly stable blends, but they are best used to refine existing emulsions. Unless you have a high-volume use for them, it may be difficult to justify their steep cost.

Equipment	Power	Example uses	Note
handheld whisk	low	light mayonnaise, vinaigrette	readily available; produces large droplets, so emulsions are not stable; best for quick and cold emulsions for immediate use
electric whisk	medium	light mayonnaise, vinaigrette	faster than a handheld whisk
hand blender	medium	beurre blanc, hollandaise	sufficient for everyday use; best with small quantities; can be used over heat source
household blender	medium	mayonnaise, vinaigrette	sufficient for everyday use
commercial blender	high	mayonnaise, vinaigrette	handles larger quantities better than household blenders
rotor-stator homogenizer	very high	restructured cream, complex oil emulsion, ultrastable beurre blanc, microemulsion	forms extremely stable emulsions; best bet for all fine emulsions
ultrasonic homogenizer	very high	ultrastable mayonnaise, ultrastable vinaigrette	best for secondary emulsion when long-term stability is needed
high-pressure homogenizer	extremely high	ultrastable ice cream, restructured cream	best for secondary emulsion when long-term stability is needed

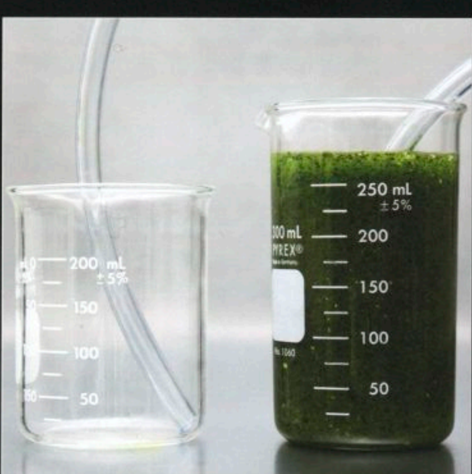
A simple whisk is an easy way to make an emulsion, but it produces a relatively coarse droplet size. This coarseness is reflected in the fairly dark color: because the droplets are large, there are fewer of them, and they don't scatter the light as much as they would if they were smaller (see page 203).

Look at the color of the emulsions on these two pages. They all have the same ratio of ingredients; the color is whiter for some only because the droplet size is smaller and thus better at scattering light. Bubble size has a similar effect in foams (see page 262).

A hand blender is a better tool for making emulsions than a whisk. Compared with a hand whisk, it produces a finer droplet size, which causes the emulsion to last longer before breaking.



A rotor-stator homogenizer is an even better tool for making an emulsion than a hand blender. It produces smaller droplets, and the emulsion it produces looks a bit whiter as a result.



The ultimate emulsifying tool is the high-pressure homogenizer, which makes an emulsion that is almost white.

How Emulsions Fail

An emulsion—even a superfine one made in a high-pressure homogenizer—is never completely stable. Given half a chance and enough time, every emulsion will separate. Sometimes it doesn't take much, as you know if you've ever had trouble keeping a mayonnaise together.

Emulsions can fail in a number of characteristic ways. We list them here not only for your general edification but also so that you can get a flavor of the sheer complexity of emulsion science.

The first and most common problem is **creaming**, the same phenomenon that drives cream to the top of raw milk. The oil phase has a lower density than the water phase, so it tends to float on the surface. Creaming happens only in O/W emulsions.

In W/O emulsions, the equivalent of creaming is **sedimentation.** In this case the dispersed phase is water, and when those droplets fail to remain suspended in the emulsion, they sink to the bottom (because they are heavier than oil) rather than rising to the top. They create a sediment of liquid.

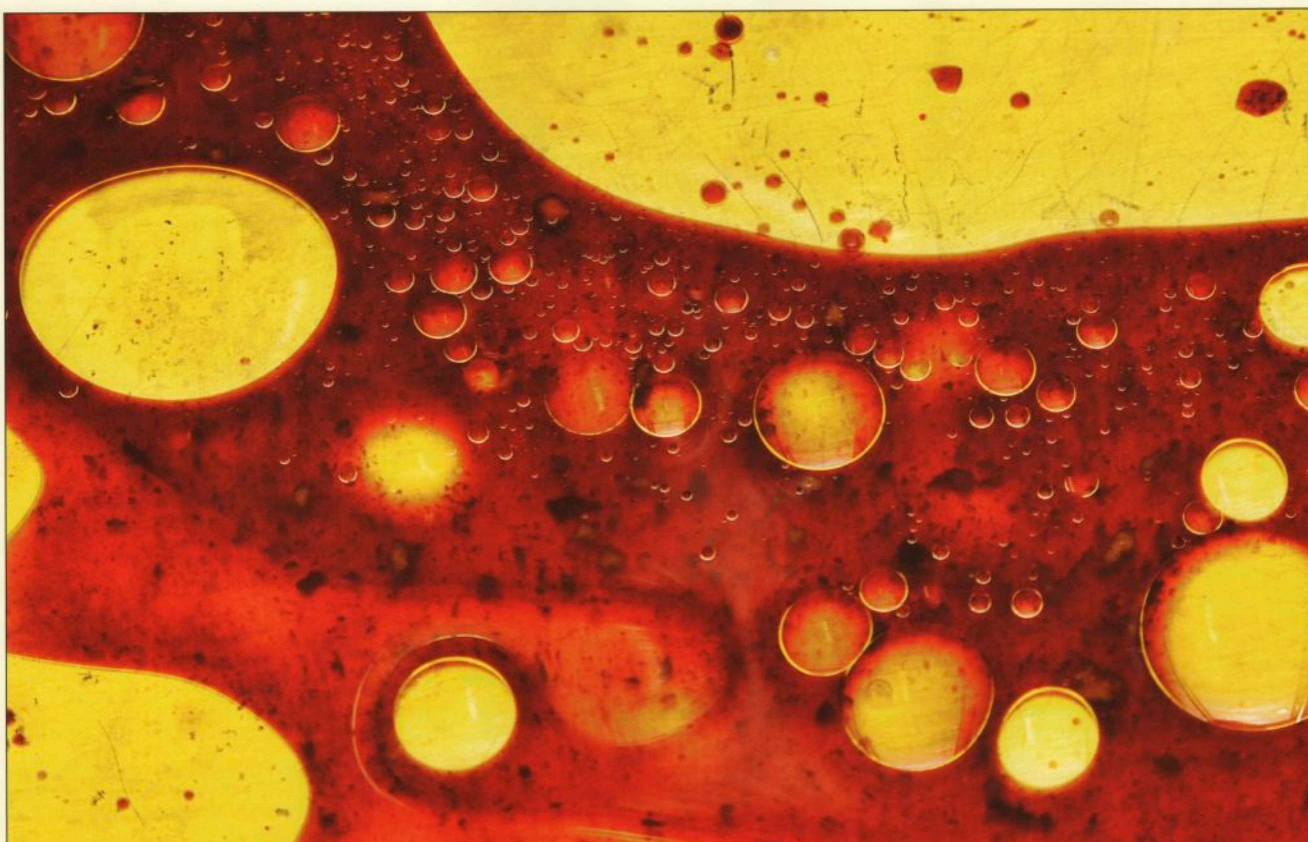
Sometimes we want to break an emulsion to separate the oil and the water. A **centrifuge** (see page 2·392) can accelerate creaming and sedimentation by magnifying the force of gravity by thousands of times.

Flocculation occurs when clumps of droplets stick together. They may cohere because they have a small electrostatic charge, or engage in chemical reactions, or experience excessive heating. Once some of the droplets clump together, the clumps move about the continuous phase, remaining separate from each other. In this state, the droplets are at greater risk of creaming. These clusters of droplets are called flocculation complexes, and they can form complicated fractal structures.

Coalescence occurs when droplets meld to become larger droplets. As we've mentioned before, smaller droplets mean a more stable emulsion. So as coalescence occurs and droplet size grows, so does the likelihood that the emulsion will break.

Flocculation and coalescence are closely related. Theories about how they work are complicated, and far more detailed than we need to go into here.

Emulsions fail in a variety of ways, but the result is the same—the phases are almost completely separated into very large droplets.



THE SCIENCE OF

The Ouzo/Pastis Effect

Many liqueurs are O/W microemulsions in which tiny oil droplets contain the liqueur's characteristic flavor. This is the case for anise-flavored liqueurs such as French pastis and absinthe, Greek ouzo, and Turkish raki. They contain a flavored oil called trans-anethole, which is found in many natural essential oils, including anise, fennel, and star anise.

In the bottle these are all clear, transparent liquids, but when water is added they suddenly turn white, almost like milk. This transformation is often called the "ouzo effect" or the "pastis effect," depending on which liqueur is being used.

The reason is **Ostwald ripening** (see next page). In the bottle, a dynamic balance maintains the droplets of essential oil in a microemulsion. Alcohol in the dispersed phase dissolves some of the flavor oil, but it redeposits at the same rate at which it dissolves, so the size distribution of droplets does not change. This balance keeps the liqueur clear and stable on the shelf.

Added water disrupts that balance, causing smaller droplets to lose oil and larger ones to gain it. This shift rapidly produces fine droplets that are 1–1.5 microns / 0.0004–0.0006 in across and make the mixture as opaque as milk. Normally an unstable emulsion keeps breaking until all the oil is separated, but not in this case. Amazingly, the emulsion stops breaking at a droplet size of 1.5 micron, and it can remain in that state for months.

Clever experiments have proved that the droplets grow by Ostwald ripening rather than by coalescence or other mechanisms. What isn't understood is why high levels of alcohol, such as in liqueurs, create small, stable droplets but lower levels of alcohol (diluted with water in the glass) do not. It turns out that there are still some mysteries lurking in a glass of pastis.

Water

Pastis poured in

The emulsion turns white in just a few moments

Don't toss out the browned milk solids left over from making clarified butter. They are especially flavorful. Aki Kamozawa and H. Alexander Talbot from Ideas in Food collect the milk solids from browned butter, add a bit of agave nectar and water, and blend the mixture into a smooth, nutty puree. This puree gives a bold, complex flavor to almost any dish that benefits from butter.

The bottom line is that both processes cause droplets within an emulsion to enlarge, thereby leading it to become more unstable.

One of most interesting ways in which an emulsion can fail is through **Ostwald ripening**. This problem is rare in cooking applications, except in cream liqueurs, in ouzo and similar anise-based liqueurs, or in other contexts in which the continuous phase of a microemulsion contains alcohol. Alcohol can dissolve into both oil- and water-based substances, which can disrupt the stability of an emulsion: the alcohol constantly dissolves small amounts of oil from the surface of the droplets, and it also constantly deposits oil on the surface. The dissolving and deposition occur with tiny fluctuations in the local concentration or small variations in the solubility.

This process of dissolving and depositing has a twist: it tends to steal more oil from small droplets than big ones. So the big droplets grow at the expense of the small ones; in effect, the rich get richer. As this process continues, it can ultimately lead to just one big droplet; i.e., the oil and the water have fully separated.

Although each of these mechanisms of emulsion failure can occur by itself, they usually happen together to one degree or another. Each one drives the other, leading to a failed emulsion.

Failure can have an upside, however. There are times when you want to break an emulsion. One example is when you are making nonfat milk, an O/W emulsion that must be broken to remove the milk fat. Another is when you are making a stock, which can be cloudy because of fat dispersed within the liquid base. Pulling away the fat to clarify the stock requires breaking the emulsion. As a general rule, most food emulsions break if heated above 70 °C / 158 °F, although there are many interesting exceptions. Techniques like centrifugation make creaming or sedimentation happen faster, and certain kinds of filtration separate the phases.

Oil resting on water, when fully emulsified with a rotor-stator homogenizer, turns creamy and thick enough to hold up a spoon.

HOW TO Make Clarified and Brown Butter

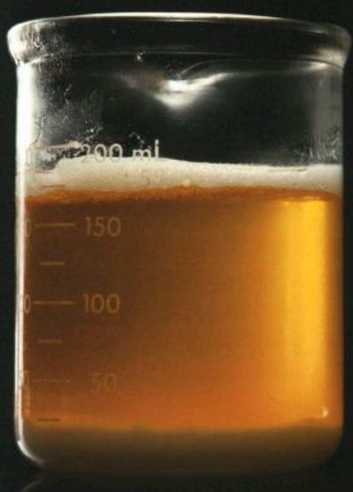
We have discussed in detail how to make and maintain stable emulsions. Clarified butter (called ghee in Indian cuisine) is an example of intentionally breaking an emulsion. Butter that is gently warmed can remain an emulsion, but when it is fully heated, the water and oil components separate. Clarified butter is pure butterfat separated from the water and milk proteins in butter.

Clarified butter is valued because it can tolerate higher temperatures without burning. It stores better because there are no milk proteins in it to go rancid. The flavor of clarified butter can be altered by cooking the milk solids either very little or until they become the dark, nutty brown/black of *beurre noisette* and *beurre noir*.

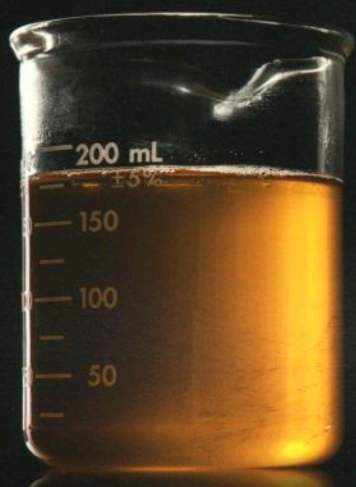
1 **Slowly melt unsalted butter in a saucepan over gentle heat.**

2 **When the butter starts to bubble, the emulsion is broken.** Set the pan aside to let the layers settle, or continue cooking to reach flavor you want.

3a **To make clarified butter, spoon off the froth on the top, and then filter through a very fine sieve or through cheesecloth placed on a coarse sieve.** Refrigerate for later use.

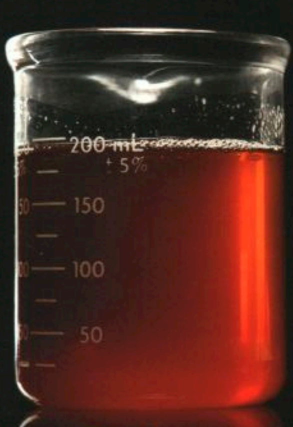


Broken butter



Clarified butter

Brown butter



Black butter

3b **To make ghee, continue to warm the melted butter over low heat for 45 min.** Milk proteins will solidify, and the flavor will be more mature from oxidation, but the butter will not brown. Sieve the ghee immediately, or let it rest overnight to develop more flavor.

Adding nonfat milk powder increases the amount of milk solids, which in turn creates more flavor in brown or black butter. We first saw this technique mentioned on the web site IdeasinFood.com.

3c **Brown butter (*beurre noisette*) and black butter (*beurre noir*) are traditionally made by continuing to heat the butter in a pan until the solids brown and darken but do not scorch. We prefer to stir 30% nonfat dry milk powder into the melted butter (i.e., 30 g milk powder for every 100 g of butter). Heat ing the mixture in a pan works best for black butter. To make brown butter, we put the mixture in a mason jar, place the jar in a pressure cooker filled with 1 cm / ½ in of water, and pressure-cook for 30 min. After cooking, filter the butter through a fine sieve to remove the solids (see previous page).**

MODERNIST EMULSIONS

Emulsions have been around for hundreds of years; what can a Modernist cook add to the arena?

Stability, for one thing. By using the appropriate emulsifiers and thickeners, you can create classic emulsions that have much greater staying power than they would otherwise. Beurre blanc can be a terrifying prospect for a cook who hasn't made it before—the sauce is notorious for separating easily and is a very fragile emulsion that's always right on edge of stability. With the right emulsifier, however, you can make an indestructible beurre blanc (see page 219) that has all the traditional, delicious properties, with the added benefit of being unbreakable. Similar things can be done to add stability to a wide range of other culinary emulsions.

A more exciting Modernist application of emulsifiers is to create emulsions that wouldn't otherwise exist. Constructed creams are perhaps our favorites. Because cream is simply an emulsion of fat in water, stabilized with casein and the other natural emulsifiers found in milk, why not mimic nature by taking any arbitrary fat and any arbitrary liquid and making a "cream?"

Our first constructed cream was pistachio cream for gelato (see page 236). We first ground pistachios to a superfine texture and separated the pistachio oil from the solids. We then made an O/W emulsion by mixing this pistachio oil with water and an emulsifier, thus creating a pistachio "cream" that had no dairy content whatsoever (and, depending on the emulsifiers used, was also vegan). The gelato made from this constructed cream offers pure and unadulterated pistachio flavor, but a traditional dairy-based gelato with eggs and other ingredients can mute the nut's essence.

Since that first tasty experiment, we have developed a whole variety of constructed creams (see page 236). Thanks to emulsification, you can create products that you couldn't make any other way. The process is particularly beneficial for ingredients (like pistachios) that have mild, nuanced flavors, but you can make a constructed cream out of almost any oil. We've even made a constructed cream based on veal fat (see page 5·33), which makes a lovely "cream" sauce to serve with a nice cut of veal. Not only is it delicious, but it might also be the world's first example of kosher veal in "cream" sauce.

A wide variety of surfactants and stabilizers make it easier to produce stable emulsions. Although the names are daunting, most of them are no more and no less processed than salt, baking soda, and other more common ingredients (see page 216).

Emulsion Stabilizers

Ever wonder how making low-fat mayonnaise is possible? After all, mayonnaise is an emulsion of fat and water—so if you remove much of the fat, why doesn't it separate or at least lose the distinctive mayonnaise texture? The answer lies in a set of thickening and gelling agents that make liquids thick or sticky. In such a viscous liquid, suspended droplets have a hard time moving around and getting together in one spot.

Because they tend to stay put longer, the emulsion remains stable. The agents listed below can be powerful stabilizers, but they aren't foolproof; we give concentration ranges and applications in which they tend to work consistently. Some of these ingredients are hydrocolloids. For more information about them, see Hydrocolloid Properties and Uses, page 42, and Hydrocolloid Interactions, page 44.

Ingredient	Typical concentration (scaling %)*	Applications		Example use	Notes	See page
		Hot	Cold			
agar	0.1–1.0	✓	✓	olive oil margarine	good for both low- and high-viscosity emulsions	235
carrageenans	0.05–1.00	✓	✓	American cheese slice	best in cold dairy applications	224
gelatin	0.2–2.0		✓	butter chantilly		281
gellan gums	0.01–0.06	✓	✓	beef suet mousseline	best in nonacidic solutions; good texture even for high-viscosity emulsions	5·8
glucose syrup DE 40	2–10		✓	bacon jam	sweetness is mildly perceptible; has some effect when warm or hot, but best in cold applications	229
guar gum	0.1–0.6	✓	✓	hazelnut cream	texture can be unpleasant at high concentrations	236
pregelatinized starch	1–5	✓	✓	olive oil margarine	texture can be unpleasant at high concentrations	235
sodium alginate	0.1–0.5	✓	✓	emulsified sausage	best in dairy applications; flavor can be unpleasant at high concentrations	3·248
xanthan gum	0.1–0.5	✓	✓	basic mayonnaise	best thickening agent overall, but texture can be unpleasant at high concentrations	226

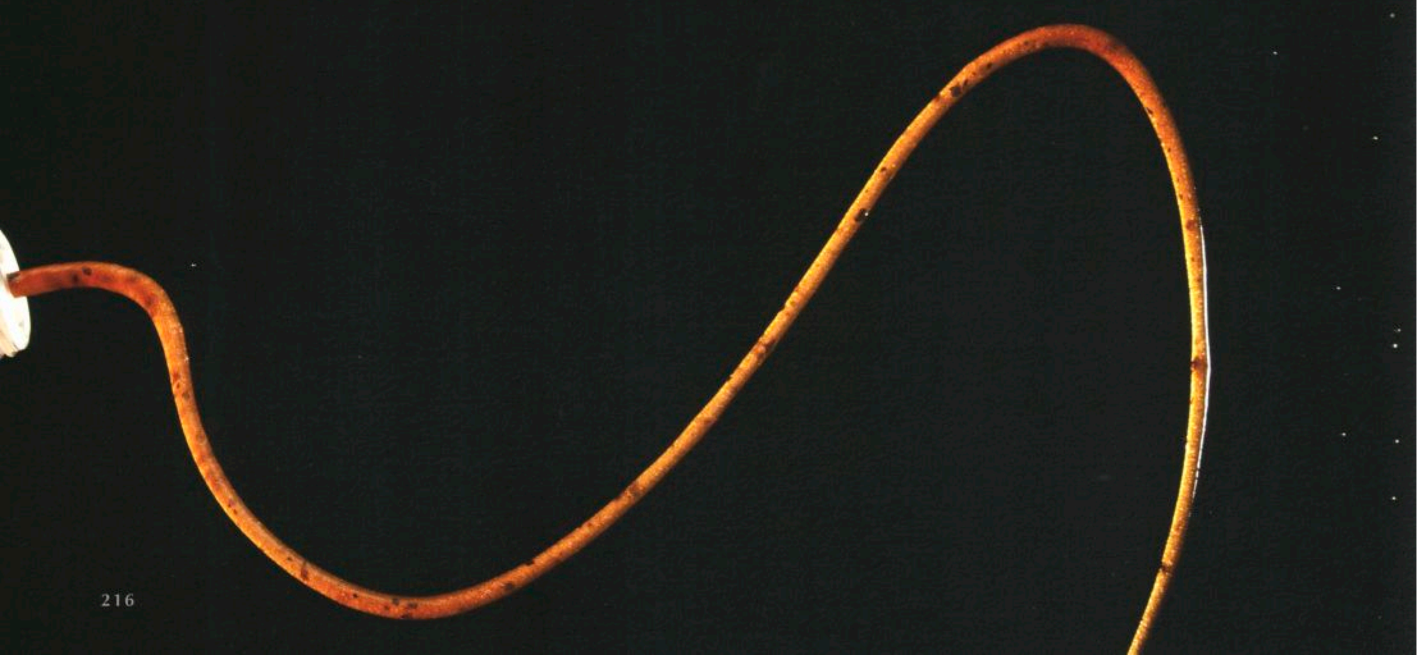
*(*set weight of fat to 100%*)

Modern Surfactant Emulsifiers

Most of the modern ingredients used as emulsifiers share a common mode of action: they are surfactants that cover droplets of oil or water and effectively restrain them from coalescing, thus stabilizing the emulsion. Surfactants help modern chefs create emulsions that can be used to produce dishes never thought possible, like nut creams that can be whipped, beverages or broths that contain a gentle perfume of essential oils, and olive oil that can be spread like butter. Using surfactants can be complicated; no simple set of rules or guidelines is adequate because there are just too many exceptions.

The table below list some of the more popular commercially available surfactants and their common applications. The HLB

Group	Emulsifier	HLB value	Type	Example uses
monoglycerides and diglycerides	stearoyl lactylate	2.6	W/O	butter and margarine spreads, bread products, powdered drinks
	glycerol monooleate	3.4	W/O	fruit juice, ice cream
	Glice (Texturas brand)	3.6–4.2	W/O	beer, breakfast cereal, cheese, frozen custard, ice cream, liqueur, mustard, sherbet
sorbitan esters (Span brand)	sorbitan tri-stearate (Span 65)	2.1	W/O	cookies, chocolate bars, peanut butter
	sorbitan mono-stearate (Span 80)	4.3	W/O	bread, chewing gum, coffee, ice cream, imitation whipped cream, milk candy
polysorbates (Tween brand)	polysorbate 60	14.9	O/W	ice cream, imitation butter and cream, mayonnaise, powdered coffee creamer, salad dressing, shortening, Twinkies
	polysorbate 80	15	O/W	
	polysorbate 20*	16.7	O/W	mayonnaise, salad dressing
propylene glycol esters	propylene glycol monostearate	3.4–3.5	W/O	chewing gum, sherbet and sorbet, fruit filling for pastry; used as wetting agent in shredded coconut and as a nontoxic antifreeze in breweries and dairies
	propylene glycol alginate	8.3	O/W	butter emulsion, noncarbonated fruit drinks, salad dressing; stabilizes foam on beer
polyglycerol esters	polyglycerol polyricinoleate	4.3	W/O	used in chocolate making to adjust flow and give smooth texture
phospholipids	oiled lecithin	3.5	W/O	chewing gum, cocoa powder, coffee creamer, confectionery, frozen desserts
	deoiled lecithin	4.5	W/O–O/W	
gum arabic	gum arabic	11	O/W	cake, cereal, frosting, soda, gummy candy, ice cream, marshmallows



value, as described on page 204, is one guide to the properties of the emulsifier. Ingredients with an HLB value of 4–6, for example, tend to form W/O emulsions, whereas those with an HLB of 8–18 tend to create O/W emulsions.

Most modern surfactants were created with the needs of processed food manufacturers, not Modernist cooks, in mind. Many are very good at increasing the stability and shelf life of commercial products, but that does not make them ideal for cooking.

Our favorite surfactant is propylene glycol alginate, both because it is widely available and because it performs well in many applications. We also find Tween products easy to use.

Typical concentration (scaling %)*	Source	Note
2–6	found in beef fat, cocoa butter, sodium and calcium hydroxide, soy oil	very slightly soluble in cold water
2–6	glycerin and oleic acid obtained from animal or vegetable fats	insoluble in water, forms microemulsion in water
2–6	glycerides in fats	mixture of oil and Glice flakes in water must be integrated slowly for optimal emulsion
1–8	sorbitol and stearic acid (found in beef fat and cocoa butter)	prevents crystal formation and graininess
0.3–0.7	sorbitol and stearic acid (found in beef fat and cocoa butter)	
1–7	condensate of stearic acid and sugar alcohol	makes foods creamy; Tween is a well-known brand of polysorbate
1–7	condensate of oleic acid and sorbitol	
1–7	ethylene oxide and sodium ethoxide (vegetable origin)	
0.5–12.0	fermentation and distillation of carbohydrates and yeast	antimicrobial, good as food preservative
0.4–1.0	seaweed	soluble in cold or hot water
0.03–1.00	castor beans	insoluble in water and alcohol
1–5	animal tissue, corn, egg yolks, peanuts, soybeans	can also be used to stabilize foams
1–5 for W/O; 5–10 for O/W		
0.5–10	hardened sap from acacia tree	low viscosity within emulsifying range

*(*set weight of fat to 100%*)

DAIRY EMULSIONS

Milk, itself an emulsion straight from the cow, is the foundation of all dairy-based emulsions. Butterfat (also called milkfat) is suspended in water, and the emulsion is stabilized by casein protein. But it is not stable for long because it is prone to a type of emulsion failure named for the result—creaming. The process of emulsifying and stabilizing butterfat droplets in liquid milk, known as homogenization, has become a household term. Cream and butter are also emulsions.

With the application of powerful modern tools and ingredients, dairy emulsions can now exist in environments not formerly possible. Beurre blanc, a delicate and fussy sauce, used to require à la minute preparation. Now it can be made well in advance and held in a water bath, or even chilled and reheated if necessary.

Compound butters often are used as a flavorful finish on grilled steaks or fish fillets, but they fail, or break, on contact with hot food. In contrast, our Beurre Montpellier melts into a luscious, fully emulsified butter sauce.

We love the consistency of melted processed cheese—but dread the flavor. By creating a stable cheese emulsion from tasty varieties like Gruyère and white cheddar, we are able to marry taste to texture for the perfect cheeseburger topping.

Lobster in beurre blanc is a classic combination, but with traditional methods it had to be made à la minute. With our heat-stable beurre blanc, this French classic becomes much more practical for busy cooks.

Beurre blanc is the rare example of a classic French technique credited to a woman. Clémence Lefeuvre first produced beurre blanc in the early 20th century in the kitchens of a Nantes château. The sauce was apparently the result of a happy accident—she (or possibly her assistant) forgot to add egg yolks to a béarnaise sauce.

EXAMPLE RECIPE

ULTRASTABLE BEURRE BLANC

Yields 220 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water, stock, or heavy cream	100 g	100%	① Dry blend agar and propylene glycol alginate, and disperse in cold liquid.
Agar	0.5 g	0.5%	② Heat to 95 °C / 203 °F. Cool until fully set, about 10 min.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	0.5 g	0.5%	③ Puree to fluid gel. ④ Reserve.
White wine (dry)	100 g	100%	⑤ Reduce until almost syrupy, and strain.
Champagne vinegar	30 g	30%	⑥ Measure 20 g of reduction, and reserve.
Shallots, finely minced	30 g	30%	
Unsalted butter, small cubed	100 g	100%	⑦ Melt butter.
Liquid soy lecithin	1 g	1%	⑧ Whisk into warm butter.
Wine reduction, from above	20 g	20%	⑨ Blend reserved wine reduction with fluid gel.
Salt	to taste		⑩ Slowly pour in warm butter mixture while blending with rotor-stator homogenizer or other high-shear appliance until fully emulsified.
Lemon juice	to taste		⑪ Season, and serve hot with poached lobster (below), or cool and refrigerate.

(2008)

EXAMPLE RECIPE

POACHED LOBSTER

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lobster tails, shelled	300 g (four tails)	300%	① Vacuum seal, and cook sous vide in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 25 min.
Beurre blanc, from above	220 g	73%	② Warm beurre blanc in 90 °C / 194 °F bath or in small pot over medium heat.
Salt	to taste		③ Slice and season lobster, and serve with warm beurre blanc.

(2010)

EXAMPLE RECIPE

BEET FLEXICURD ADAPTED FROM JOHNNY IUZZINI

Yields 900 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Isomalt (or sugar)	100 g	25%	① Dry blend.
Salt	11 g	2.75%	
LM Pectin 104 AS (Genu pectin, CP Kelco brand)	8 g	2% *(0.9%)**	
Malic acid	4 g	1%	
Agar (Texturas brand)	3.4 g	0.85% *(0.38%)**	
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	2.6 g	0.65% *(0.29%)**	
Kappa carrageenan (Texturas brand)	1 g	0.25% *(0.11%)**	
Beet juice see page 2·336	300 g	75%	② Disperse isomalt mixture into cold juice. ③ Heat to 95 °C / 203 °F, and hold at that temperature.
Unsalted butter, melted	100 g	25%	④ Blend slowly into hot mixture until emulsified.
Beet puree, brought to simmer see page 2·424	400 g	100%	⑤ Add hot puree, and hold at simmer for 1 min. ⑥ Pour mixture into plastic wrap-lined quarter sheet, and allow to set, about 3 min. ⑦ Cover with plastic wrap, and refrigerate. ⑧ Cut into desired shapes, and serve hot or cold.

(2008)

(% of total weight of final three ingredients*)

BROILED TUNA BELLY WITH MONTPELLIER BUTTER

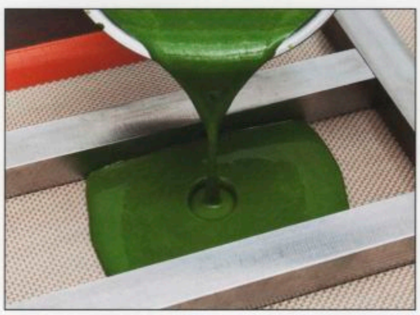
Yields 850 g of butter, 500 g of tuna with butter (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks, blended	100 g	22%	① Vacuum seal, and cook sous vide in 67 °C / 153 °F bath for 30 min.
			② Strain through fine sieve.
Unsalted butter, melted	450 g	100%	③ Heat to 65 °C / 150 °F, stirring until flakes have dissolved, and remove from heat.
Mono- and diglycerides (Glice, Texturas brand)	54 g	12%	
160 Bloom gelatin	18 g	4%	④ Hand blend into warm butter mixture.
Sodium caseinate	1.8 g	0.4%	⑤ Blend in cooked egg yolks until smooth.
Garlic chives, pureed see page 2·424	125 g	28%	⑥ Combine, and fold into butter mixture until all components are evenly distributed.
			⑦ Cast onto sheet in one layer 1.5 cm / ⅝ in thick to form Montpellier butter.
Garlic confit see page 3·354	90 g	20%	⑧ Freeze, and cut into cubes.
Anchovy paste	30 g	6.7%	
Pickled ramp bulb, brunoise see page 5·118	25 g	5.5%	
Spinach, pureed see page 2·424	25 g	5.5%	
Chives, finely minced	15 g	3.3%	
Parsley, finely minced	15 g	3.3%	
Young ginger, finely diced	10 g	2.2%	
Salt	9 g	2%	
Lemon zest	2.5 g	0.6%	
Cayenne pepper	2 g	0.4%	
Lime juice	2 g	0.4%	
Black pepper	1.2 g	0.3%	
Star anise, finely ground	0.7 g	0.2%	
Tuna belly, sliced 5 mm / ¼ in thick	400 g	89%	⑨ Arrange five slices of tuna on each of four ovenproof plates.
			⑩ Dot with cubes of Montpellier butter, and place under broiler for 1 min until butter is melted, surface is golden, and fish is just warmed through.
Salt	to taste		⑪ Season.

(2009)

The great advantage of this recipe is that it allows the butter to stay emulsified when hot. So when it melts into a fluid, it doesn't break into an oily slick the way that traditional compound butters do.

5



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EXAMPLE RECIPE

HOT BLOOD PUDDING CUSTARD ADAPTED FROM HESTON BLUMENTHAL

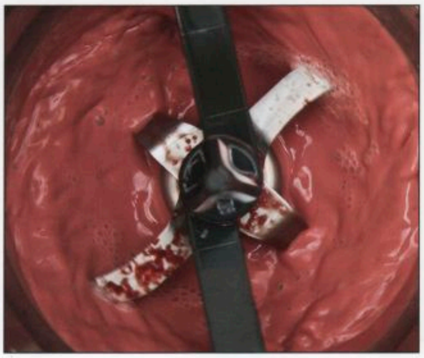
Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Star anise	1.3 g	0.19%	① Combine.
Dried ginger	0.5 g	0.07%	② Toast on baking tray at 150 °C / 300 °F until fragrant, about 10 min.
Cinnamon stick	0.3 g	0.04%	③ Cool.
Sichuan peppercorns	0.3 g	0.04%	④ Crush lightly.
Cardamom seeds, black	0.15 g	0.02%	⑤ Place spice blend on cheesecloth.
			⑥ Bundle, and tie cloth at top to form sachet.
Heavy cream, stabilized with hydrocolloids (or processed at ultrahigh temperature)	690 g	100%	⑦ Heat to 70 °C / 160 °F.
			⑧ Add spice sachet.
			⑨ Refrigerate to cool.
			⑩ Discard sachet once infused cream is fully cooled.
Fresh pig's blood	160 g	23%	⑪ Combine with infused cream.
			⑫ Transfer to Thermomix fitted with butterfly whisk attachment or to beaker set on magnetic heating plate with overhead paddle-stirring attachment.
			⑬ Cook in 70 °C / 160 °F Thermomix or beaker just until pudding has thickened to custard, about 4 h. Emulsion will split if overreduced.
Salt	8 g	1.2%	⑭ Season.
Sugar	5 g	0.7%	⑮ Vacuum seal.
			⑯ Refrigerate until needed.
			⑰ To serve, reheat sous vide in 60 °C / 140 °F bath.

(original 2007)

11a

11b



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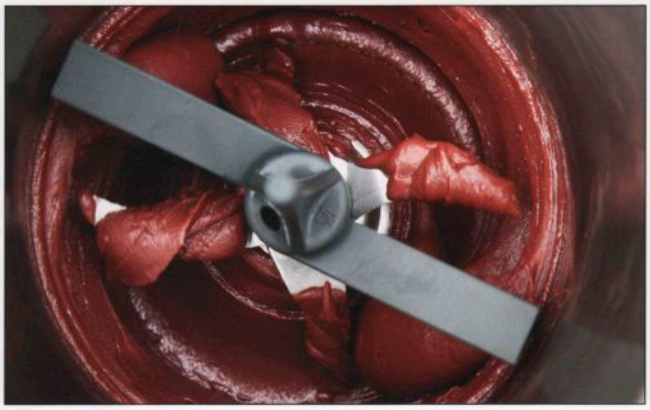


13c

THE HISTORY OF

Processed Cheese Food

Although we don't tend to think of cheese as a gel, that's exactly what it is. The casein proteins in milk coagulate to form a gel; they then settle out as curds. This process occurs at the outset of all cheese making (see page 102). The gel traps the fat droplets in the milk, turning it into a solid emulsion. The solid gel makes cheese a very stable emulsion unless it is heated sufficiently to melt the gel, at which point the emulsion breaks. Molten cheese tends to separate into two phases: a layer of oil that floats to the top of the pot, and a thick, chewy mass of milk proteins that scorches on the bottom of the pot. This tendency poses many problems for melted-cheese dishes ranging from fondue to cheese sauce to cheeseburgers. But someone discovered a solution.

James Kraft was born in 1874, the second of 11 children of Mennonite farmers in Canada. In 1903, he took $65, bought a wagon and a horse named Paddy, and set out to become a cheese distributor in Chicago. Initially he bought cheese from warehouses on South Water Street and resold it to small grocery stores across the Chicago area. After a while, he started making his own cheese, but he ran into a major problem. At the time, refrigerators were unheard of in either stores or homes, and because cheese is highly perishable, Kraft's products were apt to go bad, limiting both sales and profits. As a result, he decided to try pasteurizing and canning cheese. The preservation aspect worked, but the heat required melted the cheese and made it separate. Around 1912, he perfected a means of stabilizing the cheese by using sodium phosphate as an emulsifying salt, which kept the emulsion from breaking when the cheese melted. Swiss scientist Walter Gerber independently discovered in 1911 that sodium citrate has a similar effect.

The invention was a great success and led Kraft to obtain a U.S. patent in 1916. Suddenly cheese could be canned and sold widely in preserved form. Although today we tend to look down on processed, prepackaged cheese, at the time it was enormously popular and actually commanded a higher price than natural cheese did. Millions of pounds of Kraft cheese were sold every year. Annual cheese consumption per person in the United States ultimately increased by a factor of 10 from about 1.4 kg / 3 lb to about 14 kg / 30 lb.

Kraft's cheese became so popular that traditional cheese makers lobbied the Wisconsin legislature and the U.S. federal government to regulate the product, arguing that Kraft should not be allowed to call it "cheese." One proposed name was "embalmed cheese," clearly aimed at limiting sales. Ultimately, better-sounding names were chosen, including "cheese food," "cheese spread," "cheese product," and "pasteurized process cheese product," depending on the moisture content and other criteria. If it is based on colby or cheddar cheese, then in the United States it is permissible to call it American cheese. Today most people refer to it as processed cheese.

Although Kraft's invention was aimed at preservation, over time the company's focus shifted. In the 1950s, Kraft introduced Velveeta, a processed cheese based on mild cheddar. It melted perfectly, so it became the cheese of choice for hamburgers, another food that rose in popularity in the 1950s (see page 1·22).

Today Kraft is the second-largest food company in the world; in 2009 its annual revenues were about $40 billion. The company is a market leader; about 80% of its revenue comes from product lines that have the number one market share in their respective categories. Although Kraft has diversified into many other food businesses, it still sells about $7 billion worth of cheese annually.

The emulsifying salts discovered by Kraft and Gerber work by helping the natural emulsifiers in cheese stabilize the emulsion. We can use them to make cheese that melts perfectly (see next page) without separating and to create a cheese sauce that has a stronger cheese flavor than one produced by using lots of starch.

UNITED STATES PATENT OFFICE.

JAMES LEWIS KRAFT, OF CHICAGO, ILLINOIS.

PROCESS OF STERILIZING CHEESE AND AN IMPROVED PRODUCT PRODUCED BY SUCH PROCESS.

1,186,524. Specification of Letters Patent. Patented June 6, 1916.

No Drawing. Application filed March 25, 1916. Serial No. 86,764. REISSUED

To all whom it may concern:

Be it known that I, JAMES LEWIS KRAFT, a citizen of the United States, residing at Chicago, in the county of Cook and State of Illinois, have invented a certain new and Improved Process of Sterilizing Cheese and an Improved Product Produced by Such Process, of which the following is a specification.

This invention relates to an improved process of sterilizing cheese to render it permanently keeping, and to the product thereby produced.

The chief object of the invention is to

I understand that various cheeses, especially of the soft varieties, such as Camembert, Limburger, Brie, etc., which in the advance stages of curing become liquid or semiliquid, have been made permanently keeping by sterilizing with heat and sealing hermetically under sterilized conditions. I believe the explanation to be that in the process of making and curing soft cheeses of the varieties stated, all those bacteria which can only be killed by heat of a comparatively high degree, have been killed off, (possibly by a toxic condition of the cheese as regards such bacteria, developed by the curing)

Inventor James Kraft was awarded a U.S. patent on processed cheese in 1916. The company he founded is now the second-largest in the food industry.

PARAMETRIC RECIPE

CONSTRUCTED CHEESES

Have you ever craved the mature flavor of an aged cheese but the gooey, liquid texture of fondue or a melted American cheese slice? Dry, aged cheeses tend to break into greasy clumps when they melt because they do not form stable emulsions. So we tested ways to strengthen that emulsion by, for example, using carrageenan and melting salts such as sodium citrate. Some of the successful results appear in the table below, but these are just a starting point. You can substitute your favorite type of cheese in many of these formulas.

Soft and semisoft cheeses have enough natural moisture to melt well, but adding melting salts keeps the molten emulsion stable. Semihard to hard cheeses, with their degraded dairy proteins and an average moisture content of 45%–60%, seem to work best. Some of our favorites include Gruyère, Stilton, Fontina, Tomme, Muenster, and Camembert. If you want to use a very hard cheese with a moisture content below 41%, such as Parmesan or aged Gouda, it is best to use them in combination with other semihard cheeses such as Gruyère, and to limit them to no more than 30% of the total weight of the cheese mixture. In such cases, compensate for the dryness of the cheese by adding up to 10% more liquid than indicated in the table.

CONSTRUCTING A CHEESE

1. **Combine the liquids and other ingredients (except cheese and milk powder), and bring to a simmer.**
2. **Gradually whisk in the cheese.** Also add milk powder, if called for. Whisk and melt until the cheese is completely incorporated.
3. **Simmer for 2 min.** This step is crucial in forming a smooth emulsion rather than a grainy, broken liquid.
4. **Puree with an immersion blender until very smooth and silky.** Do not puree fondue; the stringy strands are usually considered desirable.
5. **Check pH.** A target final pH is listed in the table. If the emulsion is not stable, and the pH reading is higher than listed, it may be necessary to add more emulsifying salts (sodium citrate or one of the phosphates).
6. **Season the cheese with salt, and serve warm.** Or pour it into a lightly oiled mold, and chill for later use.
7. **Refrigerate.** Cover the cheese surface tightly to prevent a skin from forming.

Best Bets for Constructed Cheeses

Recipe	Liquid	(scaling)	Other ingredients	(scaling)	Cheese	(scaling)	Final pH	Note
fondue (hot cheese dip)	water Fino sherry or dry white wine	80% 40%	sodium citrate Joha SDS2 sodium phosphate (Fibrisol brand) lambda carrageenan	4.4% 1.2% 0.5%	Gruyère or young Fontina, grated	100%	5.8	keep hot when serving; thickens slightly if reheated
thin cheese spread, hot or cold	water	100%	sodium citrate whey protein concentrate Joha SDS2 sodium phosphate (Fibrisol brand)	2.0% 1.0% 1.2%	Swiss cheese, grated	100%	5.9	very silky texture; very good either hot or cold
thick cheese sauce/spread, hot or cold	water	100%	sodium citrate whey protein concentrate	2.0% 1.0%	Swiss cheese, grated	100%	6.1	best choice for use in macaroni and cheese, and cheese omelet
cheese soup, hot	water	160%	sodium citrate whey protein concentrate	5.2% 1.3%	Gruyère	100%	6.1	good pairings: beer and cheddar; dry Riesling and Gouda; port and Stilton
cheeseburger cheese slice	water wheat ale	67% 50%	sodium citrate iota carrageenan kappa carrageenan	6.7% 3.0% 1.0%	Emmental, grated Comté, grated	100% 90%	6.0	cast into mold quickly after combining, or mixture will set
cheese slice for baking (raclette analogue)	water	32%	sodium citrate disodium phosphate (BK Giulini brand)	2.0% 0.8%	Gruyère, grated skim milk powder	100% 4%	5.8	best cut into slices and baked until melted

THE AMERICAN CHEESE SLICE

Yields 635 g

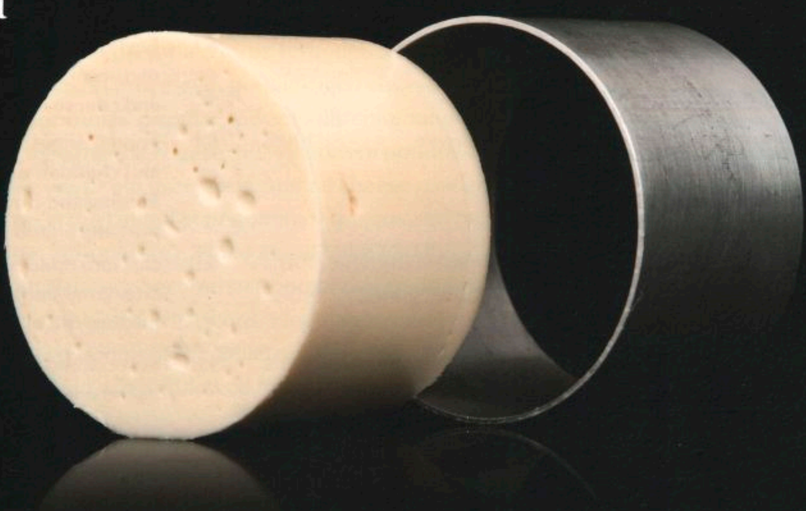
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	230 g	115%	① Mix dry ingredients, and disperse into water.
Salt	5 g	2.5%	② Bring to simmer to hydrate.
Sodium citrate	14 g	7% (*2.3%*)*	
Iota carrageenan (Texturas brand)	6 g	3% (*0.98%*)*	
Kappa carrageenan (Texturas brand)	2 g	1% (*0.33%*)*	
Swiss cheese, grated	200 g	100%	③ Add cheese gradually to simmering water mixture, blending constantly with hand blender.
White cheddar, grated	180 g	90%	④ Continue blending until texture is fluid and smooth.
			⑤ Pour cheese mixture into greased cylindrical mold 7 cm / 2¾ in. in diameter and at least 18 cm / 7 in long. Complete the transfer very quickly.
			⑥ Refrigerate for at least 2 h to set.
			⑦ Remove cheese from mold, and slice to desired thickness.
			⑧ Store refrigerated between sheets of plastic wrap or wax paper.

(2009)

(% of total combined weight of water and cheeses*)

4

7a



7b

EXAMPLE RECIPE

CHEESE IN A TUBE

Yields 215 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sodium citrate	2 g	2%	① Combine, and bring to simmer.
Whey protein concentrate	1 g	1%	
Sodium phosphate (Joha SDS2, Fibrisol brand)	1.2 g	1.2%	
Water	100 g	100%	
Aged Gouda, finely grated	50 g	50%	② Gradually whisk cheese into hot liquid until fully incorporated. Simmer for 2 min.
Monterey jack, finely grated	50 g	50%	③ Puree with hand blender until smooth.
Jalapeño, finely minced	10 g	10%	④ Fold into warm cheese mixture.
Cayenne pepper powder	2 g	2%	
Salt	to taste		⑤ Adjust seasoning.
			⑥ Transfer to squeeze bottle, and pipe into unused empty paint tubes. Reserve chilled.

(2010)

EXAMPLE RECIPE

CHEESY WHIP

Yields 480 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sodium citrate	4 g	2%	① Dry blend powders.
Whey protein concentrate	2 g	1%	
Sodium phosphate (Joha SDS2, Fibrisol brand)	2.4 g	1.2%	
Water	200 g	100%	② Disperse powder mixture in cold water, and bring to simmer.
Gruyère, finely grated	200 g	100%	③ Gradually whisk cheese into hot liquid until fully incorporated. Simmer for 2 min.
			④ Puree with hand blender until completely smooth.
Whole milk	80 g	40%	⑤ Blend into cheese mixture. Cool completely.
Salt	to taste		⑥ Season generously to compensate for aeration, and pour into 1 l whipping siphon.
			⑦ Charge with two cartridges of nitrous oxide.
			⑧ Shake vigorously, and dispense to serve.

(2010)

EXAMPLE RECIPE

CHEDDAR SOUP

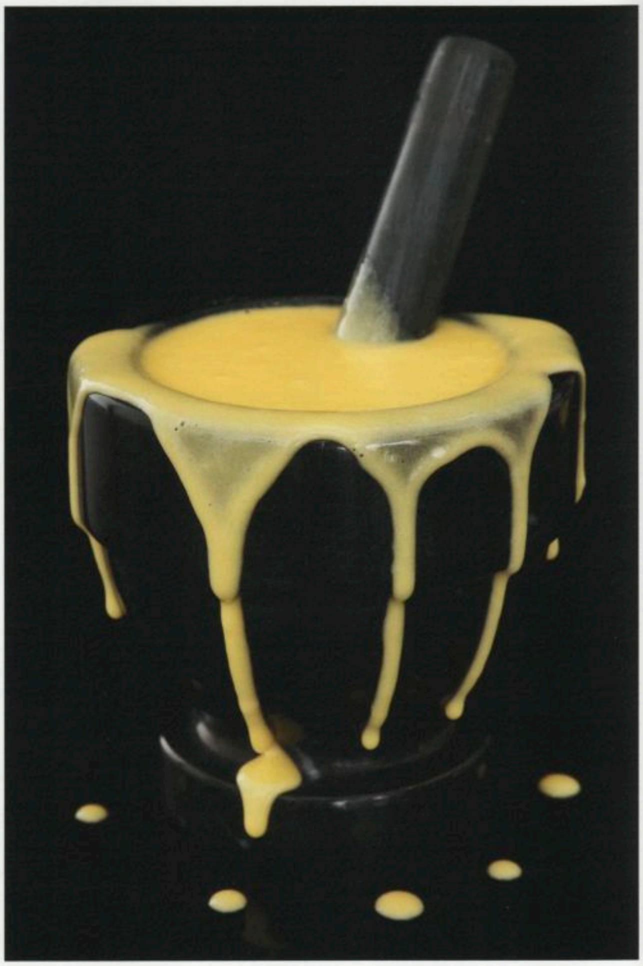
Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Brown butter see page 213	20 g	20%	① Melt butter in pot, and add shallots, garlic, and bay leaf. ② Cook over medium heat until translucent, about 7 min.
Garlic cloves, thinly sliced	15 g	15%	
Shallots, thinly sliced	100 g	100%	
Wheat beer (Hefeweizen-style)	160 g	160%	③ Deglaze pot with beer, and reduce until pan is dry.
Sodium citrate	5 g	5%	④ Dissolve sodium citrate and whey protein in water, and add to pot.
Whey protein concentrate	1.3 g	1.3%	⑤ Bring to simmer.
Distilled water	160 g	160%	
Aged cheddar, finely grated	100 g	100%	⑥ Gradually whisk into simmering liquid until completely incorporated.
			⑦ Puree with hand blender until smooth. Pass through fine sieve.
Salt	to taste		⑧ Season and serve, or chill over ice and refrigerate until use.

(2010)

Garnish soup with cubes of hot quince or green apple gel for a bright burst of sweetness and acidity (see page 166).

EGG EMULSIONS



An egg is the first ingredient most chefs reach for when they want to make an emulsified sauce. Egg yolks are naturally occurring emulsions that are high in lecithin, an excellent surfactant (see page 200). An entire branch of the French sauce-making family tree—mayonnaise, hollandaise, béarnaise, and all their wonderful variations—grew from the natural emulsification properties of the egg.

There is no reason to polarize the genre of emulsified egg sauces into cold mayonnaise and warm hollandaise anymore. Emulsified egg sauces can be created with virtually any liquid and fat combination and served at various temperatures. Modern tools and ingredients allow mayonnaise to be served warm with steamed asparagus or grilled salmon fillets without fear of emulsion failure. Hollandaise can be made with a variety of flavorful fats, even cocoa butter or coconut oil. Our bacon jam is a spreadable sauce made with egg yolks and bacon fat. The variations are limited only by the chef's imagination.

Three techniques have improved the stability of egg emulsions. First, the new machines now used in the modern kitchen, like the rotor-stator homogenizer, make the dispersed oil droplets much smaller and therefore more stable. Second, ingredients that stabilize emulsions are now widely available. And finally, water baths can be used to carefully cook eggs. The warmed eggs are blended into a fluid gel (see page 176) for increased viscosity, which creates a sturdier emulsion. Chef Michel Bras makes a creamy, rich, garlic mayonnaise with soft-boiled eggs.

EXAMPLE RECIPE

BASIC MAYONNAISE

Yields 470 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks, blended	45 g	15%	① Vacuum seal, and cook sous vide in 67 °C / 153 °F bath for 30 min.
Water	75 g	25%	② Whisk together, and puree with cooked egg yolks until smooth.
Dijon mustard	21 g	7%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.7 g	0.23% *(0.15%)**	
Grapeseed oil	300 g	100%	③ Drizzle slowly into egg mixture while blending until mixture is fully emulsified.
Lemon juice	15 g	5%	④ Season.
White wine vinegar	10 g	3.3%	⑤ Refrigerate.
Salt	to taste		

(2010)

(% of total combined weight of all other ingredients*)

Pasteurizing eggs is recommended if you plan to serve them to immune-compromised people. (See page 1·162 for more on food-safety considerations and page 78 for egg pasteurization.) Pasteurizing eggs does not change their emulsifying properties.

For a low-fat version of the mayonnaise, replace the 300 g of oil with 50 g of oil and a fluid gel made from 250 g of water or other liquid and 1.75 g of agar (0.7% of the total weight of the liquid). Blend in 7 g of Ultra-Sperse 3 (1.5% of total weight). See page 178 for more details on making a fluid gel.

Water can be replaced with stock, fruit juice, vegetable juice, or any infusion to create a boldly flavored mayonnaise.

EXAMPLE RECIPE

SOFT-BOILED EGG AND GARLIC EMULSION INSPIRED BY MICHEL BRAS

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Garlic confit, pressure cooked see page 3·354	30 g	30%	① Puree until smooth.
White wine vinegar	25 g	25%	② Pass through fine sieve.
Whole eggs	100 g (about two large)	100%	③ Vacuum seal, and cook sous vide in 67 °C / 153 °F bath for 35 min. ④ Blend with garlic puree until smooth.
Grapeseed oil	100 g	100%	⑤ Drizzle in slowly while blending into egg-garlic mixture until fully emulsified.
Olive oil	100 g	100%	
Walnut oil	50 g	50%	
Salt	to taste		⑥ Season.
Green onions, very thinly sliced	30 g	30%	⑦ Fold in, and refrigerate.

(published 2002, adapted 2010)

EXAMPLE RECIPE

SOUS VIDE LEMON CURD

Yields 850 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolks	120 g	30%	① Vacuum seal, and cook in 65 °C / 149 °F bath for 35 min. ② Cool and reserve.
Sugar	300 g	75%	③ Bring to boil to dissolve sugar and acid.
Water	120 g	30%	④ Cool to room temperature.
Citric acid	8 g	2%	
Unsalted butter, room temperature	400 g	100%	⑤ Blend butter with egg yolks and sugar syrup until smooth. ⑥ Add more essential oil to taste. Other oils besides lemon may be used.
Lemon essential oil (optional)	1 g	0.5%	⑦ Vacuum seal.
Salt	0.4 g	0.1%	⑧ Refrigerate until firm, 4–24 h.

(2010)

This recipe allows you to make large amounts of basic lemon curd without the hassle of a double boiler and the risk of overcurdling. The curd can also be foamed by using a whipping siphon.

EXAMPLE RECIPE

HOT EGG MAYONNAISE ADAPTED FROM FERRAN ADRIÀ

Yields 490 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole eggs	130 g	65%	① Blend until smooth.
Egg yolks	60 g	30%	② Vacuum seal, and cook in 65 °C / 149 °F bath for 35 min.
Dijon mustard	35 g	17.5%	
Sunflower oil (or other neutral oil)	200 g	100%	③ Combine. ④ Blend with warm egg mixture until emulsified.
Extra-virgin olive oil	50 g	25%	
Salt	to taste		⑤ Season.
Sherry vinegar	to taste		⑥ Pour contents into 1 l whipping siphon, and charge with one cartridge of nitrous oxide. ⑦ Hold filled siphon in 62 °C / 144 °F bath until ready to serve. ⑧ Dispense mayonnaise from siphon, and serve with grilled asparagus or poached fish.

(original 2000)

EXAMPLE RECIPE

DEEP-FRIED HOLLANDAISE ADAPTED FROM WYLIE DUFRESNE

Yields 1.2 kg (40 pieces)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Unsalted butter, melted	640 g	640%	① Soften gelatin leaves in cold water.
160 Bloom gelatin sheet	60 g	60%	② Drain, and dissolve gelatin in butter.
			③ Reserve warm.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	3.5 g	3.5%	④ Dry blend.
Sodium hexametaphosphate	2 g	2%	
Citric acid	0.6 g	0.6%	
Water	170 g	170%	⑤ Add blended powders to pot of water.
			⑥ Bring to boil, and remove from heat.
			⑦ Pour into container.
			⑧ Refrigerate until set, about 5 min.
Egg yolks, blended	100 g	100%	⑨ Puree gel with yolks until fluid, and reserve.
Water	110 g	110%	⑩ Whisk to combine.
Ultra-Sperse M (National Starch brand)	10 g	10%	⑪ Blend into yolk gel mixture until smooth.
			⑫ Drizzle in reserved warm butter while continuously blending to make hollandaise.
Lemon juice	to taste		⑬ Season hollandaise.
Salt	to taste		⑭ Cast into mold 2.5 cm / 1 in thick.
			⑮ Refrigerate until set, about 1 h.
			⑯ Cut set gel into cubes.
All-purpose wheat flour	100 g	100%	⑰ Dredge cubes evenly in flour, and shake off excess.
Eggs, blended	100 g	100%	⑱ Coat cubes evenly with blended eggs.
English muffins, dried and ground into powder	200 g (four muffins)	200%	⑲ Roll cubes in bread crumbs. Shake off any excess. Repeat breading procedure once.
			⑳ Freeze for 30 min to harden crusts.
Frying oil	as needed		㉑ Deep-fry cubes in 190 °C / 375 °F oil until golden, about 1½ min.
			㉒ Drain on paper towels.

(original 2008)

EXAMPLE RECIPE

SOUS VIDE INSTANT HOLLANDAISE INSPIRED BY DANIEL HUMM

Yields 345 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White wine (dry)	100 g	133%	① Combine.
Shallots, finely minced	50 g	67%	② Reduce to syrup-like consistency.
White vinegar	35 g	47%	③ Strain.
			④ Measure 20 g of wine reduction.
Egg yolks	75 g (four large)	100% (*28%*)*	⑤ Blend thoroughly with wine reduction.
			⑥ Vacuum seal.
Stock or water	20 g	27%	⑦ Cook in 65 °C / 149 °F bath for 30 min.
Unsalted butter, melted	225 g	300%	⑧ Remove cooked egg yolk mixture from bag, and blend in butter mixture until fully emulsified.
Salt	4 g	5.3%	⑨ Season.
Malic acid	1 g	1.3%	⑩ Transfer to 1 l siphon.
			⑪ Charge with two cartridges of nitrous oxide, and shake vigorously.
			⑫ Hold siphon in 60 °C / 140 °F bath.
Two-stage fried egg see page 2·174	four eggs		⑬ Garnish eggs with hollandaise.

(original 2009, adapted 2010)

(% of total weight of wine reduction, stock, and unsalted butter*)

If you choose to use stock rather than water, consider the ingredient for which the hollandaise is being prepared: use fish stock for fish, poultry stock for poultry, and so on. For stock recipes, see page 2·296.

Alternatively, the hollandaise base can be cooked sous vide in a 63 °C / 145 °F bath to produce a lighter foam, or in a slightly warmer 67 °C / 153 °F bath for a denser foam.

EXAMPLE RECIPE

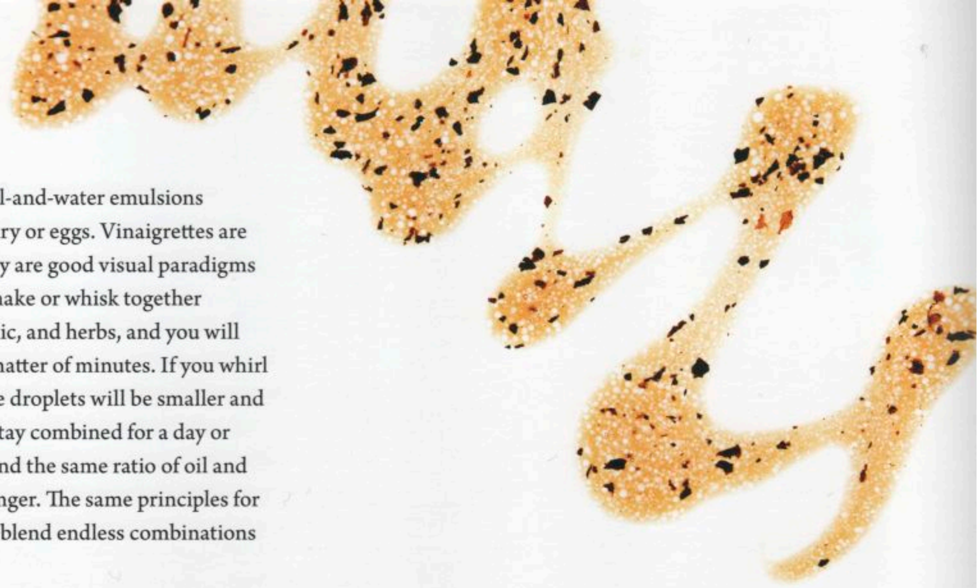
BACON JAM

Yields 375 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Isomalt	50 g	50%	① Combine, and heat to **90** °C / **195** °F until fully dissolved.
Sugar	40 g	40%	② Cool and reserve.
Water	30 g	30%	
Maple syrup (Grade B)	30 g	30%	
Egg yolks	75 g	75%	③ Vacuum seal, and cook in **66** °C / **151** °F bath for **30 min**.
			④ Strain through fine sieve.
			⑤ Blend into cooled syrup.
Rendered bacon fat, warm	100 g	100%	⑥ Drizzle slowly into egg syrup while blending constantly until fully emulsified.
			⑦ Refrigerate.
Bacon strips, finely diced	120 g	120%	⑧ Fry or bake in **175** °C / **350** °F oven until crisp, about **25 min**.
			⑨ Drain on absorbent paper towels. Cool, and store in dry, cool place.
Salt	to taste		⑩ Season jam with salt.
Liquid caramel coloring (optional)	as needed		⑪ Add coloring to achieve desired shade.
			⑫ Fold in 50 g of bacon bits, and serve with warm biscuits (see page 5·77).
			⑬ If mixture has been refrigerated, it should be tempered for about 20 min before use.

(2008)

This bacon "jam" is essentially a sweetened and stabilized Hollandaise made with bacon fat. It goes very well with our cornbread (see page 5·76).



OTHER EMULSIONS

It can be challenging to create sturdy oil-and-water emulsions without the stabilizing properties of dairy or eggs. Vinaigrettes are perhaps the most familiar example. They are good visual paradigms of how emulsions both work and fail. Shake or whisk together vinegar and oil with some mustard, garlic, and herbs, and you will create an emulsion, but it may fail in a matter of minutes. If you whirl the vinaigrette in a blender or mixer, the droplets will be smaller and better dispersed, and the recipe might stay combined for a day or two. Add an emulsifier to your recipe, and the same ratio of oil and vinegar will remain emulsified much longer. The same principles for combining fat and water can be used to blend endless combinations of other ingredients.

EXAMPLE RECIPE

BLACK OLIVE PUREE ADAPTED FROM FERRAN ADRIÀ

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
160 Bloom gelatin sheet	2 g	4%	① Soften gelatin in cold water. ② Drain, and set aside.
Black olive juice see page 2·336	50 g (from 150 g pitted Kalamata olives)	100%	③ Heat 10 g of olive juice. ④ Melt softened gelatin in warm juice. ⑤ Add remaining 40 g of juice, and mix.
Sucrose esters (Sucro, Texturas brand)	0.5 g	1%	⑥ Blend into juice mixture. ⑦ Set aside.
Olive oil Mono- and diglycerides (Glice, Texturas brand)	50 g 0.5 g	100% 1%	⑧ Warm oil to 65 °C / 149 °F. ⑨ Dissolve Glice flakes in oil. ⑩ Add oil mixture slowly to juice until it emulsifies and forms puree. ⑪ Refrigerate puree until thickened, about 2 h.

(original 2005)

EXAMPLE RECIPE

THICKENED OIL ADAPTED FROM FERRAN ADRIÀ

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Extra-virgin olive oil (or other oil)	100 g	100%	① Heat to 65 °C / 149 °F in saucepan.
Mono- and diglycerides (Glice, Texturas brand)	7 g	7%	② Add, and stir to dissolve. ③ Cool oil to room temperature. ④ Transfer to bowl held in ice-water bath. ⑤ Whisk until cold, opaque, and thickened to consistency of mayonnaise. ⑥ Serve as spread, or use as garnish. ⑦ Thickened oil can also be transferred to 1 l whipping siphon, charged with two cartridges of nitrous oxide, and dispensed to form thick oil foam.

(original 2008)

The thickened oil or oil foam may be used only at room temperature or cold. Heating the mixture will cause it to lose its viscosity.

EXAMPLE RECIPE

INVINCIBLE VINAIGRETTE

Yields 325 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Champagne vinegar	80 g	80%	① Combine, and heat to **60 °C / 140 °F**.
Quince vinegar	35 g	35%	② Blend over heat until ingredients are completely incorporated.
Pear juice	20 g	20%	
Dijon mustard	5 g	5%	
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	0.98 g	0.98% *(0.3%)**	
Extra-virgin olive oil	100 g	100%	③ Combine oils.
Pistachio oil	55 g	55%	④ Drizzle slowly into vinegar mixture while blending; process until emulsified.
Walnut oil	30 g	30%	
Liquid soy lecithin (NOW brand)	1.85 g	1.85% *(1%)***	
Salt	to taste		⑤ Season.

(2010)

(% of total weight of all ingredients*); **(*% of total weight of oils*)

Use this recipe as a template for any basic vinaigrette. Different oils and acids can be used to create a variety of effects. The vinaigrette is completely heat stable, so it can be made with animal fats or dairy fat for use in warm salads, eggs, and cooked meats.

For a low-fat version of this vinaigrette, replace 100 g of oil with 100 g of flavorful liquid, 1 g of Ultra-Sperse 5, and 0.2 g of xanthan gum. The overall flavor will be more acidic, so the liquid used should be quite flavorful or the quantity of vinegar used should be reduced.

EXAMPLE RECIPE

MUSTARD VINAIGRETTE

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sous vide vegetable stock (or other flavorful liquid) see page 2·303	300 g	100%	① Whisk together.
Sherry vinegar	60 g	20%	
Polysorbate 80	1.5 g	0.5%	② Combine.
Xanthan gum	1.5 g	0.5%	③ Disperse in stock mixture, and blend until fully hydrated.
Extra-virgin olive oil	150 g	50%	④ Slowly blend into stock mixture until emulsified.
Walnut oil	130 g	43%	
Grain mustard	60 g	20%	⑤ Fold in.
Black peppercorns, finely crushed	to taste		⑥ Season.
Salt	to taste		

(2010)

For low-fat versions of the vinaigrettes on this page, substitute 100 g of flavorful liquid and 0.2 g of xanthan gum for 100 g of oil. Without the extra oil to balance the flavor, the vinegar may make the vinaigrette too acidic, in which case reduce the amount of vinegar.

EXAMPLE RECIPE

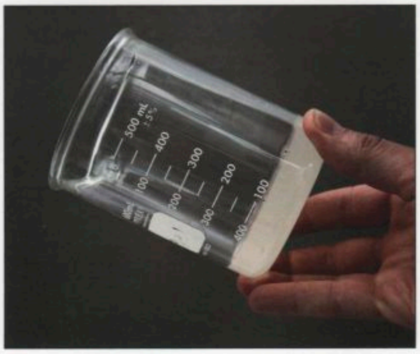
EGGLESS MAYONNAISE

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	200 g	100%	① Disperse agar in water.
Agar (Texturas brand)	1.2 g	0.67%	② Bring to boil, and hold for 1 min to fully hydrate.
			③ Cool completely until set, about 5 min.
Sucrose esters (Sucro, Texturas brand)	2 g	1%	④ Puree with set gel until smooth.
Olive oil	200 g	100%	⑤ Dissolve Glice flakes in oil heated to 50 °C / 122 °F.
Mono- and diglycerides (Glice, Texturas brand)	2 g	1%	⑥ Gradually blend oil into cold agar mixture until emulsified.
			⑦ Cool at room temperature.
Salt	to taste		⑧ Refrigerate for 2 h before serving.

(2010)

1



3

4

6a

6b

6c

This "mayonnaise" has no egg, which allows the flavor of the oil to be much more assertive without the egg getting in the way. Here we use olive oil, but any flavorful oil would work. Alternatively, you could use a flavorless oil and add flavor with a few drops of an essential oil.

We refer to this recipe as a "mayonnaise" because of the texture it yields. However, it contains neither vinegar, lemon juice, nor mustard. These and other typical flavorings can be added as desired to make the flavor profile closer to traditional mayonnaise.

EXAMPLE RECIPE

SPOT PRAWNS WITH FOIE GRAS NAGE INSPIRED BY THIERRY RAUTUREAU

Yields 1.2 kg (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Brown vegetable stock see page 2·296	250 g	100%	① Dry blend propylene glycol alginate and salt. ② Disperse powder blend into cold stock. ③ Heat to 60 °C / 140 °F to hydrate.
Salt	3 g	1.2%	
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	0.2 g	0.08%	
Raw foie gras, cubed	40 g	16%	④ Blend with warm stock until fully emulsified.
White miso paste	15 g	6%	
Chervil, chopped	8 g	3.2%	⑤ Add, and steep nage for 1 min. ⑥ Strain.
Lime juice	to taste		⑦ Season nage, and reserve warm.
Salt	to taste		
Spot prawns	12 prawns (about 720 g)	about 290%	⑧ Steam in combi oven at 60 °C / 140 °F and 100% relative humidity for 12 min; or vacuum seal, and cook in 60 °C / 140 °F bath for 12 min.
Fresh lychees, peeled and seeded (or canned)	60 g	24%	⑨ Divide prawns among four bowls. ⑩ Garnish. ⑪ Pour warm nage around each portion.
Pink Lady apples, peeled and finely shaved with mandoline	60 g	24%	
Peanuts, roasted and crushed	10 g	4%	
Anise hyssop, small leaves	3 g	1.2%	

(original 1995, adapted 2010)

1

3a

3b

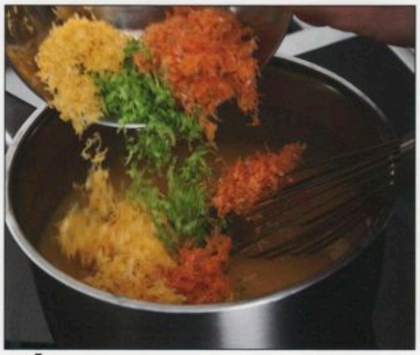
EGGLESS CITRUS CURD INSPIRED BY PASCAL BARBOT

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lemons, washed, whole	300 g	385%	① Vacuum seal in retort pouch, or place in large Mason jar.
			② Place pouch or jar in pressure cooker filled with 2.5 cm / 1 in of water.
			③ Pressure-cook for 30 min at gauge pressure of 1 bar / 15 psi, and cool.
			④ Remove lemons from pouch or jar, and puree.
			⑤ Pass through fine sieve, and measure 130 g of puree.
Lemon puree, from above	130 g	100%	⑥ Mix together, and reserve.
Grapefruit juice	100 g	77%	
Lime juice	60 g	46%	
Lemon juice	50 g	38%	
Lemon zest, finely grated	14 g	11%	
Grapefruit zest, finely grated	6 g	4.6%	
Lime zest, finely grated	2 g	1.5%	
Water	130 g	100%	⑦ Combine, and boil for 3 min.
Honey	35 g	27%	⑧ Stir in citrus puree.
Sugar	30 g	23%	⑨ Bring mixture to simmer.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	5 g	3.8%	
Salt	5 g	3.8%	
Unsalted butter, cubed	200 g	154%	⑩ Blend or whisk butter cubes into hot citrus mixture in small batches until fully emulsified.
			⑪ Strain through fine sieve, and refrigerate for at least 3 h.

(original 2006, adapted 2010)

7a



7b

10a

10b

10c

11

EXAMPLE RECIPE

OLIVE OIL "MARGARINE"

Yields 420 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	80 g	31%	① Dry blend agar and propylene glycol alginate.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	1.85 g	0.7% (*0.44%*)*	② Disperse powder mixture into cold water. ③ Bring mixture to boil to hydrate.
Agar (Texturas brand)	1 g	0.4% (*0.24%*)*	④ Cool at room temperature until set. ⑤ Puree gel until smooth to form fluid gel.
Pregelatinized starch paste see page 29	80 g	31%	⑥ Blend into fluid gel.
Olive oil	260 g	100%	⑦ Warm to 30 °C / 85 °F. ⑧ Blend oil gradually into fluid gel slowly until emulsified.
Salt	to taste		⑨ Season and chill.

(2010)

(% of total weight of other ingredients*)

CONSTRUCTED CREAMS

Dairy creams are natural O/W emulsions composed of droplets of butterfat stabilized with naturally occurring protein emulsifiers. A Modernist chef does not have to limit himself to natural animal milks because, with a bit of effort and the right emulsifier, any fat can be turned into a "cream." We have made dense, rich creams from flavorful oils such as hazelnut, but something similar works for extra-virgin olive oil, toasted-sesame oil, and other flavorful oils. These creams can be used directly, or can be combined with sugar to make a rich gelato that has no dairy to get in the way of the oil flavor.

Soy milk and other nut milks have been around a long time, usually as infusions made from ground nuts or seeds. Constructed creams are quite different because they can be made from oil alone and do not require a high-protein ingredient like soy. One reason to make these constructed creams is to ease past dietary restrictions; if you start with a vegetable-based oil, you can make faux "creams" without any animal products.

A very different approach to constructed creams is to make an animal fat "cream" that never passed through a teat. Our veal "cream" uses rendered veal fat with veal stock to create a cream that is much deeper in flavor than dairy cream (see page 5·33). Similar creams can be made with rendered pork fat or even bacon fat.

Perhaps our favorite emulsion is jus gras. Savory jus and flavorful, rendered fats are emulsified into a stable, meaty sauce with the silky richness of beurre blanc or hollandaise. When made with rendered chicken fat, it is an all-chicken "cream" from an animal that never produced milk. Something similar can be done with fish oils.

EXAMPLE RECIPE

PISTACHIO GELATO

Yields 1.1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	680 g	100%	① Blend until smooth.
Pistachio butter see page 2·418	210 g	30.9%	
Sugar	155 g	22.8%	
Pistachio oil	102 g	15%	
Salt	22 g	3.2%	
Locust bean gum (POR/A2 Powder, TIC Gums brand)	3 g	0.44%	② Dry blend, and disperse in pistachio mixture. ③ Warm to 60 °C / 140 °F.
Lambda carrageenan (Texturas brand)	2 g	0.3%	④ Homogenize until very smooth, and cool. ⑤ Season with more salt, if desired.
Polysorbate 80	0.8 g	0.12%	⑥ Churn, and reserve in freezer; or freeze in Pacojet container, and pacotize to serve.
Glycerol monostearate	0.15 g	0.02%	

(2010)

If using a Pacojet in step 6, omit the locust bean gum.

This ice cream is also delicious when made with roasted-hazelnut butter or cashew butter.

EXAMPLE RECIPE

HAZELNUT "CREAM"

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	250 g	100%	① Dry blend hydrocolloids other than polysorbate.
Tapioca starch	11.2 g	4.48%	② Disperse in cold water, and blend in polysorbate.
Whey protein isolate	6 g	2.4%	③ Homogenize thoroughly with commercial blender or rotor-stator homogenizer, if available.
Citric acid	0.5 g	0.2%	
Polysorbate 80	0.4 g	0.16%	④ Warm to 85 °C / 185 °F, and hold mixture at that temperature.
Xanthan gum (Keltrol T, CP Kelco brand)	0.16 g	0.06%	
Roasted-hazelnut oil see page 2·367 (or store-bought)	80 g	32%	⑤ Warm oil to 85 °C / 185 °F. ⑥ Drizzle into hydrocolloid mixture while shearing at full speed until fully emulsified, and then cool.
Salt	to taste		⑦ Season cream, and vacuum seal. ⑧ Store refrigerated; serve hot or cold.

(2008)

Salmon oil cream can be made by using the same procedure. Replace the hazelnut oil with rendered salmon fat, and use 50 g of water. The cream will be thicker and similar in texture to sour cream. We use it as a garnish for our Salmon Rus (see page 5·161).

EXAMPLE RECIPE

JUS GRAS

Yields 280 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Shallots, minced	80 g	40%	① Sauté shallots until golden, about 5 min.
Neutral oil	20 g	10%	
Fino sherry	100 g	50%	② Add to pan of sautéed shallots.
White port (dry)	50 g	25%	③ Reduce mixture to glaze.
Brown chicken stock see page 2·296	450 g	225%	④ Combine with glaze in pot. ⑤ Reduce until syrupy, to about one-third of original weight.
Sous vide chicken juice see page 2·344	200 g	100%	⑥ Strain, and measure 200 g of reduced jus base.
Reduced jus base, from above	200 g	100%	⑦ Disperse emulsifiers into reduced jus base. ⑧ Warm to hydrate PGA, and blend in commercial blender or rotor-stator homogenizer until very smooth.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	0.6 g	0.3%	
Liquid soy lecithin (NOW brand)	0.4 g	0.2%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.4 g	0.2%	
Rendered chicken fat, or butter, melted see page 3·145	80 g	40%	⑨ Drizzle slowly into warm jus, blending constantly until fully emulsified.
Salt	to taste		⑩ Season and serve. Or cool, vacuum seal, and refrigerate until use.
Lemon juice	to taste		

(2010)

Jus gras is best made by using pressure-rendered fat prepared with baking soda, which creates a strong roast chicken flavor. See page 3·145.

Jus gras is a traditional stock- and jus-based sauce enriched with fat. The difference between this classic version and ours is that we use chicken fat rather than butter, which gives it a more assertive chicken flavor. The emulsifiers help it resist breaking.

NANOEMULSIONS

Nanoemulsions are O/W suspensions with droplet sizes so tiny the mixture remains clear. Soft drinks are the most familiar nanoemulsions. Aromatic oils like tangerine, cinnamon, and cola nut are dispersed and suspended so that they are perceptible only as a gentle perfume and not as a peppery barrage of spicy, concentrated droplets.

The broth for our chilled chicken noodle soup is also a nanoemulsion enhanced with essential oils of bay and thyme. It is important that the flavors be present in every spoonful and not floating on top or clouding the broth. This is achieved using gum arabic as an the emulsifier to make a nanoemulsion.

EXAMPLE RECIPE

CHILLED CHICKEN-NOODLE SOUP

Yields 1.2 kg (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken thigh meat, ground	600 g	200%	① Puree until smooth.
White chicken stock see page 2·301	300 g	100%	② Pass through fine sieve. ③ Divide into 100 g portions.
Salt	10 g	3.3%	④ Place each portion between two layers of plastic wrap, and roll evenly into layer 1.5 mm / ⅟₁₆ in thick.
Activa RM	8 g	2.7%	
Sodium tripolyphosphate (Nutrifos 088, ICL Performance Products brand)	0.15 g	0.05%	⑤ Vacuum seal sheets individually. ⑥ Cook sous vide in 62 °C / 144 °F bath for 12 min. ⑦ Refrigerate sheets for 3 h. ⑧ Remove from sous vide bags, and cut chilled sheets into noodles 3 mm / ⅛ in thick, yielding about 100 g per portion. Reserve.
Gum arabic	30 g	10%	⑨ Homogenize until smooth.
Bay essential oil	15 g	5%	
Thyme essential oil	15 g	5%	
Consommé Madrilène see page 2·374	300 g	100%	⑩ Blend 1.2 g of gum-oil mixture into cold consommé. Liquid will remain clear.
Salt	to taste		⑪ Season consommé.
Tarragon leaves (small)	to taste		⑫ Divide noodles among four bowls, forming nest in each.
Thyme leaves	to taste		⑬ Pour consommé over noodles. Garnish chilled soup with leaves.

(2010)

Serve chilled; the emulsion will break if the mixture is heated.

EXAMPLE RECIPE

GINGER COLA

Yields 340 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Distilled water, cold	200 g	100%	① Combine, and steep at room temperature for 20 min.
Ginger, peeled and grated	35 g	17.5%	② Strain, and reserve 125 g of ginger water.
Ginger, thinly sliced and blanched three times in boiling water to remove bitterness	300 g	150%	③ Combine, and simmer until sugar is dissolved. ④ Remove from heat, and steep at room temperature for 20 min.
Distilled water	200 g	100%	⑤ Cool completely, and reserve 200 g of ginger syrup.
Sugar	120 g	60%	
Gum arabic	20 g	10%	⑥ Blend to form smooth essential oil base.
Brominated vegetable oil	5 g	2.5%	
Lemon essential oil	5 g	2.5%	
Sweet orange essential oil	5 g	2.5%	
Vanilla extract	2.5 g	1.25%	
Ginger syrup, from above	200 g	100%	⑦ Blend together until combined.
Ginger water, from above	125 g	62.5%	⑧ Pour mixture into soda siphon.
Lime juice	16.5 g	8.25 g	⑨ Vent with one cartridge of carbon dioxide, and then charge with two cartridges.
Liquid caramel color	1.25 g	0.62%	
Essential oil base, from above	0.33 g	0.16% (*0.1%*)*	⑩ Refrigerate siphon on ice for at least 3 h before serving.

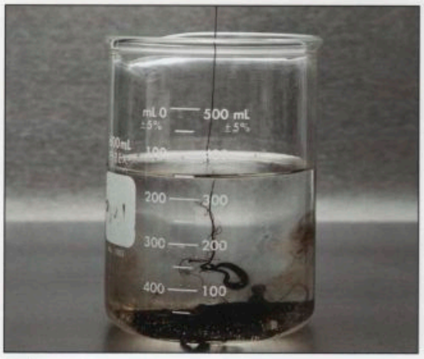
(2010)

(% of total weight of ginger water and ginger syrup*)

Other sodas can be made in a similar way by using a nano-emulsion with essential oils. Stock or an infusion can be used in place of the water.

"OpenCola" is a commercial drink with a published recipe (available on the Internet) said to be inspired by Coca-Cola. You can use that recipe with the techniques described here to make your own cola or to experiment with other ingredients. Ferran Adrià, Marc Veyrat, Jean-Georges Vongerichten, and a number of other chefs have featured homemade sodas in their restaurants.

For a step-by-step procedure on carbonating liquids, see page 2·468.



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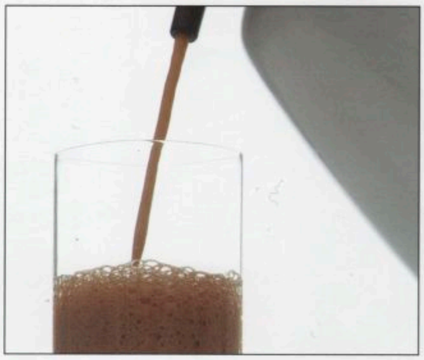
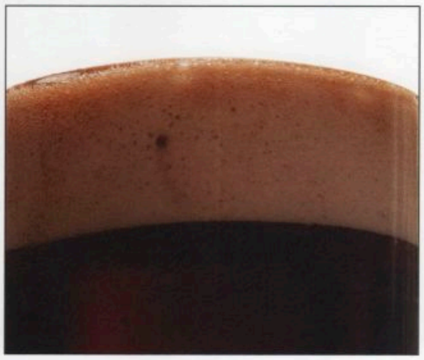
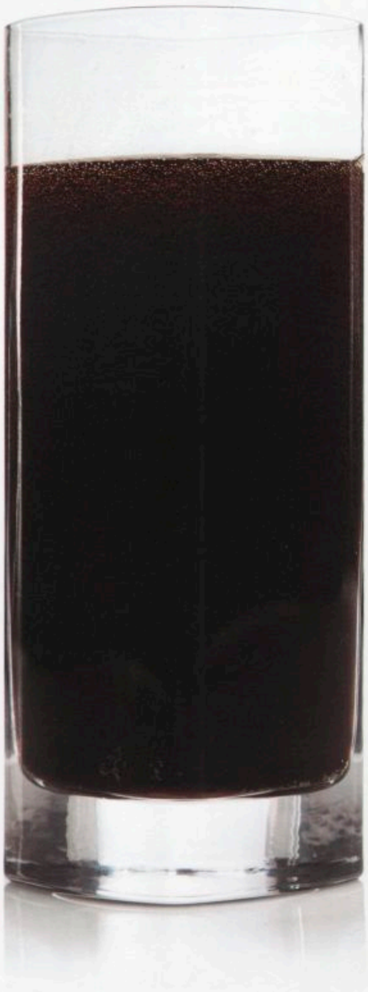
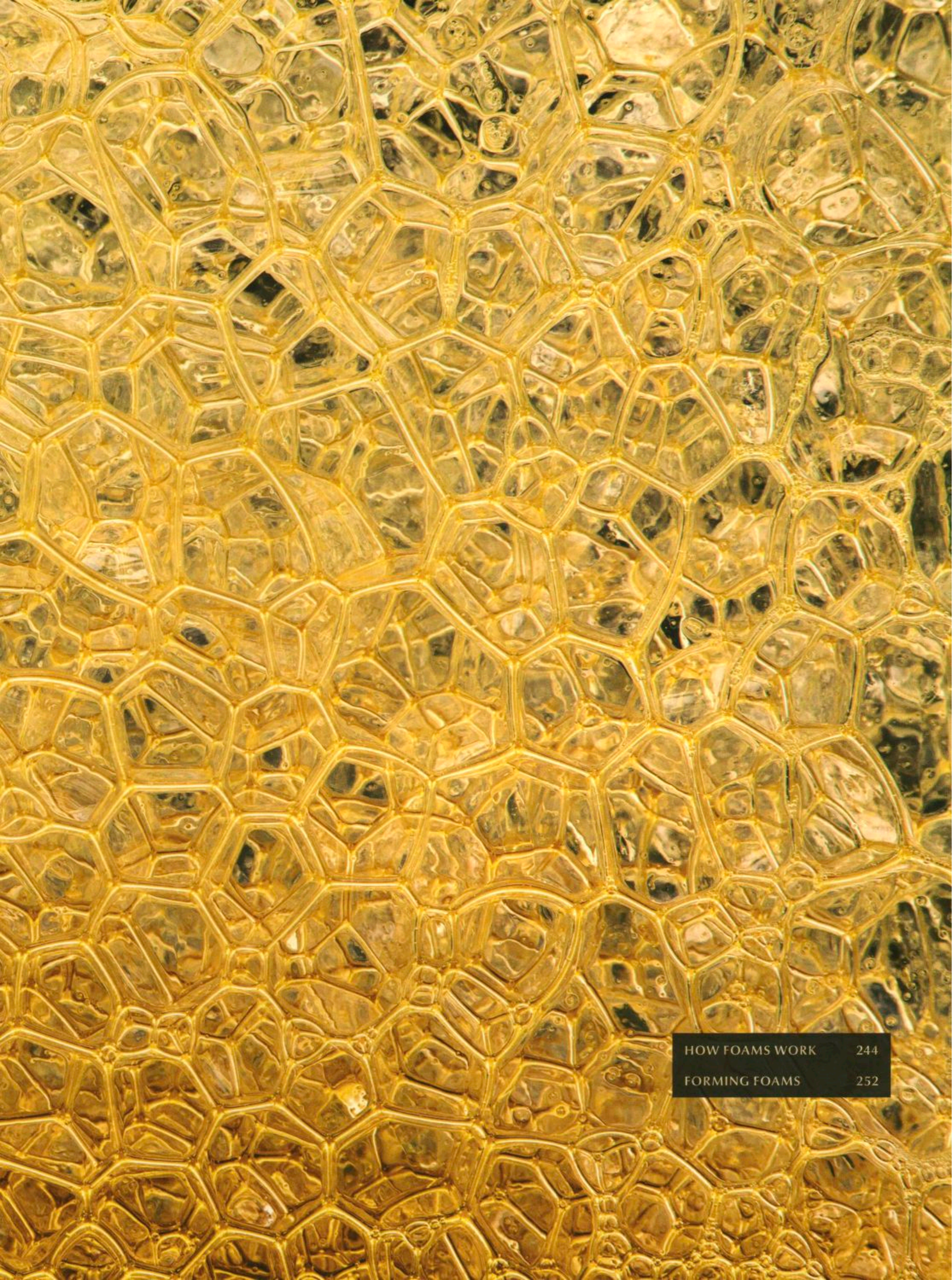






16 FOAMS



FOAMS

Look around an active kitchen as a big meal is under preparation, and you're likely to see foams in many forms: a sink full of soap suds, a beer with a frothy head, a caffè latte, a loaf of bread, a meringue-covered pie accompanied by ice cream and whipped cream. Each of these is a **foam,** a very interesting structure that's nearly all air (or some other gas) enclosed in bubbles made of thin membranes of liquid. Modernist chefs have pioneered all kinds of novel culinary uses for foams, making frothy varieties of mashed potatoes, honey, cheese—even foie gras. Making stable foams can be tricky, but an understanding of the basics, coupled with the patience to experiment, will allow you to explore a vast universe of new food textures and appearances.

You can think of a foam as a kind of G/W (gas in water) **emulsion**. Emulsions, the subject of the previous chapter, exist because oil and water don't mix. Nitrogen, oxygen, carbon dioxide, and some of the other components of air are water soluble—but only weakly. Oxygen in water is what enables fish to live, but only a tiny amount of it dissolves. Carbon dioxide is more successful at dissolving, as shown by fizzy drinks. But like any gas in water, CO_2 quickly reaches gas saturation, or its **solubility limit,** at very low concentrations.

Like an emulsion, a foam has two parts: a **dispersed phase** and a **continuous phase.** In a foam, a gas (usually air) plays the role of the dispersed phase. Often a water-based solution or mixture surrounds the air bubbles as the continuous phase, although the bubbles in foams are generally much larger than the oil droplets dispersed in an emulsion. G/O foams also exist—whipped butter, for example, consists of gas surrounded by oil—but these are generally more important in industry than they are in the kitchen.

Also like emulsions, foams are complex. Scientific textbooks and journals devote endless pages to describing the physicochemical mechanisms that stabilize or destabilize foams. Whether cooking traditional dishes or Modernist creations, you'll find it invaluable to have a basic understanding of the most important phenomena involved in foaming and of the ingredients that make or break foams.

Work on the fundamental science has inspired many tools, ingredients, and techniques for creating culinary foams. But, as we discuss below in Forming Foams, the practice of foaming still relies much more heavily on experiments than it does on underlying theory. When working with foams in the kitchen, you just have to start with combinations that are known to work and branch out on your own path from there.

For more on how to make foams of mashed potatoes, honey, cheese, foie gras, and butter, see pages 267, 272, and 281.

If foams are G/W (gas in water) emulsions, then what about the opposite? It turns out that W/G emulsions do exist; each one is composed of droplets of water suspended in a continuous phase of a gas. Fog and clouds are the most familiar examples. The smoke-like fog that emanates from dry ice or liquid nitrogen is another.

When we think of traditional cooking foams, we usually picture whipped cream or meringue. But foams also include light froths (left), dense, colorful foam (right), and fully set items like soufflés or even bread. Foams range from light to heavy, coarse to fine, soft to fully set. All of these foams exist in traditional cuisine, but Modernist techniques have elevated them to another level.

HOW FOAMS WORK

Just as emulsifiers help stabilize an emulsion, a **foaming agent** or **foam stabilizer** will, under the right conditions, delay the bursting or disappearance of bubbles in a foam. Some foaming agents and stabilizers are familiar ingredients, such as egg whites; others are more specialized. But any substance that does the job can be called a foaming agent or a foam stabilizer. These foaming aids generally fall into six categories: fats, proteins, gelling agents, starches, surfactants, and solids. The stability and other properties of any foam depend in large part on what kind of agent is protecting the bubbles inside it.

One class of foaming agents consists of **surfactants,** the double-ended molecules that can also be used as **emulsifiers.** The typical surfactant combines a **hydrophilic** (water-loving) portion with a **hydrophobic** (water-avoiding, gas-loving) portion. In foams, the hydrophilic part of the surfactant molecule is attracted to the water phase, while the hydrophobic portion migrates to the gas phase of the bubble. As a result, surfactants tend to coat the surfaces of foam bubbles, stabilizing them.

For more on emulsifiers, see chapter 15 on Emulsions, page 196. For more on gels, see chapter 14, page 64.

Some antifoaming agents destabilize undesirable foams. These agents generally are not used in cooking, except in certain industrial processes like brewing.

We know this from everyday experience with soaps and detergents, which are surfactants. More broadly, we can use certain surfactants as foaming agents, with the usual proviso that their effectiveness will be influenced by the other ingredients involved.

Fat droplets are the key stabilizing components in the most familiar foam in cooking: whipped cream. When you beat the cream, the mechanical action both pushes bubbles of air into the liquid and also pushes fine droplets of butterfat to the outer edge of the air bubbles. The tiny semisolid fat globules stick together around the surfaces of the bubbles, forming a network that reinforces the bubbles and enables the whipped cream to support its own weight as it stands up in peaks.

A hot-cold treatment makes cream whip up better to produce a finer foam that has a much longer shelf life. Heat the cream to 30 °C / 86 °F, hold it at that temperature for 30 min, and then chill it to 5 °C / 41 °F before whipping. The treatment anneals and modifies the crystal structure of the fat droplets, in much the same way that the tempering process changes the crystal structure of chocolate.

Amazingly, the heat treatment also works *after* the cream has been whipped—but only if done very carefully so as not to overheat and melt the whipped cream. Vacuum-sealing isn't an option, and combi ovens and water-vapor ovens aren't accurate enough at low temperature, so heat-treating already whipped cream can be tricky

You might expect that the milk foam in a caffè latte works in much the same way, but in fact an entirely different agent is at work in that foam: protein. High-temperature water vapor from the steam wand of the espresso machine cooks—or in chemical terms, partially **denatures**—protein molecules in the milk. Thus transformed, the milk proteins coat the surface of the air bubbles and set into a strong skin-like gel that helps the foam hold its structure.

Many kinds of proteins make good foaming agents when heated. Traditional cooking often exploits the proteins in egg whites and yolks for this purpose, for example. When you make a sabayon, the whipping and heating denature proteins in egg yolks, which then stabilize the bubbles created by the vigorous beating. A soufflé benefits from additional proteins provided by whipped egg whites and heat from an oven rather than a stove top. You might not think of soufflés and caffè lattes as having similar properties, but each is stabilized by proteins, albeit different proteins, set into a gel by heat.

We call these **"set foams,"** because heat causes them to set into **thermo-irreversible** gels. Modernist foam recipes sometimes call for proteins such as Versawhip, a proprietary product made by treating soy proteins with enzymes, or for cellulosic gums such as methylcellulose. Like the proteins in eggs or milk, these modern ingredients can cover the surfaces of foam bubbles and thus help create or stabilize a foam.

It would be only natural to think that if one foaming agent is good, two are better. But many foaming agents function only solo—pairing them with others just doesn't work. For example, fat is the enemy of many foams stabilized by proteins, including the head of a poured beer, an egg-white meringue, or a foam made with Versawhip.

So, counterintuitive as it may seem, the same fats that support whipped cream actually undermine the stability of the hot foam in a caffè latte. The fat globules block the heated proteins from performing their stabilizing job. That competition explains why nonfat milk produces a stiffer and more durable foam for espresso drinks than whole milk does—and why cream is even harder to make into a proper steamed foam (see page 392).

The proteins that work best for set foams form gels when they denature, so it makes sense that you can also stabilize a foam by using a gelling or thickening agent instead, with the benefit that heat is not always required. Many of the cold foams pioneered by Ferran Adrià at elBulli, for example, are stabilized by gelatin. The mixtures form fluid

Whipping is the classic traditional technique for making a foam. Modernist chefs have many other options, but whipping still works, particularly for light foams.

gels that can flow through the nozzle of a **whipping siphon.** The gels help trap bubbles of air entrained in the process. In mashed-potato foam, gelled starch from the potato similarly stabilizes the foam after it has passed through a whipping siphon.

Thickeners that do not gel generally aren't sufficient by themselves to enable creation of a stable foam, but they can play a strong supporting role. In general, the thicker the liquid, the longer bubbles in it can last. So any thickening agent, such as xanthan gum, that increases viscosity also tends to stabilize a foam. The long polymer molecules of the thickener tangle to form a network that slows the rate at which the liquid in the bubbles' walls can drain away, which is how foams die.

Bread offers an even more dramatic example of how foaming agents and stabilizers can sometimes work synergistically. Bread, muffins, and other baked goods are also examples of starch-stabilized set foams. In these cases, we cook or bake the batter in order to fully gelatinize and set the foam bubbles. Although starch is one of the key elements at work in baked-good foams, it is not the only one. Eggs are often used as binding and gelling agents in cakes and batters; their proteins contribute to stability, as do the gluten proteins from wheat flour in many breads and baked goods.

These foams are much stiffer than a sabayon or caffè latte; baked foams have real structural strength and hold their shape for days or weeks, even when sliced, buttered, or used in a sandwich. Nonetheless, they are just another type of set foam.

A **frozen set foam** is stabilized by simple solidification. If you heat a solid above its melting point, inject gas into it, and then let it cool below the melting point, you will create this type of set foam. Industrial applications of this approach include foamed glass (used for insulation) and foamed

THE ARCHITECTURE OF
Foam Geometry

Bubbles seem simple enough at first glance. They're minimalists: they use the least surface area required to enclose their volume. Dip a metal hoop into soapy water, and the film that forms is a flat disc. A single isolated bubble is always a perfect sphere. When two bubbles meet, they adopt the configuration with the smallest possible surface area. Think of them as lazy—they expend as little energy as possible.

Foams with more than two bubbles follow the same principles but are more complex. A bubble is held together by **surface tension**, a kind of attraction to self—yet in a foam, each bubble's liquid surface is also attracted, at a molecular level, to those of nearby bubbles, and this, too, is an example of **surface tension**. It's fascinating to watch the tiny bubbles shift, mate, and burst.

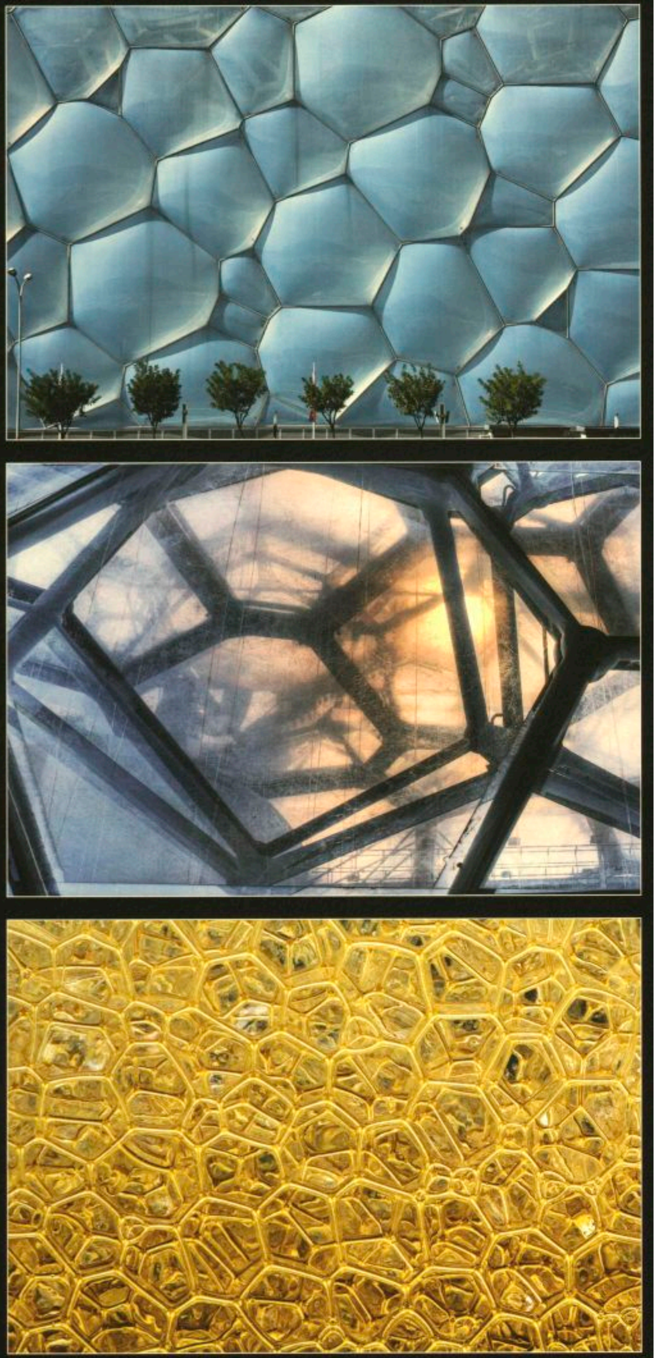
Mathematical physicists have contemplated foams for more than a century. In 1887, Lord Kelvin was looking for the most efficient bubble form. He wondered: how would one divide three-dimensional space into cells of equal volume with minimum total surface area? That is a mathematical statement of what foams try to do as they settle into the lowest-energy configuration.

This came to be known as "the Kelvin Problem," and Kelvin's solution was a fourteen-sided polyhedron called a **tetradecahedron**, with six square sides and eight hexagonal sides. The hexagonal faces, he proposed, would be slightly curved, as observed by Belgian physicist Joseph Plateau.

There the matter stood until 1993, when two Irish physicists, Denis Weaire and Robert Phelan, discovered a structure requiring even less surface area—only 0.3% less, but that still counts. Known as the Weaire-Phelan structure, it contains two geometric shapes: irregular tetradecahedrons and irregular dodecahedrons. They are called irregular because the edges are not all the same length.

The end result of this arrangement is now famous, even if few people can name it, because the Weaire-Phelan structure inspired the Beijing National Aquatics Center, known as the Water Cube, used during the 2008 Summer Olympics. The design was the idea of Australian architecture firm PTW, designer Chris Bosse, and engineering firm Arup.

The glowing blue building's steel space frame, wrapped in a translucent polymer, repeats the same two shapes. When you look at a slice through the structure, as you see on the sides of the Water Cube, the shapes appear to be randomly distributed, despite having a very regular order. The cube is also elegant and beautiful.



The exterior of the Beijing National Aquatics Center (top) is based on the Weaire-Phelan structure, formed by repeatedly joining two different shapes of equal volume to minimize their shared surface area. The interior of the building (middle) shows the polyhedral structure more clearly. A very coarse foam (bottom) looks strikingly similar.

metal (used for lightweight strength). In the kitchen, we can make this type of foam from butter. If you heat it just above its melting point and put it in a whipping siphon, you can create a soft butter foam (see page 286). Pipe this foam into liquid nitrogen or otherwise chill it, and you'll get a stiffer frozen set foam. A similar thing happens with melted chocolate, which solidifies into a frozen set foam if properly aerated, as described on page 313. Ice cream is another kind of set foam—we may not typically think of it as a foam, but in fact most ice cream is about 50% air by volume.

Foams can take multiple forms, depending on how you prepare them. Whipped egg whites—the basis for mousses and similar foods—form a soft foam stabilized by the egg-white proteins alone. Using egg-white powder produces an even better foam because the protein is more concentrated.

One can also add heat and sugar to egg-white foams to create a meringue. Meringues made in this way are stabilized in part by a protein gel from the partially cooked egg whites and in part by the viscosity of the sugar syrup. Such a meringue can be eaten as is, or it can be folded into a butter-cream frosting to lighten it.

Alternatively, we could bake the meringue at low heat, which essentially dehydrates the protein gel and evaporates most of the water out of the sugar syrup. Depending on the amount of sugar used, among other factors, we could get a very crisp meringue or a chewy one, both of which are examples of fully set foams.

Or we could fold the whipped egg whites into a soufflé batter and bake the mixture to create a set foam. Although they are "set," most soufflés are not very stable. Unlike baked goods that are fortified with starch and flour proteins, the egg gels that form the bubble walls of a soufflé are not strong enough to support the whole structure by themselves. They rely in part on the gas pressure in the bubbles to hold them up. As soon as you cut into them, the gases inside (hot air and water vapor) escape (or cool and lose pressure), and the soufflé collapses. Thus, the same initial foam—

For more on how proteins can link up to form a gel, see page 70.

For more on cold foams developed by Ferran Adrià, see pages 265 and 272.

Antifoaming agents are sometimes used to keep foam from forming, such as in motor oils and in liquids blended by high-shear mixing. To our knowledge, antifoaming agents have little application in the kitchen, but it's entirely possible that some creative chef will find a culinary use for them in the future.

Traditional Foams

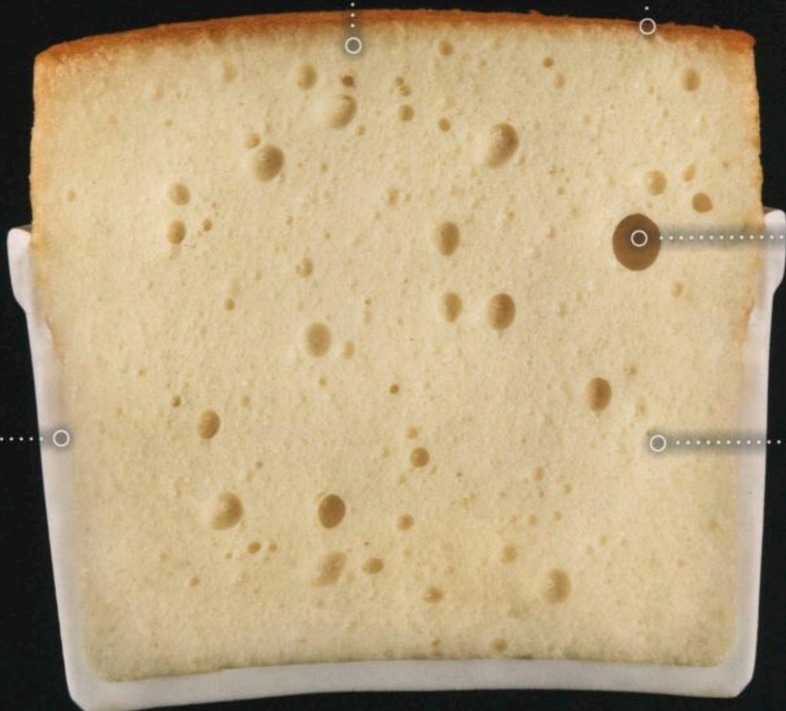
Foams can be fine or coarse, hot or frozen, light as air or dense and thick. Whipped cream is perhaps the first edible foam that comes to mind for most people, because the transformation from liquid to foam is so striking. Light foams, like whipped cream or the froth on a cappuccino, gradually lose their structure as gravity pulls the liquid down until the bubble walls are simply too thin to survive. Peaks of delicate meringue, mousses, and soufflés are all created with the excellent foaming properties of eggs. Gelatin is often used with cold or frozen egg foams to enhance their structure and stabilize them.

A slice of bread is also a good tool to illustrate the basic structure of foam. Air or gas bubbles are combined and suspended in a liquid–in this case, dough. The finished bread is a set foam, a matrix of bubbles separated by solid walls of starch. Puffed snacks are also foams, but they are rarely thought of that way.

Type	Example	Stabilizer	Gas	Foaming method	Note
fat foam	whipped cream	milk fat	air, nitrous oxide	whisk, siphon	most common traditional foam
	parfait	milk fat and gelatin	air, nitrous oxide	whisk, siphon	longer shelf life when made with gelatin or other stabilizers
starch foam	baked goods	flour	carbon dioxide, steam	fermentation, chemical leavening	starch gel is often supplemented by egg gel
	puffed snacks	tapioca, other	steam	frying in oil	gelatinized and dehydrated before frying
egg foam	sabayon	egg-yolk gel	air, steam	whisk while heating	egg gels hold foam bubbles well and are used in many traditional foams
	meringue	egg-white gel	air	whisk while heating (in some cases)	
	soufflé	mixed-egg gel	air, steam	whisk, and then bake	
other protein foam	caffè latte foam	milk proteins	steam	steam wand	foam for espresso drinks
	mousse	gelatin	air	whisk	mainly used in cold or frozen desserts

THE RISE AND FALL OF A SOUFFLÉ

Few culinary creations have as much mystique as soufflés, but the principles behind them are very simple. The initial batter is a foam that is usually made by folding whipped egg whites into a thicker base, which typically contains some starch. Baking the soufflé inflates the bubbles in the foam batter, both by heating the air and by evaporating some water. This process creates a heat-set foam, but soufflés are notorious for being only lightly set—they can fall or collapse if shaken or simply cooled, so they must be cooked to order and served quickly.

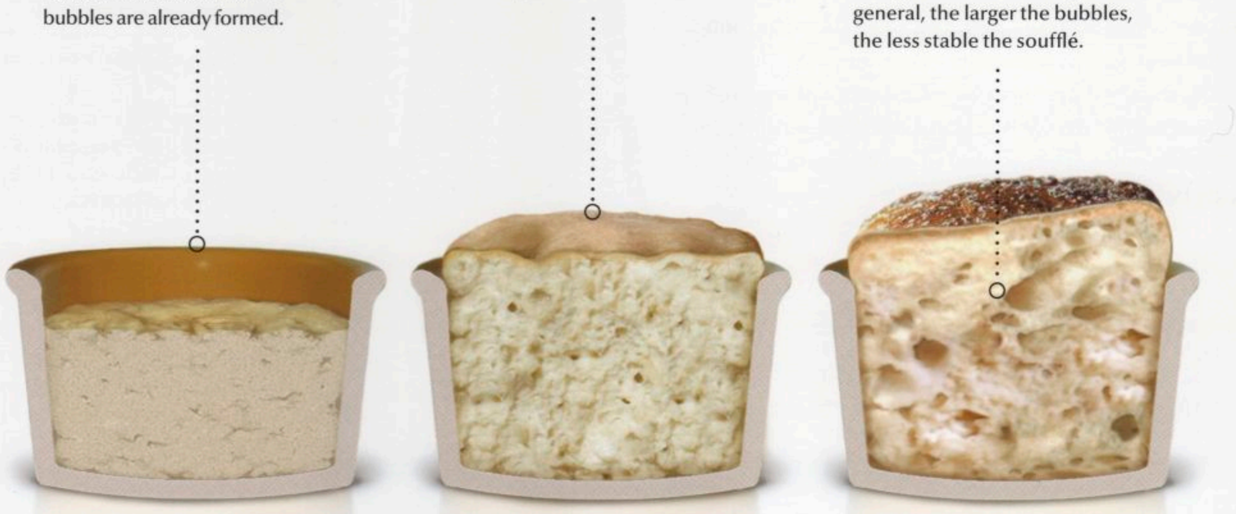


For more on hot whipped cream, see page 278.

egg white whipped with air and stabilized by its own proteins alone—can take many different forms once it is mixed or cooked with other ingredients.

Most foams, rather than being fully stable, are instead **metastable,** meaning they remain stable for a period of time but destabilize eventually. A whipped cream made in the traditional fashion can last for days in the refrigerator. With the proper heat treatment, it can last even longer. Normally, heat is the enemy of whipped cream, ruining the foam. But applying just the right amount of heat helps recrystallize and stabilize the fat globules that are holding the air bubbles in place.

Another option is to add a stabilizer, such as gelatin, to the cream to extend its life. But this approach never yields the stability of a set foam. Eventually the whipped cream will lose its structure and flow freely again. This happens in part because, like many foams, whipped cream is a **shear-thinning fluid,** as described on page 5.



THE SCIENCE OF

Foams Versus Emulsions

Foams are similar to emulsions, in that they are both structures formed by two phases that don't dissolve in each other. In the case of emulsions, oil and water are the immiscible components; for foams, these roles are played by gas and liquid. In general, foams are much less stable than emulsions: a jar of commercial mayonnaise keeps for months, but foams generally don't last that long. There are several technical reasons why.

First, the gas bubbles in a foam are typically much larger than the droplets in an emulsion. Fine foams may have bubbles 0.01–0.1 mm across; coarse foams have bubbles several millimeters in diameter. The droplets in most food emulsions, in contrast, range from 0.001–0.01 mm in diameter, a factor of 10–100 smaller than those in foams.

In both foams and emulsions, the smaller the bubble or droplet, the higher the pressure within it (due to the bubble's surface tension), a phenomenon known as Laplace pressure. In foams, this causes small bubbles to either dissolve or burst.

Aside from size, density plays a role as well. The liquid and the gas phases of a foam differ more in density than do the oil and water in an emulsion. Phenomena like **creaming** and **sedimentation** that occur in emulsions also occur in foams—in a process called draining—but happen much faster.

Yet another reason for the evanescent nature of foams is that the bubbles in them press tightly together to form polygonal structures (see page 246) separated only by a thin film. Gas, which is more soluble in water than oil is, diffuses through the liquid between bubbles, in a foam equivalent of **Ostwald ripening** (described on page 211) that shortens the longevity of the froth.

HOW GUINNESS GETS ITS HEAD

Guinness draft beer is famous for both its taste and its velvety, foamy head. But this doesn't translate well to the beer that's distributed in cans. In the late 1980s, Guinness developed an answer: a special can, pressurized not just with CO_2, as normal beer cans are, but also with nitrogen. Cans—and more recently, bottles—of Guinness contain a floating plastic container called a widget, which releases additional nitrogen when the container is opened. This sophisticated combination has been very successful in mimicking draft Guinness. In 2006, the company introduced another option: the Surger, an ultrasonic device that sits under the beer glass and sends out a pulse of ultrasound to create cavitation, driving bubbles out of the solution.

Small holes in the widget release bubbles of gas that whip the beer into a froth, helping to generate the creamy head that characterizes draft Guinness. Unlike the nitrous oxide used in a whipping siphon or the carbon dioxide used in carbonation, not very much nitrogen dissolves in the beer because nitrogen has low solubility in liquids. The widget physically holds the nitrogen in and slowly releases it, mimicking carbon dioxide gradually emerging from solution.

The foamy head is whipped by release of the gas inside the widget, which acts a bit like an inside-out whipping siphon (see page 261) but with a different mechanism.

Bottles of Guinness are pressurized through the direct use of gas. The pressure forces gas and beer into the widget, which then releases it over time when the bottle is opened. Cans of Guinness are pressurized indirectly by injecting liquid nitrogen into the can. The nitrogen then boils into gas.

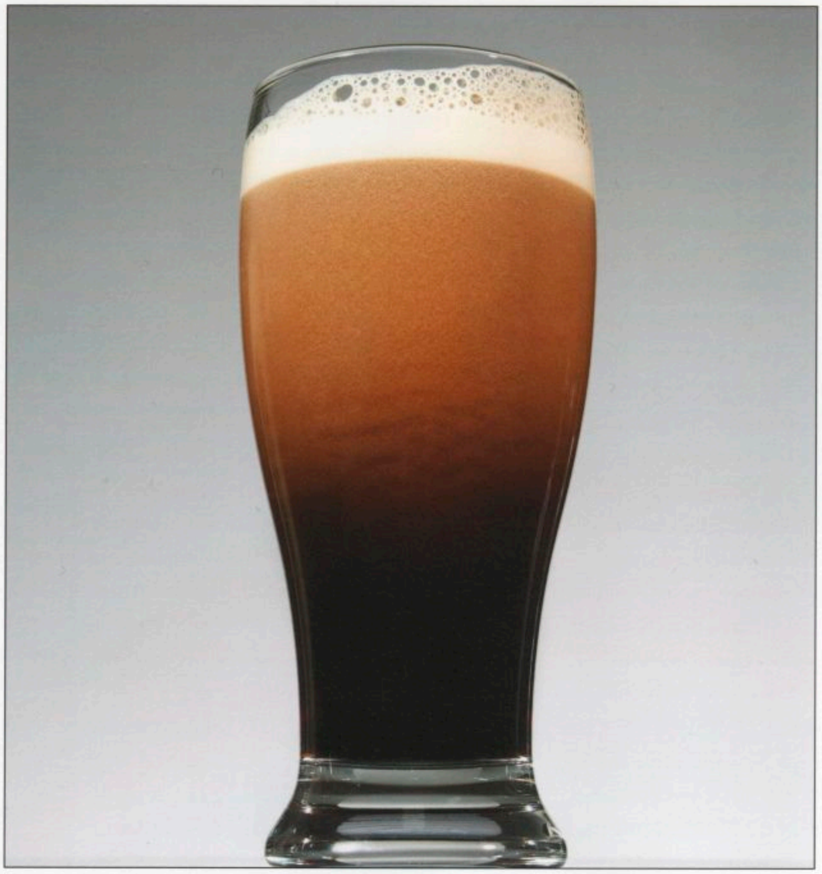
The "rocket widget" shown here is just one of several designs for widgets that Guinness has used over the years.

The widget contains nitrogen under pressure, which is released when the bottle is opened. Some beer is also forced inside the widget. The nitrogen gas bubbles whip the beer much as a whisk would.

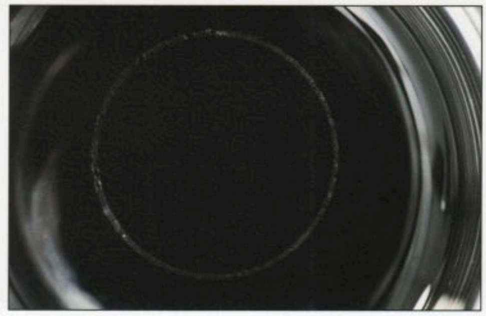
Fins on the side prevent the widget from leaving the bottle and going down the drinker's throat. Spherical widgets are used in canned Guinness.

The widget is triggered by the release of pressure when the bottle is opened. Until then, the can or bottle must remain stable, including when shaken or exposed to heat. Most gas escapes when the bottle is opened, but more is released every time you tip the bottle to drink.

Foaming agents in the beer, including alginate and others, help retain the head.



Many beer lovers want a foamy head and will go to great lengths to get it. The bubbles in beer foam are formed as CO_2 dissolved in the liquid comes out of solution slowly. For this process to happen, the bubbles need a **nucleation site**—a place to form. One trick is to use a beer glass with a laser-etched pattern in the bottom. The rough surface helps the bubbles form. Many Champagne glasses have a similar feature.



Guinness has a long history of technical and scientific innovation. From 1899 to 1937, William Sealy Gosset was a Guinness brewer. He also became one of the world's leading statisticians and spearheaded the application of statistical methods to quality control. Gosset discovered many important statistical concepts. But because the company policy forbade employees from publishing scientific papers, he published them in secret under the pseudonym "Student." Today, every statistics class covers "Student's *t*-distribution," which predicts the errors you should expect when measuring a small sample of a population.

Traditional Foaming Agents

You can't make foam with water alone—if you want foam, you need to add an ingredient that will help stabilize and suspend air bubbles. The most common foaming agents are eggs, milk, and cream. These ingredients are rich in albumin, lecithin, whey, and casein proteins, all components with excellent foaming properties that can be used in various concentrations. Gelatin and soy protein are also household items with good foaming potential.

Example	Foaming agent	Typical concentration	Typical uses	Note
egg white	albumin	8%–100%	meringue, soufflé, sponge cake	one egg white contains 12.5% albumin
egg yolk	lecithin	3%–30%	hollandaise, sabayon	will not create same volume as egg-white foam
butter	milk protein and milkfat	1%–75%	whipped butter	combines with other proteins to form stable emulsion when between 46 °C and 56 °C / 115 °F and 133 °F
soy	lecithin	0.5%–2.5%	sponge cake, vegan mousse	neutral flavor; makes dry, coarse foams
gelatin	gelatin	0.2%–2.0%	fish mousse	cold foams only, unless in the presence of transglutaminase; protein-binding with transglutaminase makes foam heat-stable
milk	casein and whey proteins	5%–100%	steamed milk foam	enjoyed on popular coffee drinks
dairy	casein and whey proteins	2%–100%	milk shake, protein shake, whipped cream	these proteins give dairy products their natural foaming ability

FORMING FOAMS

It is pretty simple, in principle, to make a foam: you need to introduce lots of little bubbles into a liquid of some kind. The classic way to do this is with a whisk, which does the job well for two reasons. The first is that as you pass the cluster of wires through the air and then the liquid, each one entrains air, leaving a trail of bubbles in its wake. The more wires the whisk has, the more air it is able to incorporate. The other thing that a whisk does is to create **shear forces** that split existing bubbles into even smaller bubbles, helping refine the texture of the foam. Just as smaller oil droplets produce a more stable emulsion, smaller bubbles almost always yield a more stable foam.

For more on how gases dissolve in liquids, see Water as a Solvent, page 1·330.

Don't let the similarities between emulsions and foams lead you to believe that the best tools for one are ideal for the other. A blender, for example, is poor at making foams, because the blades are at the bottom of the apparatus, where there is no air that can be worked into the liquid. If you rigged a tube that could blow air or another gas into the bottom of the blender while the blade was in action, then the blender would be able to create foams. Otherwise it's quite difficult to incorporate air into the mixture. In fact, that's partly why blenders are so useful for other kitchen tasks: foam creates volume and changes texture, which can be annoying outcomes if they're not the desired ones.

Shaving cream is a familiar foam created by pressurized gas from a can. It replaced foam whipped by hand with a brush and soapy water. Shaving cream is a complicated product that can have more than 200 ingredients.

Unlike a conventional blender, a hand blender (aka immersion blender) allows you to control how deep the blade goes into the liquid. Holding an immersion blender near the surface of a liquid can be an ideal way to make a foam. To do this most effectively, however, you don't want to use the cutting blade. Instead, insert the flat disc, which entrains more air into a mixture and subjects more of the liquid to shear forces. This process will further break down those bubbles to tinier and tinier, and thus more and more stable, sizes.

A rotor-stator homogenizer is also useless for making foams, because, like those of a blender, its blades are fully immersed in the liquids and don't entrain much air. Two other great tools for making emulsions—the high-pressure homogenizer and the ultrasonic homogenizer, are likewise poor candidates for making foams.

Foam-making has a special tool all its own that does an admirable and reliable job of incorporating tiny bubbles into a fluid. Whipping siphons, such as those made by ISI and Liss (see page 261), are a very convenient way to make a foam. Most chefs use a simple handheld version of the siphon, but industrial-size versions exist as well and are used to make commercial desserts.

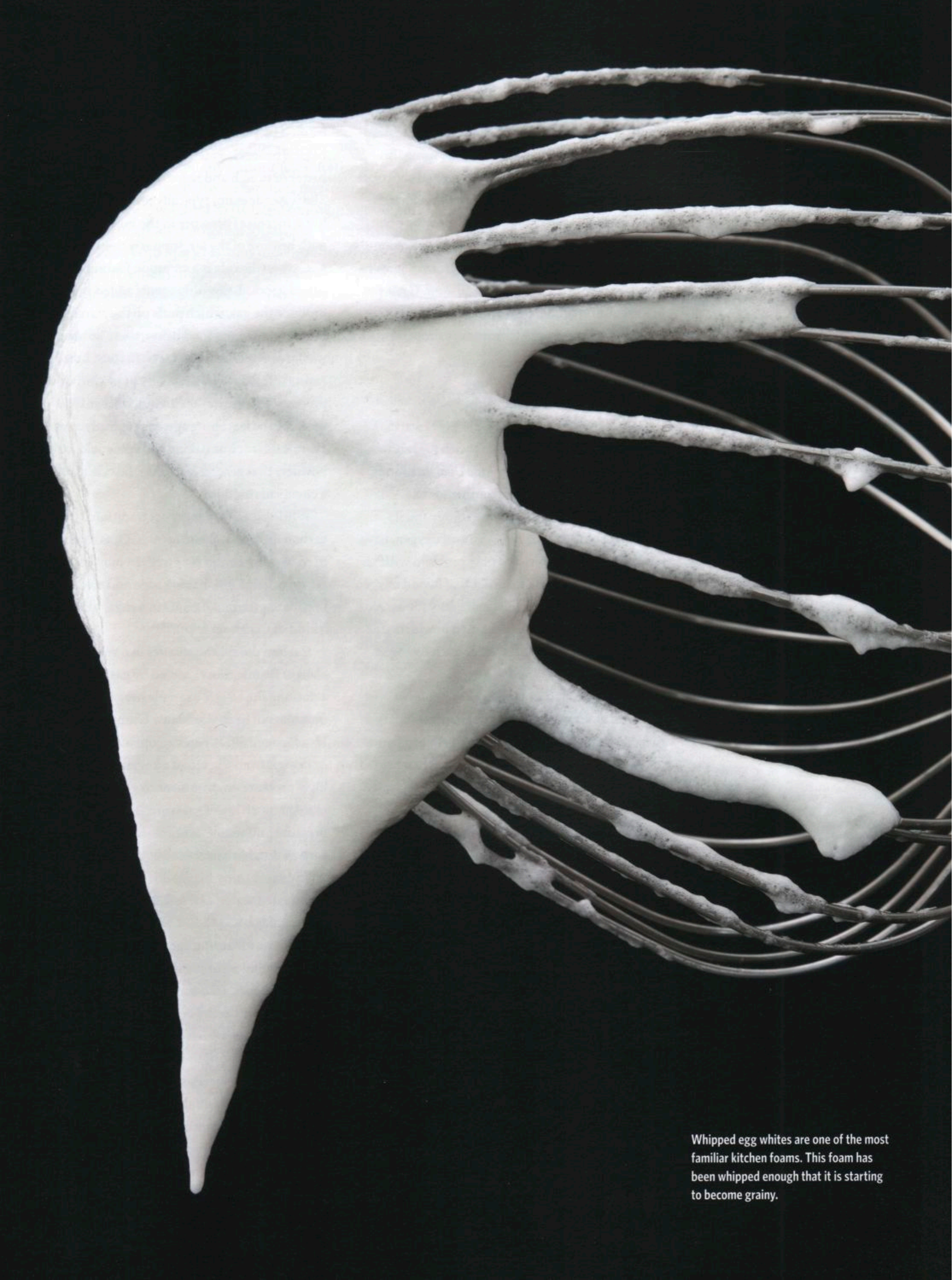
A very simple approach to producing a foam is **vacuum inflation.** Whereas a siphon uses the pressurized gas in the charger to produce bubbles, vacuum inflation works in the opposite way, depressurizing the ingredient the foam is to be made from. In this method, you place an ingredient in a vacuum chamber, which removes pressure from the outside. The difference in pressure between the outside and the inside of the ingredient makes the gases in it expand.

Vacuum inflation does not work unless the liquid to be foamed contains some dissolved gas or existing bubbles. The amount of gas that can remain in a liquid solution depends on the pressure. Increase the pressure, and more gas will go into solution. Conversely, if you pull a vacuum, the dissolved gas comes out of solution as bubbles.

When you heat a pan of water on the stove, small bubbles soon start to appear, clinging to the bottom and sides of the pan. Those initial bubbles are not formed by steam; instead, they inflate as the water releases gas that is dissolved in it (see page 1·314). Unlike most solids, gases dissolve better in cold water than they do in warm water (see page 1·330), so it is easier to dissolve gas in a foam if it is cold.

A variation on this approach is to take a dense or weak foam that already contains some bubbles, and put it in a vacuum to expand the bubbles. Of course, the bubbles deflate as soon as the vacuum is removed unless something is done to make the foam set. So usually you will turn a vacuum-created foam into a rigid set foam.

Surprisingly, this technique is used in the industrial production of white sandwich bread. Instead of using yeast to leaven the bread, industrial bakeries make a dough with a certain amount of air entrained into it, and then put it into a vacuum oven. Bubbles expand while the heat



Whipped egg whites are one of the most familiar kitchen foams. This foam has been whipped enough that it is starting to become grainy.

Modernist foams got their start in 1994 when Ferran Adrià served his first savory foam, or *espuma*. The reaction to Adrià's foams was extreme and immediate (see page 1·34). Some people loved them, others were highly critical. Why should foam be acceptable in a sabayon or mousse but radical in another context? Apparently the dining public and many food critics harbored deep-seated views about when and where foams are appropriate.

For a photo of foamed chocolate, see page 313. For more on creating ice cream with a vacuum, see page 312.

For more on pommes soufflées, including recipes and a step-by-step procedure, see page 306. For a potato chip recipe, see page 3·330. Recipes for prawn and crab crackers appear on pages 303 and 5·190, and deep-fried pork skin is described on page 3·129.

bakes the bread; the result is a vacuum set foam.

Vacuum-inflated foams can also be stabilized by freezing. Chocolate foam bars, similar to the Aero brand of British chocolates, are made using this method. Under vacuum pressure, melted chocolate, which contains dissolved nitrous oxide, expands and foams. When it cools below its melting point, the bubbles freeze in place. You can even accomplish this type of foaming with ice cream. Conventional ice cream is already up to 50% air. If it is put in a vacuum chamber before it fully hardens, it expands further. As the temperature drops, it freezes into place.

Now You're Foaming with Gas

The bubbles in a foam are filled with gas, and the most common gas is the one that surrounds us—air. Air has much to recommend it as a foaming gas: it is free, for one thing; and its principal components, nitrogen and oxygen, have low solubility in water. The only problem with air is that that oxygen makes up 21% of it, and oxygen causes oxidation and spoilage of many foods. As a result, many commercial foamed products (for example, baked goods) are made with nitrogen rather than air.

Surprising as it may sound, the next most common gas in culinary foams is water—in its gaseous form, steam. Water is the primary foaming gas in items that puff into a foam when heated, such as deep-fried puffed snacks. As liquid water flashes to steam during frying, it increases in volume by a factor of nearly 1,700, which greatly expands the matrix that the water is in and creates a foam.

One example of this process is the deep-frying of protein gels to produce snacks such as chicharrones and cracklings. Pork skin is first cooked into a gel, and then dehydrated to remove most (but not all) of its water. Upon frying, the water in the gel expands enormously, creating an appealingly crunchy foam. Prawn crackers, a popular Asian snack, are made in similar way, with a dehydrated starch gel that foams when its residual water comes to a boil in a deep fryer. Puffy *pommes soufflées*, potato chips with bubbly outsides, and pita bread are all produced using this same basic principle.

Water also acts as a secondary foaming gas for any baked set foam. In foams like bread, muffins, soufflés, and meringues, the bubbles are created primarily by either air whipped in or carbon dioxide formed by yeast or baking powder. During the baking process, water vapor evaporates from the batter or dough and helps to expand the bubbles. The water does not typically reach the boiling point, but it increases pressure in the bubbles and, along with heating of the air, supports their inflation.

Carbon dioxide is a common foaming gas in baked goods. Leavening agents added to doughs produce the gas, which puffs up the starch and protein gel. As the food bakes, these bubbles swell with steam before the gel sets. In most breads, carbon dioxide is generated by yeast during the process of fermentation. In quick breads like muffins, the leavening agent is typically a set of chemicals (such as baking soda plus acid, or baking powder) that generates carbon dioxide through a chemical reaction.

While breads are the most traditional forms of carbon dioxide-inflated foam, CO_2 is sometimes used in other contexts as well. In our prune coals recipe on page 314, baking soda and acid are used to generate carbon dioxide in a sugar glass to form a kind of frozen set foam.

Carbon dioxide also exists in a very different class of foams: those created by gas coming out of solution. The classic example here is the foam head on a glass of beer—see How Guinness Gets Its Head, page 250. When you open a bottle of beer or draw it from the tap of a keg, it goes from a cold, high-pressure environment to a warmer environment at much lower pressure. The change in pressure and temperature causes much of the carbon dioxide to bubble out of solution.

The same thing happens in champagne, carbonated water, and soft drinks (see Carbonated Drinks, page 1·334). But none of those beverages contains any foaming agents, so the carbon dioxide bubbles simply rise to the surface of the liquid and burst into the atmosphere. The head on a glass of beer occurs because beer *does* contain foaming agents, which trap the bubbles by forming a foam. Some of these foaming agents occur naturally, but since many beer lovers prefer a brew with a substantial foamy head, brewers also deliberately add foaming agents of many kinds when making their products. In addition, brewers like Guinness have created very sophisticated technology to produce a draft-beer-style head on

Modernist Foams

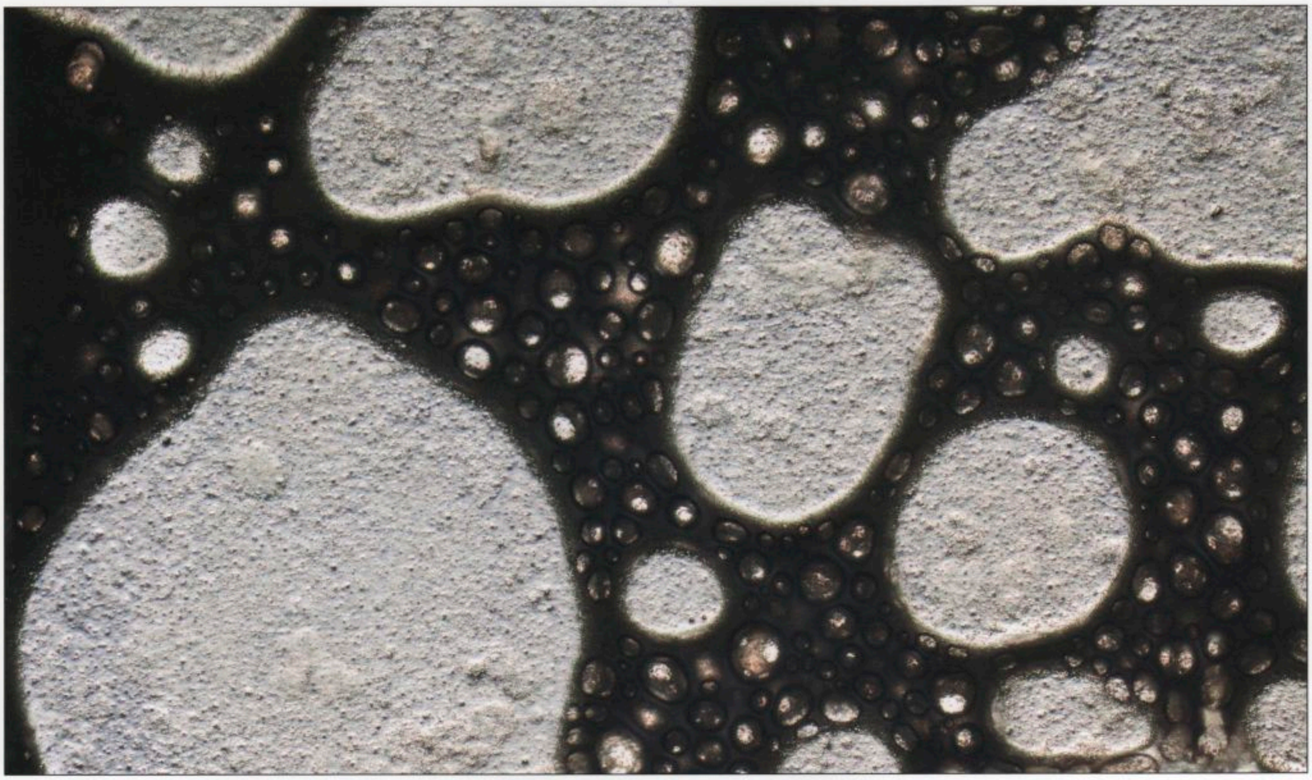
Ferran Adrià began experimenting with culinary foams in the mid-1990s at elBulli as part of his quest to present diners with new and unexpected culinary experiences. Rather than rely on eggs, cream, or starch, he researched the scientific fundamentals and switched to isolated foaming ingredients like lecithin. He created ethereal foams from "impossible" ingredients like cod, foie gras, and mushrooms. The principles of foam remain the same, but the modern culinary applications have been vastly expanded with chef Adrià's insights.

Modernist foams differ from their traditional cousins in two ways: the tools used to create the foam and the stabilizer or foaming agent used to stabilize the foam. The old foaming tools like whisks still work, but new tools like the siphon and the vacuum chamber have had a big impact.

Perhaps the most important tool in the creation of modern foams is the whipping siphon. With a siphon and nitrous oxide cartridges, you can transform fatty or starchy ingredients—even fluid gels—into foams. For example, sabayon, a dessert sauce, was traditionally made by laboriously beating egg yolks over boiling water until the bubbles set. Now the ingredients for a perfect sabayon can be poured into a siphon, kept warm in a water bath, and used as needed throughout dinner service by just pulling the siphon trigger.

The stabilizers for Modernist foams include some of the old standbys like gelatin and eggs, but they also include xanthan gum, gellan, agar, methycellulose, and proprietary whipping products like Versawhip.

Type	Stabilizer	Method	Gas	Example use	Note	See page
fat-based foam	milk fat and hydrocolloid gel	siphon	nitrous oxide	hot whipped cream, long-lasting whipped cream	add agar or gellan to increase stability, including while hot	278
	milk fat	whisk, siphon	nitrous oxide, air	whipped cream	annealing fat crystals with heat treatment improves texture of whipped cream	244
	cocoa butter	whisk, siphon	nitrous oxide, air	chocolate chantilly	fatty liquids other than cream can also be whipped	281
	cheese			cheese chantilly		276
	foie gras fat			foie gras chantilly		281
	milk fat	vacuum	air	aerated ice cream	expand by vacuum, and then freeze	312
starch foam	potato starch	siphon	nitrous oxide	baked potato foam		281
	gelatinized starch	deep-frying	steam	puffed snacks		302
egg foam	egg yolk and stabilizers	siphon	nitrous oxide	sabayon	siphoned versions of classic egg foams	274
	egg white and stabilizers	siphon	nitrous oxide	instant swiss meringue		284
	blended egg and stabilizers	siphon	nitrous oxide	soufflé		297
	egg white	siphon, vacuum oven	nitrous oxide, air	vacuum meringue	use vacuum oven to expand and set	298
sugar-glass foam	sugar and baking soda	chemical leavening	vacuum	honeycomb or prune coals		314
fluid-gel foam	agar fluid gel	siphon	nitrous oxide	hot whipped cream		278
	low-acyl gellan fluid gel	siphon	nitrous oxide	cauliflower foam		5·283
methylcellulose foam	methylcellulose and xanthan gum	electric whisk	air	hot marshmallow		293



When seen under a microscope, the bubbles in whipped cream reveal pockmarks on their surfaces. These are the fat globules. Only the largest show up here; many smaller globules lie in between those that are visible in this image.

The fat globules form a network that helps enclose and stabilize the air bubbles. The large bubbles are bright because they are pressing against the thin cover glass on the microscope slide and holding up the cover. The smaller bubbles are dark where a layer of liquid comes between them and the cover glass. In some parts of the photo, you can see bubbles that are touching or even squashed together but still remain separate because they are stabilized by the network of fat globules that coats them.

The solubility of gases in liquids is proportional to the pressure. At 5 bar / 75 psi, about five times as much gas will dissolve than as will at 1 bar / 14.7 psi.

canned beer (which normally foams much less because of a difference in carbonation levels).

Perhaps the most interesting foaming gas is nitrous oxide, which is used in whipping siphons. This gas is a bit less soluble in water than carbon dioxide, but still very soluble for a gas. About 2 g of nitrous oxide will dissolve in a 1 l siphon full of water at 4 °C / 39 °F and a standard atmospheric pressure of 1 bar / 14.7 psi. Nitrous oxide is five to six times more soluble in fats and oils than it is in water, depending on the temperature and the specific fat or oil. The gas also has the advantage that it won't cause cream and other fatty liquids to oxidize, the way that air or oxygen does. And nitrous oxide tends to stop bacteria from growing—another plus. For these reasons, the gas is also used as the propellant in some nonstick cooking sprays.

A whipping siphon can work only if the nitrous oxide dissolves into the liquid. A standard charger contains 8 g of nitrous oxide gas, which is under enough pressure to condense it into liquid form. Depending on the size of the siphon and the ingredients, you may need two to four chargers to charge the siphon. Some of this nitrous oxide dissolves into the liquid; some remains a gas and pressurizes the siphon. Because of nitrous oxide's enhanced solubility in fat, cream (which is typically about 36% fat) is especially easy to aerate by using a siphon. When the siphon lever is depressed, the mixture of liquid and nitrous oxide is exposed to the lower pressure of the atmosphere and expands, creating a bubbly foam (see page 261).

You can also charge a siphon with carbon dioxide, but this approach has two problems. First, carbon dioxide is more soluble than nitrous oxide at the same temperature, so not all of the carbon dioxide leaves the liquid right away; some remains and emerges from solution gradually. The foam thus ends up fizzy, like the head on beer, champagne, or other carbonated drinks. The fizz does eventually dissipate, but the fizzy foam you have in the meantime is not always what you want.

A second, more important, problem is that carbon dioxide has a characteristic taste. Indeed, it's a big part of the flavor of carbonated drinks. Although it might be interesting to have a fizzy foam with a carbon dioxide taste in certain contexts, in most cases these are distracting side effects.

Foam Stabilizers

You can make a foam stronger and longer lasting by adding a foam stabilizer to the liquid. Many types of foam, like the bubbles that form on top of a freshly made milk shake, are a fleeting thing. To make similar bubbles that stick around longer, you can combine the milk, ice cream, chocolate syrup, and malt powder in a siphon with a little locust bean gum. Now the foam on your milk shake is ready to serve whenever you choose, and it will make it to the table without fading into a thin, chocolate puddle.

Keep in mind that stabilizers are not foaming agents themselves. Sugar, for example, will not create foam, but it will make whipped cream or meringue sturdier and more durable, because it thickens the liquid that surrounds the bubbles. Modernist ingredients, including xanthan gum and many other hydrocolloids, do the same. They stabilize the foam by effectively retarding the drainage from the bubbles.

Ingredient	Application	Typical concentration	Example use	Note
agar	siphoned foam	0.2%–1.2%	hot whipped cream	fluid gel-based foam, hot and cold applications
carrageenan	siphoned foam	0.1%–1.0%	cheese and milk foams	best for hot applications
locust bean gum	siphoned foam	0.1%–1.0%	milk shake foam	best for dairy applications
low-acyl gellan	siphoned foam	0.05%–0.80%	hot cauliflower foam	fluid gel-based foam, hot and cold applications
modified starches	siphoned and whipped foams	0.5%–4.0%	meat and shellfish jus foams, potato foam	good with liquids that have a high ratio of suspended solids
propylene glycol alginate	siphoned and whipped foams	0.1%–0.4%	hollandaise, whipped cream	emulsifier that stabilizes foam
sodium alginate	siphoned and whipped foams	0.1%–1.2%	beer foam, whipped topping	increases stability of calcium-rich liquids
sugar solids (and nonsweet sugars)	vacuum and whipped foams	2%–30%	lecithin foam, whipped cream	good for stabilizing fat- and protein-based foams
xanthan gum	siphoned and whipped foams	0.1%–0.7%	light foam, sucrose esters foam	increases viscosity, thereby stabilizing suspended bubbles

Foam Inhibitors

There may be rare occasions in the kitchen when foam and bubbles interfere with the preparation or presentation of your dish and need to be subdued. Some commercial antifoaming agents can help handle such situations.

A more common scenario, however, is that the foam you are trying to create just doesn't seem to bubble up quite right. Most every cook knows that egg yolk interferes with the volume of whipped egg whites, for example. That is because fat can inhibit foam formation.

If you are not getting the foam you want, refer to the table below to see whether you have accidentally created an environment unfriendly to foam.

Ingredient	Type	Example use	Note
acid	pH 2-5		although a small amount of acid can actually stabilize a protein foam, lowering the pH too far typically inhibits foam and coagulates protein
alcohol	>30 proof (15%)	dairy foams can withstand as much as 15% alcohol by volume	adding alcohol can dissolve or coagulate proteins and prevent foams from stabilizing
antifoaming agent	liquid glycerides	can prevent foam head from forming in processed beverages such as orange and pineapple juices and milk products	emulsifiers with hydrophilic-lipophilic balance values between 0 and 2 (see page 204) prevent foams from stabilizing
	polydimethylsiloxane	diet soda	a type of silicone; good for controlling effervescence
	silicone oil	frying oil	insoluble in foaming agents
fat	oils and fats from animal and plant foods	whipping egg whites to as much as eight times their original volume if no fat is present, or increasing their volume by threefold if fat is in the mixture	can prevent hydrophobic molecules of proteins from bonding with each other during whipping; competes with the hydrophilic molecules that stabilize the bubbles

FOAM MAKERS

We've come a long way from a simple whisk. The combination of technologically advanced tools and information available on the properties of isolated foaming agents lets you customize your foam to get exactly the results you want.

Tool selection is driven by the desired product, which can vary greatly. Do you want big, coarse bubbles or a very fine, dense foam? Is it meant to supply a whisper of evanescence or a solid crunch? What are the properties of the recipe? Is it thin, sticky, quick-setting?

A whisk will make great egg-white foams, and milk shake makers and steam wands are used only for making dairy foams. A handheld whipping wand, designed to froth hot milk into cappuccino foam, is quick, handy, and inexpensive—but not especially powerful.

The siphon is an indispensable tool for creating culinary foams. Charge the siphon with up to two to four nitrous oxide cartridges for variations in thickness and density. Aquarium bubblers are like little culinary Jacuzzis. While vacuum chambers, deep fryers, and ovens do not exactly create bubbles, they do activate the gases that form set foams, and they impose their own characteristics. Each of these considerations informs the choice of tool and method.

STRATEGIES FOR CREATING FOAMS

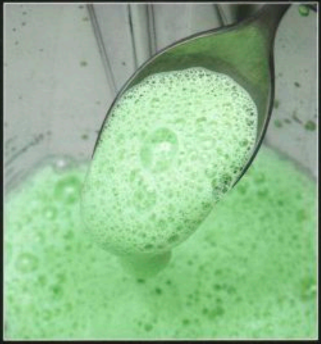
Equipment	Air and froth	Light foam	Dense foam	Set foam	Note
whisk		✓	✓	initial foaming	readily accessible, low power; best for egg foams
hand blender	✓	✓			practical, medium power; best for foams made from thin fluids
blender	✓	✓			same qualities as hand blender; less practical because it is stationary
milk shake maker		✓			high power; great for dairy foams
handheld whipping wand (Aerolatte style)	✓	✓			very practical, medium power; best for foams made from thin fluids
electric whisk (hand mixer or stand mixer)		✓	✓	initial foaming	works like a whisk, but motor-driven
siphon	✓	✓	✓	initial foaming	very practical for many foams; instant release; good for holding cold and hot foams during service
steam wand	✓	✓			only for milk-based foams
vacuum chamber				✓	only for quick-setting foams
aquarium bubbler	✓				only for very light foams and bubbles
deep fryer				✓	only for puffed snacks made from dried protein or starch gels
oven				✓	for breads and other baked goods; heat expands natural bubbles created by fermentation or chemical leavening

Electric whisk

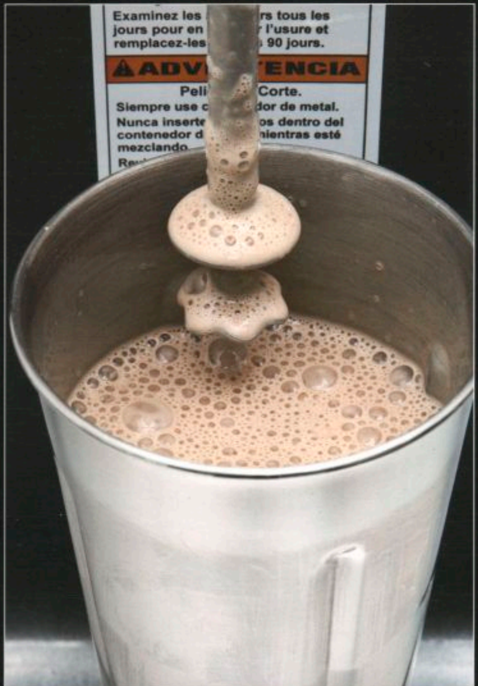

Hand blender



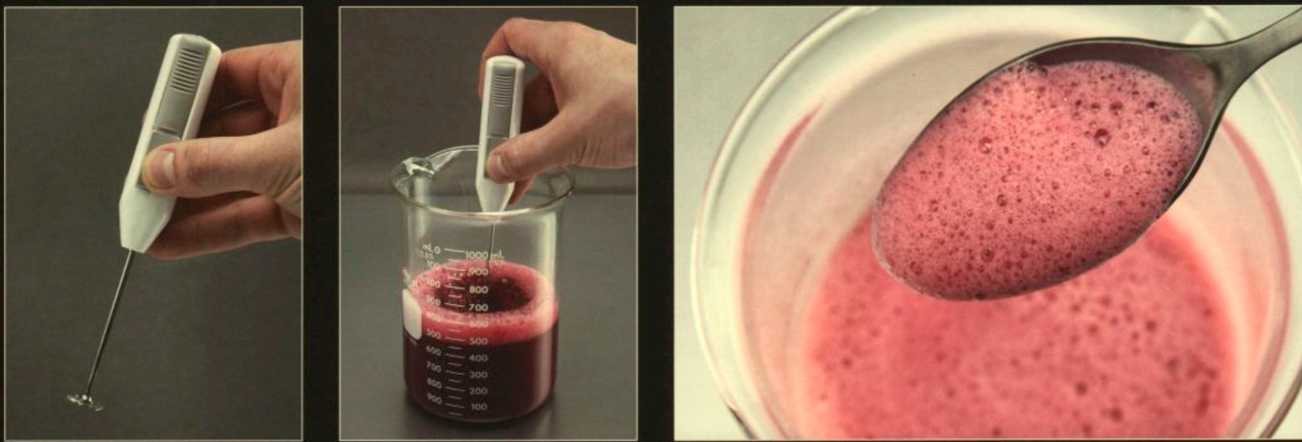
Blender

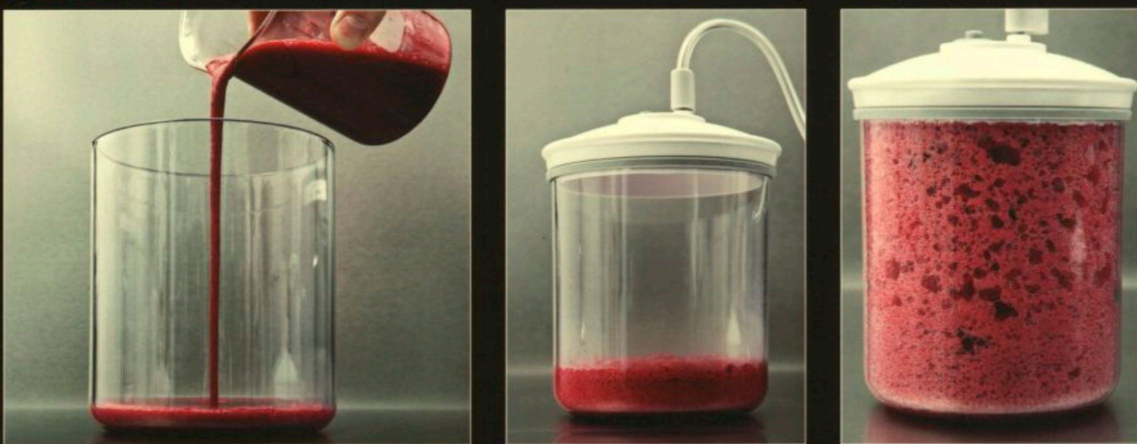
Milk shake maker



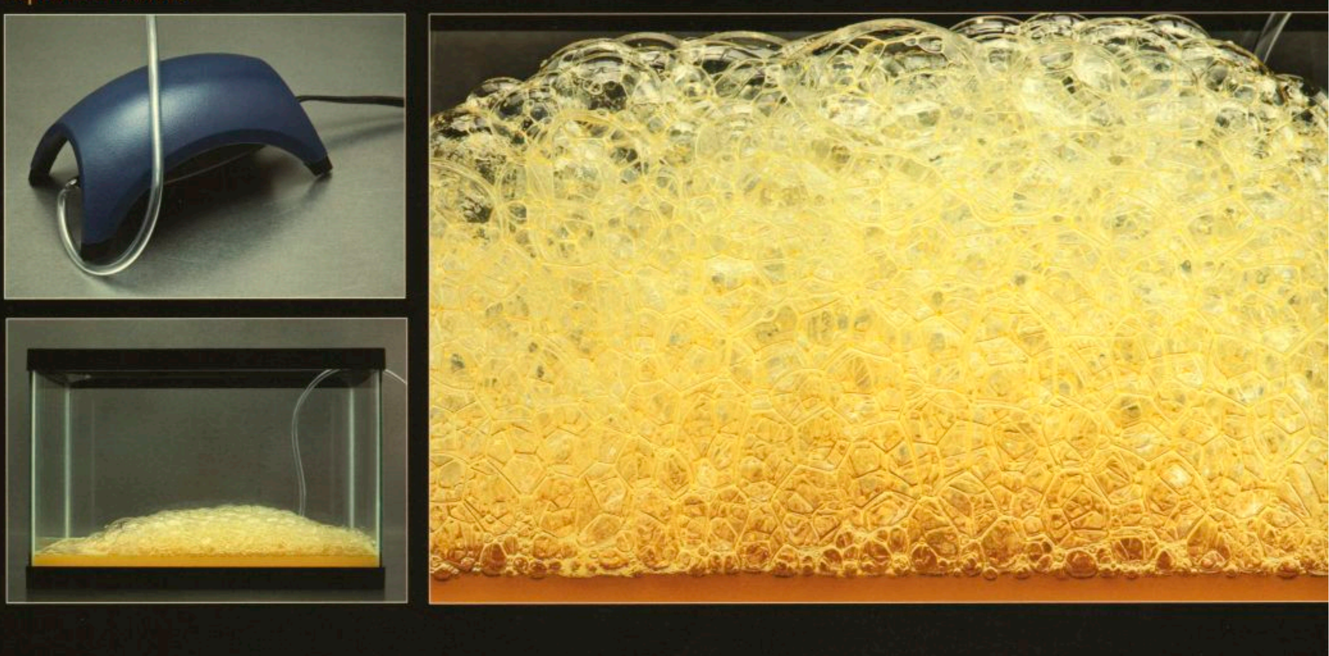

Milk frother (Aerolatte)



Vacuum chamber



Aquarium bubbler



WHIP IT GOOD

A standard whipping siphon uses gas pressure to force a soluble gas (usually nitrous oxide) to dissolve in the liquid to be whipped. The pressure also pushes the liquid through a valve out of which the gas emerges from the solution, thereby creating bubbles and whipping the foam.

Nitrous oxide dissolves much better in fat than in water, so high-fat liquids generally foam better in a siphon than low-fat ones do, although you can make even zero-fat liquids foam up. Whipping siphons were designed to whip cream, which is an ideal liquid for whipping because of its high fat content.

THE MANY FACES OF FOAM

There are many ways to make a foam, and they each have different characteristics. The finer the bubbles, the lighter the color will be. The bubble size distribution, which is important to the texture, is also evident. The stabilizing characteristics differ, too—some foams hold for days in the refrigerator; others collapse as you watch. Here we have whipped the same liquid into a foam by using many different approaches. Color differences are due only to the bubble sizes of the resulting foams.

Gelatin foam, aerated by siphon

Agar fluid gel, aerated by siphon

Iota carrageenan and guar gum foam, aerated by siphon

Sucrose ester and whey protein isolate foam, whipped by Aerolatte ...

... after 2 min ...

... and after 15 min

Xanthan gum foam, aerated by siphon

WPI and sodium alginate foam, whipped by Aerolatte

Albumin powder foam, whipped by electric whisk

Soy lecithin foam, whipped by fish tank bubbler

Soy lecithin and xanthan gum foam, whipped by Aerolatte ...

... after 15 min

PARAMETRIC RECIPE

FROTHS, AIRS, AND BUBBLES

The dishes most associated in the popular mind with Modernist restaurants are unusual foams. Ferran Adrià at elBulli deserves much of the credit for the excitement over these creations (also known as *espumas*, the Spanish word for foams).

Done right, a creative foam entertains the palate with aerated flavors and intriguing textures. It can invigorate a tired presentation, lighten a thick sauce, and add a tactile dimension. Think of the silky richness of a cappuccino—or the childlike joy evoked by a perfect root beer float.

Dry, coarse foams are little more than flavored air, the skeletal remains of bubbles that hold virtually none of their original liquid. Such wisps of texture must be made using strong-flavored liquids otherwise they lack flavor. An example is the sherry vinegar foam elBulli makes to serve with oysters (see next page).

Froths and bubbles are wet, coarse liquids; traditional milk foam is the archetype. Many techniques yield good froths or bubbles; those listed in the table below all work about equally well. But innovation continues. Andoni Luis Aduriz of Mugaritz in San Sebastián, Spain, for instance, has experimented with a fish tank bubbler to create large, flavorful bubbles, a technique described on page 267.

WHIPPING UP A FROTH

1 **Select a texture, and choose your foaming agents.** See the table below for our recommendations.

2 **Combine the foaming agents and the liquid.** Many flavorful liquids, including fruit juices and vinegars, foam well. The proportions given are relative to the weight of the liquid (for example, whip in 1.25 g of soy lecithin for every 100 g of apple juice to make a dry, coarse apple air).

3 **Process, using the tool suggested in the table, until the desired texture appears.** All foams are heat stable unless otherwise noted.

Best Bets for Airs, Bubbles, and Froths

Texture	Foaming agents	(scaling)*	Equipment	Notes	Example	See page
dry, coarse airs	de-oiled soy lecithin powder	1.25%	handheld milk whipper	drain for 4 min	mignonette air	next
	Sucro (Texturas brand)	1.2%	electric whisk		milk foams	
	160 Bloom gelatin Activa RM	2% 1%	electric whisk	disperse cold, then heat for 10 min at 40 °C / 104 °F	dairy foams	
wet, coarse bubbles	glucose syrup DE 40 albumin powder xanthan gum	10% 2% 0.1%	fish tank bubbler	use liquids with a pH of at least 4.5	honey bubbles	267
wet, coarse froths	de-oiled soy lecithin xanthan gum	1% 0.2%	hand blender	allow liquid to drain for 2 min before serving	citrus air	next
	glucose syrup DE 40 de-oiled soy lecithin powder	8% 0.7%	handheld milk whipper	light sweetness from glucose	fruit and vegetable juice foams	
	butter, melted Sucro (Texturas brand)	10%-20% 1.2%	hand blender		foamy butter sauce	
	whey protein isolate sodium caseinate	2% 0.5%	handheld milk whipper	heat-stable up to 85 °C / 185 °F	foamy broths, light soups	
	sodium caseinate de-oiled soy lecithin	1% 1%	handheld milk whipper	heat-stable up to 85 °C / 185 °F	light, beer-like foams	
	Sucro (Texturas brand) whey protein isolate	1.2% 1%	handheld milk whipper	heat-stable up to 85 °C / 185 °F	latte style foams, light milk shake foams	266

*(*set weight of liquid to 100%*)

EXAMPLE RECIPE

OYSTERS WITH MIGNONETTE AIR INSPIRED BY FERRAN ADRIÀ

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	200 g	50%	① Blend.
Sherry vinegar	150 g	37.5%	② Refrigerate for 1 h to macerate.
Seaweed vinegar see page 2·315	50 g	12.5%	③ Strain, yielding 400 g of vinegar mixture.
Shallots, thinly sliced	50 g	12.5%	
White balsamic vinegar	50 g	12.5%	
Black pepper, coarsely ground	5 g	1.25%	
Salt	to taste		
Vinegar mixture, from above	400 g	100%	④ Blend until lecithin powder is fully dissolved.
De-oiled soy lecithin powder (Lecite, Texturas brand)	5 g	1.25%	⑤ Whip with hand blender or handheld whipping wand until thick and coarse foam forms. ⑥ Allow foam to drain for 2 min to stabilize.
Kumamoto oysters	four oysters		⑦ Garnish with foam.

(original 2003, adapted 2010)

Soy lecithin-based "airs" are considered dry foams because most of the water that is used to create the foam drains away very quickly. Once the water drains away, there is very little left but a coarse matrix of bubbles. These types of foams should always be made with very intense flavors for their impact to be more than simply aesthetic.

EXAMPLE RECIPE

CITRUS AIR INSPIRED BY MARC VEYRAT

Yields 80 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lime juice	120 g	100%	① Combine and blend until sugar, lecithin, and xanthan are dissolved.
Lemon juice	80 g	67%	
Sugar	8 g	6.7%	② Whip with handheld foaming wand or hand blender until sufficient foam is formed.
Salt	2 g	1.7%	③ Allow to drain for 2 min for foam to stabilize.
De-oiled soy lecithin powder (Lecite, Texturas brand)	2 g	1.7% *(1%)**	
Xanthan gum (Keltrol T, CP Kelco brand)	0.4 g	0.3% *(0.2%)**	

(original 2010)

**(% of total weight of lime and lemon juices)*

Marc Veyrat found that increasing the viscosity of lecithin foams prevents them from losing so much water and therefore gives them a better final texture and appearance. This can be done either with a hydrocolloid thickener such as xanthan gum or with dissolved solids such as sugar.

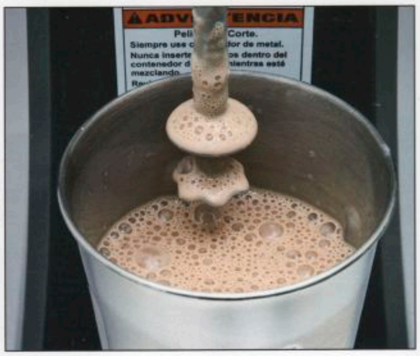
EXAMPLE RECIPE

CAPPUCCINO FOAM INSPIRED BY FERRAN ADRIÀ

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
2% milk	500 g	100%	① Combine.
Coffee beans, coarsely crushed	100 g	20%	② Vacuum seal.
Sugar	40 g	8%	③ Refrigerate for 12 h to infuse.
Glucose syrup DE 40	10 g	2%	④ Strain coffee milk, discarding coffee beans and cardamom seeds, and measure 350 g for recipe.
Black cardamom seeds	1 g	0.2%	
Infused milk, from above	400 g	100%	⑤ Dry blend powders, and disperse in infused milk.
Sucrose esters (Sucro, Texturas brand)	4.8 g	1.2%	⑥ Place in beaker of milk shake whipper; process until very frothy.
Whey protein isolate	4 g	1%	

(original 2003, adapted 2010)



6a

6b

6c

EXAMPLE RECIPE

GEODUCK WITH SEAWATER FOAM

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Geoduck juice, reserved from shucking	200 g	100%	① Blend with hand blender until powders are fully incorporated. ② Whip with handheld whipping wand until stiff seawater foam forms at liquid's surface.
Water	50 g	25%	
White soy sauce	35 g	17.5%	
Sodium caseinate	2.5 g	1.25% (1%)*	
De-oiled soy lecithin powder (Texturas brand)	2.5 g	1.25% (1%)*	
Geoduck siphon, cleaned, peeled, and trimmed see page 5·197	200 g	25%	③ Slice thinly. ④ Divide equally, and arrange on center of each plate.
Ficoïde glaciale (ice plant)	40 g	5%	⑤ Garnish.
Pickled ramps, thinly sliced see page 5·118	40 g	5%	⑥ Spoon some seawater foam on top of each portion.

(2010)

(% of total weight of fish stock and oyster juice*)

EXAMPLE RECIPE

EDIBLE SOAP BAR WITH HONEY BUBBLES ADAPTED FROM ANDONI LUIS ADURIZ

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	1 kg	100%	① Blend fully with hand blender.
Wildflower honey	150 g	15%	② Strain.
Albumin powder	20 g	2%	③ Vacuum seal to remove accumulated bubbles.
Xanthan gum (Keltrol T, CP Kelco brand)	1 g	0.1%	④ Refrigerate honey bubble base.
Salt	0.5 g	0.05%	
All-purpose flour, sifted	110 g	11%	⑤ Arrange in thin, even layer on baking sheet. ⑥ Bake at 170 °C / 340 °F until golden brown, about 20 min.
Hazelnut flour	40 g	4%	⑦ Combine, and whisk into warm, browned all-purpose flour.
Sugar	30 g	3%	
Salt	3 g	0.3%	
Rendered ham fat, melted	40 g	4%	⑧ Combine.
Cocoa butter, melted	30 g	3%	⑨ Fold into flour mixture.
Olive oil	30 g	3%	⑩ Pour into small rectangular silicone molds that resemble bars of soap. ⑪ Freeze "soap" bars completely, about 30 min. ⑫ To serve, transfer honey bubble base to open container. ⑬ Place aquarium bubbler tube at bottom of container. ⑭ Turn on bubbler, and leave until desired amount of bubbles have accumulated, about 5 min. ⑮ Arrange soap bar in center of each plate, and garnish with bubbles.

(original 2007)

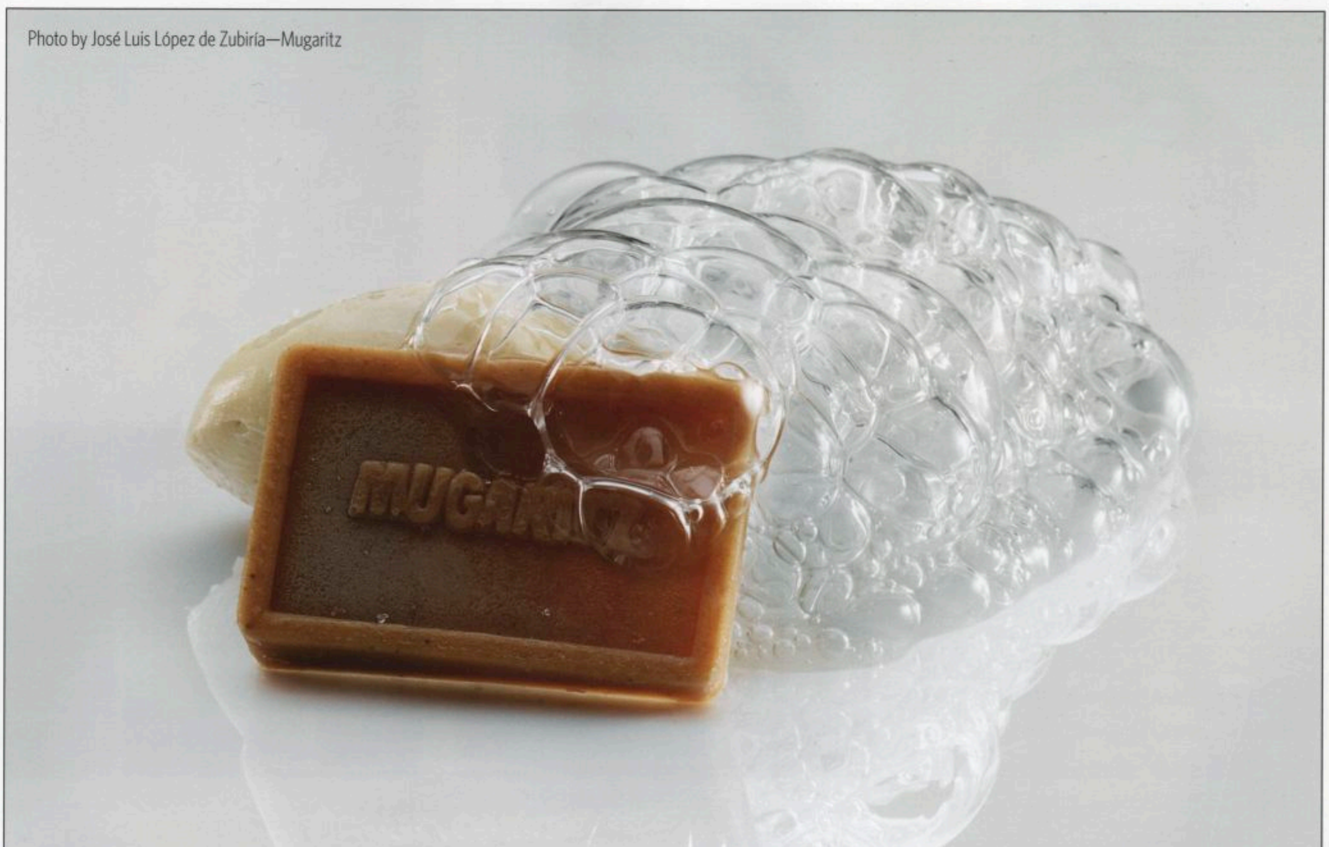


Photo by José Luis López de Zubiría—Mugaritz

EXAMPLE RECIPE

LYCHEE AND LIME SODA

Yields 200 g (four servings)

INSPIRED BY SANG-HOON DEGEIMBRE

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lychee juice, clarified	200 g	500%	① Season lychee juice.
Fructose	to taste		② Reserve refrigerated.
Malic acid	to taste		
Dextrose	40 g	100%	③ Combine to form lime base.
Baking soda	15 g	37.5%	④ Grind into fine powder with mortar and pestle.
Citric acid	15 g	37.5%	
Lime essential oil	0.05 g	0.1%	
Water	7 g	17.5%	⑤ Add slowly to lime base, incorporating small amount at a time; make sure mixture does not foam. ⑥ Pack into circular molds (2.5 cm / 1 in. in diameter and 2.5 mm / 1 in high). This will produce 3 g tablets. Store in cool, dry place.
Lime tablets, from above	four tablets		⑦ To serve, pour 50 g of lychee juice into each of four serving glasses. ⑧ Add one lime tablet to each glass; tablet fizzes as it dissolves. ⑨ Allow to dissolve completely before consuming soda.

(published 2009, adapted 2010)

You can use store-bought lychee juice if you wish, but we prefer fresh. For methods of clarifying fresh fruit juice, see page 2·351.

This dish makes tablets reminiscent of Alka-Seltzer, which produces a fizzy drink when dissolved in water.

3

4

6a

6b

8a

8b

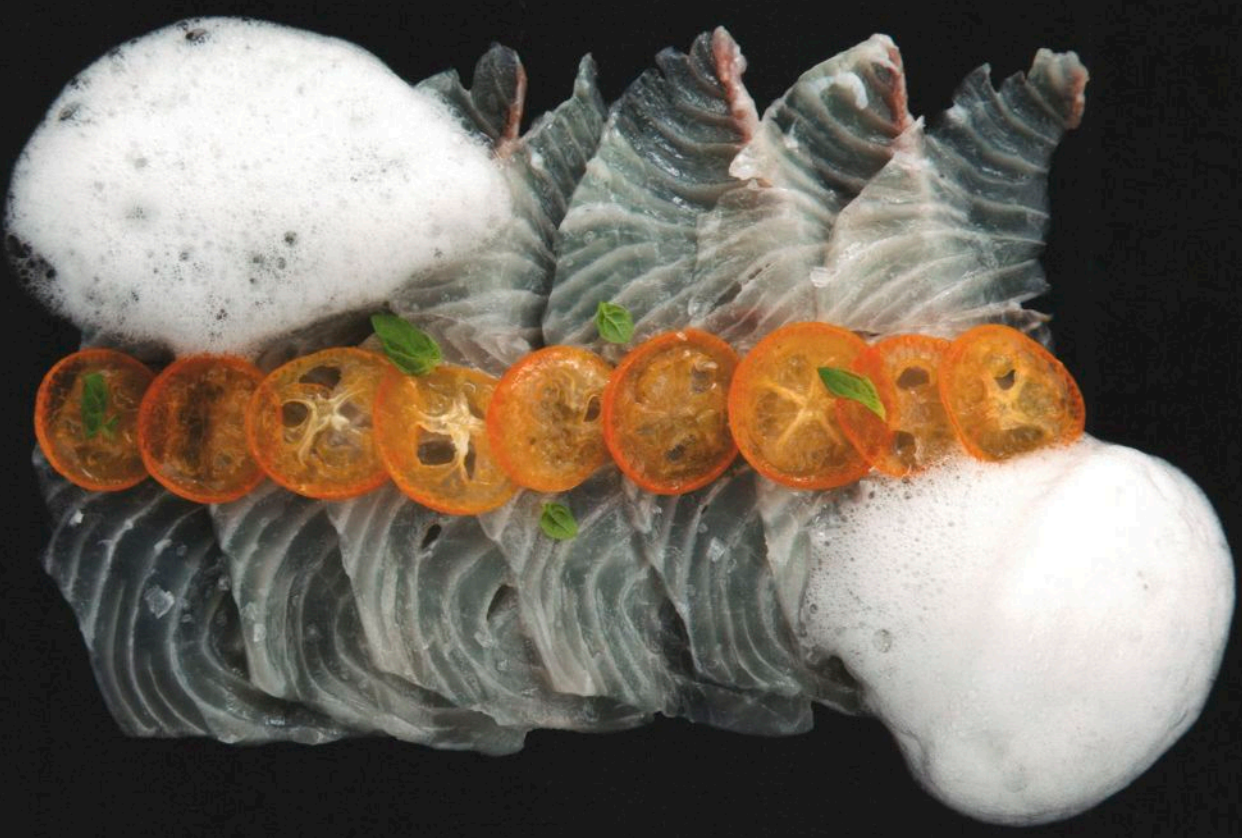
EXAMPLE RECIPE

KANPACHI SASHIMI WITH CITRUS FOAM INSPIRED BY QUIQUE DACOSTA

Yields 320 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White fish stock see page 2-303	500 g	100%	① Combine. ② Heat stock to **60** °C / **140** °F, and hold for 12 min. ③ Strain infused stock into open container. ④ Cool completely.
Lemongrass, finely chopped	30 g	6%	
Lemon verbena (fresh)	7 g	1.4%	
Makrud (kaffir) lime leaves	5 g	1%	
Lemon zest	3.5 g	0.7%	
White peppercorns, crushed	0.75 g	0.15%	
Sucrose esters (Sucro, Texturas brand)	1.5 g	0.3%	⑤ Blend into cold, infused stock.
Salt	to taste		⑥ Season stock generously.
Lemon juice	to taste		⑦ Foam citrus-seasoned stock with fish tank bubbler.
Kanpachi (raw), thinly sliced	200 g	40%	⑧ Arrange fish on center of four plates, 50 g on each plate.
Kumquats, thinly sliced	40 g	8%	⑨ Garnish.
Mint leaves, torn	4 g	0.8%	
Sous vide ponzu see page 2-313	50 g	10%	⑩ Pour around fish. ⑪ Garnish each portion with citrus foam.

(original 2010)



PARAMETRIC RECIPE

LIGHT FOAMS

Part of the appeal of edible foams is their ethereal and airy quality. A mass of fluffy cloud fills your mouth and then disappears, sometimes with a delicate popping sensation. Light foams form soft peaks and gentle waves, like a classic warm sabayon or the foam on top of a fresh cappuccino. They work especially well as toppings or sauce substitutes because they add flavor and texture but little mass.

It is best to start with a thin liquid when making a light foam. If the liquid does not have natural foaming qualities, add an unobtrusive foaming agent that won't clutter the flavor. The table below offers formulations for velvety foams composed of fine, small bubbles as well as for coarser, drier foams with larger bubbles.

MAKING A LIGHT FOAM

1. **Select the recipe that matches the temperature and bubble size you want.**
2. **Measure the ingredients carefully, and combine the foaming agents with the liquid.** Set the weight of the liquid to 100%. For example, to make a hot, coarse foam, add 0.35 g of xanthan gum and 0.20 g of guar gum for every 100 g of liquid.
3. **Hydrate, using the temperature and time given.** This is not required for cold-soluble foaming agents.
4. **Chill or heat the liquid to serving temperature.**
5. **To serve, aerate the mixture with a whisk or mixer.** Alternatively, pour the liquid into a 1 l whipping siphon, pressurize by using the number of nitrous oxide cartridges suggested in the table, and dispense.

Best Bets for Light Foams

Serving temperature	Bubble size	Foaming agents	(scaling)*	Hydrate (°C)	Hydrate (°F)	Hydrate (min)	Foaming method	Nitrous oxide	Example	See page
cold	fine	160 Bloom gelatin	1%	60	140	5	siphon	2	blood orange foam	272
		160 Bloom gelatin	0.90%	60	140	5	siphon	2–3	corn foam	273
		xanthan gum	0.27%							
		albumin powder	10%		cold		electric whisk or siphon	3	light coating foam	
	coarse	xanthan gum	0.7%		cold		siphon	3	lemon verbena and peach froth	273
		xanthan gum	0.20%	95	203	3	siphon	2	cava foam	277
		agar **	0.25%							
hot and cold	fine	low-acyl gellan**	0.3%	95	203	3	siphon	2	eggless sabayon, warm, beer-like foam	
		agar**	0.4%	95	203	3	siphon	2		
		egg yolk**	29.0%	70	158	30	siphon	3	bergamot sabayon	274
		Maltrin M100	5.5%							
	coarse	xanthan gum	0.25%		cold		siphon	3	dairy-free milk shake	
		guar gum	0.15%							

*(*set weight of liquid to 100%*); **(*make fluid gel before filling siphon*)

A light foam is a beautiful complement to a slice of preserved lemon (see page 3·350).

EXAMPLE RECIPE

WHIPPED CHEESE INSPIRED BY ALEX STUPAK

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Gruyère water see page 2·310	500 g	100%	① Season cheese water. ② Reserve
Salt	to taste		
Maltrin M100 (GPC brand)	20 g	4%	③ Dry blend powders.
Iota carrageenan (Genuvisco J, CP Kelco brand)	1.25 g	0.25%	
Lambda carrageenan (Texturas brand)	0.75 g	0.14%	
Cheese-infused milk, from above	500 g	100%	④ Disperse powder mixture in cold milk. ⑤ Bring to simmer, and remove from heat. ⑥ While still warm, pour into standing mixer, and whip at high speed until stiff foam forms and becomes cold. ⑦ Spoon into piping bag, and pipe to order.

(original 2008, adapted 2010)

Alex Stupak aerates a carrageenan fluid gel as it is setting. This process is quite versatile and can be adapted to make various aerated textures that are not dependent on a whipping siphon.

EXAMPLE RECIPE

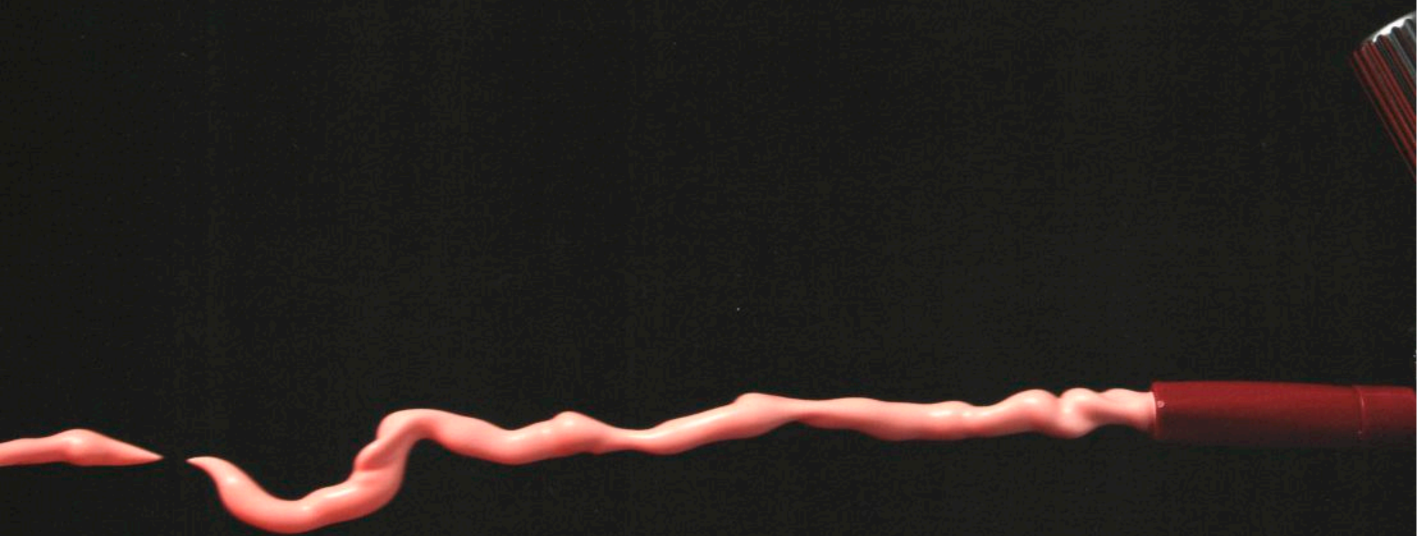
BLOOD ORANGE FOAM ADAPTED FROM FERRAN ADRIÀ

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
160 Bloom gelatin	2.5 g	1%	① Disperse into 50 g of cold juice and heat until gelatin is fully dissolved.
Blood orange juice	250 g	100%	② Combine with remaining cold juice. Strain. ③ Transfer to siphon, and charge with one nitrous oxide cartridge. ④ Refrigerate siphon for at least 2 h before use.

(original 1998)

This basic formula can be used for any cold foam.



EXAMPLE RECIPE

CORN FOAM ADAPTED FROM FERRAN ADRIÀ

Yields 150 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Corn juice	110 g (from 250 g corn kernels)	100%	① Combine xanthan gum with 55 g of corn juice.
Xanthan gum (Keltrol T, CP Kelco brand)	0.4 g	0.4% *(0.27%)**	
160 Bloom gelatin	1 g	0.9% *(0.7%)**	② Disperse gelatin into remaining 55 g of corn juice.
			③ Heat until fully dissolved.
Heavy cream	40 g	36%	④ Combine cream with corn juice and gelatin mixtures.
			⑤ Strain.
Salt	to taste		⑥ Season corn cream.
			⑦ Transfer to 1 l whipping siphon, and charge with one cartridge of nitrous oxide.
			⑧ Refrigerate for at least 3 h before use.

(original 1994)

(% of total weight of other ingredients*)

EXAMPLE RECIPE

LEMON VERBENA AND PEACH FROTH ADAPTED FROM QUIQUE DACOSTA

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	800 g	114%	① Combine.
Dried peaches	200 g	28.5%	② Bring to boil.
			③ Cool to 60 °C / 140 °F, and hold.
Lemon verbena (fresh)	50 g	7%	④ Add.
			⑤ Cover, and steep at 60 °C / 140 °F for 3 min.
			⑥ Strain through fine sieve, measuring 700 g of peach infusion.
			⑦ Cool completely.
Peach infusion, from above	700 g	100%	⑧ Blend until mixture thickens.
Xanthan gum (Keltrol T, CP Kelco brand)	5 g	0.7%	⑨ Transfer to 1 l whipping siphon, and charge with three cartridges of nitrous oxide.
			⑩ Shake vigorously, and dispense in desired amounts.
Seasonal herbs and blossoms	as needed		⑪ Garnish.

(original 2006, adapted 2010)

SOUS VIDE SOLE WITH BERGAMOT SABAYON

Yields 900 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Vermouth (dry)	100 g	40%	① Combine.
Champagne vinegar	50 g	20%	② Reduce to syrup.
Shallots, finely minced	50 g	20%	③ Strain, discarding shallot bits.
			④ Measure 25 g of wine reduction, and set aside.
Egg yolks, blended	208 g	83.2% (*65%*)*	⑤ Cook sous vide in 70 °C / 158 °F bath for 35 min, and reserve.
Cream sherry	30 g	12%	⑥ Vacuum seal together.
Fino sherry	25 g	10%	⑦ Infuse in 85 °C / 185 °F bath for 6 min.
Earl Grey tea leaves	7.5 g	3%	⑧ Strain, reserving tea infusion.
White fish stock see page 2·303	250 g	100%	⑨ Combine.
			⑩ Blend with cooked egg yolks until smooth to make sabayon base.
Tea infusion, from above	45 g	18%	
Wine reduction, from above	25 g	10%	
Maltrin M100 (GPC brand)	15 g	6%	
Bergamot essential oil	0.1 g	0.04%	⑪ Season sabayon base generously.
Cayenne pepper	to taste		⑫ Transfer to 1 l whipping siphon, and charge with two cartridges of nitrous oxide.
Lemon juice	to taste		⑬ Hold filled siphon in 62 °C / 144 °F bath to reserve.
Salt	to taste		
Black mussels, live	250 g (24 small)	100%	⑭ Vacuum seal in one even layer.
			⑮ Submerge in boiling water for 3 min.
			⑯ Shock in ice water, and remove from bag.
			⑰ Shuck, reserving juices in bag and shells.
			⑱ Strain juice over shucked mussels.
			⑲ Refrigerate mussels.
Rex sole, skin removed	four whole (small)	varies	⑳ Vacuum seal each sole individually with 10 g of butter.
			㉑ Cook sole packets sous vide in 47 °C / 117 °F bath to core temperature of 46 °C / 115 °F, about 30 min.
Clarified unsalted butter see page 213	40 g	16%	㉒ Remove from packets, and place one fish on each serving plate.
			㉓ Warm mussels in small pot.
Salt	to taste		㉔ Season sole.
			㉕ Garnish with sabayon and mussels.
Bergamot (fresh)	one whole		㉖ Grate zest finely over sole to finish. Serve with crispy potatoes or potato puree.

(2010)

(% of total weight of stock, tea infusion, and wine reduction*)

For recipes for ultrasonic fries and potato puree, see pages 3·325 and 3·296.

EXAMPLE RECIPE

MUSHROOM AND BACON CAPPUCCINO INSPIRED BY MARC VEYRAT

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Smoked bacon, thinly sliced	100 g	50%	① Fry in dry nonstick pan until golden, about 10 min.
Heavy cream	60 g	30%	② Add to bacon, and simmer for 20 min.
Water	20 g	10%	③ Strain cream through fine sieve.
			④ Cool.
			⑤ Measure 75 g of bacon cream.
White pork stock, cold see page 2·296	200 g	100%	⑥ Whisk together, and season generously to compensate for aeration.
Bacon cream, from above	75 g	37.5%	
Whole milk, cold	15 g	7.5%	
Salt	to taste		
Agar (Texturas brand)	2 g	1% (*0.7%*)*	⑦ Disperse in cold stock and cream mixture.
			⑧ Heat to 95 °C / 203 °F, and hold for 3 min to fully hydrate.
			⑨ Pour into container, and allow to set, about 5 min.
			⑩ Puree to fluid gel, and transfer to 1 l whipping siphon.
			⑪ Charge with two cartridges of nitrous oxide.
			⑫ Heat siphon in 50 °C / 122 °F bath for 15 min to make bacon foam.
Mushroom jus see page 2·348	200 g	100%	⑬ Combine, and simmer for 2 min.
Madeira	15 g	7.5%	
Dry shiitake, thinly sliced	5 g	2.5%	
Star anise	1 g	0.5%	
Coffee butter see page 371	10 g	5%	⑭ Blend into hot mushroom jus mixture.
			⑮ Pour into cups or bowls.
			⑯ Garnish with bacon foam.

(published 2003, adapted 2010)

(% of total weight of cold stock and cream mixture*)

EXAMPLE RECIPE

POACHED APPLE WITH PECORINO FOAM

Yields 450 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	650 g	163%	① Combine, and vacuum seal.
Pecorino Romano, grated	350 g	88%	② Infuse, refrigerated, for 12 h.
			③ Strain through fine sieve, and measure 400 g infused milk.
Cheese infused milk, from above	400 g	100%	④ Blend until smooth.
Heavy cream	100 g	25%	
Lambda carrageenan	1 g	0.25%	
Salt	to taste		⑤ Season cheese mixture.
			⑥ Transfer to 1 l whipping siphon, and charge with one cartridge of nitrous oxide.
Pink Lady apples, peeled, cored, and halved	200 g (two medium)	100%	⑦ Vacuum seal each apple half individually with equal quantities of cider, butter, bay leaf, and vanilla seeds.
Hard apple cider	50 g	25%	⑧ Cook sous vide in 80 °C / 176 °F bath for 2 h.
Unsalted butter	50 g	25%	⑨ Strain apples over small pot to catch cooking juices.
Bay leaf, thinly sliced	0.1 g	0.05%	⑩ Reduce juices to glaze.
Vanilla seeds and pulp, scraped from pod	0.1 g	0.05%	⑪ Serve warm apples with warm apple glaze, cool Pecorino Romano foam, and toasted brioche.

(2010)

EXAMPLE RECIPE

GRAPEFRUIT AND BLACK PEPPER ADAPTED FROM DANIEL PATTERSON

Yields 1.1 kg (12 servings)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For grapefruit-black pepper sorbet:			
Sugar	60 g	12%	① Dry blend.
Pectin LM-104 (CP Kelco brand)	6 g	1.2%	
Glucose	30 g	6%	② Combine 100 g of grapefruit juice with the glucose, sorbitol, and sugar-pectin mixture.
Sorbitol	30 g	6%	③ Bring to boil to form syrup, strain through fine chinois, and chill over ice.
Grapefruit juice (fresh)	500 g	100%	
Salt	to taste		④ Combine remaining 400 g of grapefruit juice with chilled syrup, and season.
Lemon juice	to taste		⑤ Strain through fine sieve, and freeze in Pacojet beaker to make grapefruit sorbet.
For grapefruit mousse:			
Grapefruit juice	415 g	83%	⑥ Combine juices.
Lemon juice	30 g	6%	⑦ Mix in essential oils.
Ginger essential oil	one drop		
Black pepper essential oil	three drops		
Grapefruit essential oil	four drops		
160 Bloom gelatin	14 g	2.8%	⑧ Disperse in cold water.
Honey	15 g	3%	⑨ Combine in pot, and add enough juice mixture to cover.
Sugar	50 g	10%	⑩ Gently warm; add gelatin, stirring until dissolved.
			⑪ Combine with remaining juice mixture, and chill over ice.
			⑫ When completely set, puree in blender until fluid, and pass through fine sieve.
			⑬ Transfer to 1 l siphon, and charge with two cartridges of nitrous oxide. Refrigerate.
Pink grapefruit	one whole		⑭ Cut into supremes. Slice sections on bias in 1 cm / ½ in segments.
Tarragon, fine julienne	as needed		⑮ To serve, season grapefruit segments.
Simple syrup	to taste		⑯ Pacotize sorbet once more.
Cognac	to taste		⑰ Place spoonful of segments in bottom of each bowl.
Lemon juice	to taste		⑱ Top with quenelle of sorbet, and cover with mousse.

(2006)

EXAMPLE RECIPE

OYSTERS WITH CAVA FOAM ADAPTED FROM JOAN ROCA

Yields 700 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cava or other sparkling dry white wine	400 g	100%	① Shear gum into wine. ② Transfer to 1 l whipping siphon.
Xanthan gum (Keltrol T, CP Kelco brand)	1.6 g	0.4%	③ Charge siphon with one cartridge of carbon dioxide, and seal. ④ Refrigerate.
Apple juice	100 g	25%	⑤ Disperse agar in juice.
Agar (Texturas brand)	1 g	0.25% (*1%*)*	⑥ Bring juice to boil. ⑦ Remove from heat, and cool until gelled. ⑧ Puree gel until completely fluid.
Kusshi oysters	20 oysters		⑨ Shuck and rinse. ⑩ Divide equally among four bowls.
Candied lemon peel (store-bought)	four cubes		⑪ Garnish each bowl with dab of apple fluid gel, one cube of lemon peel, two pieces of ginger dice, and two pieces of pineapple dice.
Crystallized ginger, brunoise	eight pieces		
Fresh pineapple, brunoise	eight pieces		
Cumin seeds, ground fine	0.4 g	0.1%	⑫ Season.
Pain d'épices spice powder see page 5·22	0.4 g	0.1%	⑬ Dispense cava foam at table.

(original 2005)

(% of weight of apple juice*)

PARAMETRIC RECIPE

THICK FOAMS

Thick foams are dense and unctuous but remain inherently airy. Bubbles in thick foam are fine and packed tightly together; the tighter they're packed, the stiffer the foam. But what keeps any foam unctuous is ample liquid trapped between the bubbles. Ingredients that prevent this liquid from draining away are the key to a thick, velvety foam.

Droplets of semisolid fat, neither too cold nor too warm, are the key to getting cream to whip into stiff peaks. A network of these droplets surrounds air bubbles and stabilizes them. But if the bubbles get too warm, they lose cohesion, and the foam comes undone. Yet the same fat droplets will interfere with a protein-stabilized based foam.

Gelatin foams must also be kept cold. Other hydrocolloids that thicken, such as xanthan gum, carrageenan, cellulosic gums, or even fluid gels made with gellan or agar stabilize dense, thick foams so that they can be served hot or cold. For more on making fluid gels, see page 176. Hot whipped cream can be made with these ingredients.

MAKING A THICK FOAM

1. **Select a serving temperature and foaming agents.** The table below suggests multiple formulations for creating cold and hot foams, both with and without fat.

2. **Measure the ingredients carefully, and combine the foaming agent with the liquid.** Set the weight of the liquid to 100%. For example, to make whipped caramel, add 1 g of Versawhip and 0.15 g of xanthan gum for every 100 g of caramel.

3. **Disperse and heat the liquid (not required for cold-soluble solutions).** See the table for appropriate times and temperatures.

4. **Heat or cool the liquid to serving temperature.**

5. **To serve, aerate the mixture with an electric whisk or mixer or use a siphon to expand it.** Siphoning does not work well with very thick liquids; the upper limit is about the thickness of mayonnaise.

Best Bets for Thick, Fine-Textured Foams

Service temperature	Foaming agents	(scaling)**	Hydrate (°C)	Hydrate (°F)	Hydrate (min)	Foaming method	Nitrous oxide charges	Example
cold	160 Bloom gelatin	1.5%	60	140	5	siphon	2–3	thick fruit and vegetable juice foams
	Versawhip	1.00%	cold			electric whisk	n/a	shaving cream-like foam, whipped caramel
	xanthan gum	0.15%						
	albumin powder	14%	room temp.		20	siphon	2	savory and sweet mousses
	isomalt or sugar	10%						
	pregelatinized starch paste	5%	60	140	5	siphon	2	whipped puddings
	160 Bloom gelatin	1.2%						
hot and cold	low-acyl gellan*	0.8%	95	203	3	siphon	2–3	coconut chutney foam, hot whipped cream
	agar*	1.0%	95	203	3	siphon	3	thick, hot whipped cream; hot whipped topping
	xanthan gum	0.2%						
	methylcellulose F50	1.00%	100	212	5	electric whisk	n/a	eggless sabayon
	xanthan gum	0.15%						
	Ultra-Sperse 5	4.0%	80	176	10	siphon	3	potato and other starch foams
	iota carrageenan*	0.4%						
	albumin powder	7.0%	room temp.		20	siphon	1–2	hot whipped cream
	xanthan gum	0.2%						

*(*make fluid gel before foaming*); **(*set weight of liquid to 100%*)

Note	See page
allow gelatin to set for at least 3 h before serving	
do not use with liquids containing fat	283
	29
make fluid gel before foaming; needs source of calcium for best results; if gellan does not hydrate, see table on page 129	282
see page 170 for the hydration procedure for methylcellulose	
reheating base will increase viscosity considerably	
do not heat above 60 °C / 140 °F	

EGGPLANT FOAM ADAPTED FROM JOAN ROCA

Yields 950 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Italian eggplant	1 kg (about two eggplants)	200%	① Roast whole at 190 °C / 375 °F until charred and thoroughly cooked, about 1½ h. ② Cut open, and scoop out flesh while still hot. Discard seeds and skin. ③ Puree flesh, and pass through fine sieve. Measure 500 g of puree.
Charred eggplant puree, from above	500 g	100%	④ Blend. ⑤ Strain through fine sieve. ⑥ Pour into 1 l whipping siphon. ⑦ Warm siphon in 50 °C / 122 °F bath for 15 min.
Heavy cream	250 g	50%	
Albumin powder	25 g	5% *(3.3%)**	
Xanthan gum (Keltrol T, CP Kelco brand)	1.5 g	0.3% *(0.2%)**	
Salt	to taste		
Fresh sardines, cleaned and gutted	200 g (four fish)	40%	⑧ Grill for 2 min on each side until just cooked through, and season.
Sumac	10 g	2%	⑨ Garnish grilled sardines with foam and remaining ingredients.
Mint leaves	5 g	1%	
Olive oil	to taste		

(published 2005, adapted 2010)

(% of total weight of heavy cream and eggplant puree*)

EXAMPLE RECIPE

BAKED POTATO FOAM

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Yukon Gold potatoes, peeled and thinly sliced	500 g	200%	① Simmer until tender. ② Press through fine tamis. ③ Measure 250 g of puree, and keep warm.
Baked potato broth, cold see pages 2·309 and 3·302	150 g	60%	④ Disperse iota carrageenan and xanthan gum into broth.
Iota carrageenan (Genuvisco J, CP Kelco brand)	1.25 g	0.5% *(0.2%)**	⑤ Heat mixture to 95 °C / 203 °F, and hold for 3 min to fully hydrate.
Xanthan gum (Keltrol T, CP Kelco brand)	1 g	0.4% *(0.16%)**	⑥ Remove from heat.
Heavy cream	125 g	50%	⑦ Blend into warm broth.
Olive oil	35 g	14%	
Yukon Gold potato puree, from above	250 g	100%	⑧ Fold in cream and broth mixture.
Salt	to taste		⑨ Season. ⑩ Transfer to 1 l whipping siphon, and charge with one cartridge of nitrous oxide. ⑪ Hold in 60 °C / 140 °F bath until needed.

(2009)

**(% of total weight of baked potato broth, heavy cream, olive oil, and prepared potato puree)*

Baked potato foam is a lighter alternative to potato puree. In this version, we use a broth made with baking soda to enhance the baked flavor, but a potato skin infusion could be used instead (see page 2·309). We use olive oil as a fat in this recipe, but melted butter could be substituted.

Hot potato foams were first made by Ferran Adrià, who made them with just potato and water. We find that adding some thickness with xanthan and a fluid gel improves the texture. In this recipe, we use iota carrageenan, but agar or gellan would also work here.

EXAMPLE RECIPE

CHOCOLATE CHANTILLY ADAPTED FROM HERVÉ THIS

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Semisweet chocolate (50% cocoa), chopped into small chunks	300 g	100%	① Vacuum seal. ② Warm sous vide in 50 °C / 122 °F bath until completely melted; reserve.
Water	200 g	67%	③ Pour into bowl set over ice-water bath. ④ Incorporate chocolate into water gradually with electric whisk. ⑤ Whip at high speed to form dense foam, about 5 min. ⑥ Refrigerate foam until ready to serve.

(published 1995)

The same procedure used here can also be used to make chantilly-style foams of camembert, foie gras, or butter. For foie gras, use 200 g of melted foie gras for every 100 g of water or flavorful liquid. For butter, use 100 g of butter and 4 g of gelatin for every 20 g of water.

3

4

5

COCONUT CHUTNEY FOAM

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cilantro leaves	8 g	4%	① Puree herbs in food processor to fine paste.
Mint leaves	4 g	2%	② Pass through fine sieve.
Green chili (fresh), thinly sliced	2 g	1%	③ Measure 10 g of herb puree.
Coconut cream	200 g	100%	④ Blend.
Coconut milk (stabilizer free)	200 g	100%	
Herb puree, from above	20 g	10%	
Salt	to taste		⑤ Season coconut herb cream.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	3.4 g	1.7% *(0.8%)**	⑥ Combine.
Sodium citrate	0.6 g	0.3%	
Water, cold	20 g	10%	⑦ Disperse gellan mixture in water.
			⑧ Whisk gellan water into herb cream to form foam base.
			⑨ Bring to a simmer while blending to fully hydrate.
			⑩ Remove from heat, and pour foam base into mold.
			⑪ Refrigerate until fully set, about 10 min.
			⑫ Blend set gel to fine puree.
			⑬ Place in siphon, and charge with one cartridge of nitrous oxide.
			⑭ Warm siphon in 60 °C / 140 °F bath for 15 min, and serve.

(2010)

(% of total weight of coconut cream, herb puree, and water*)

EXAMPLE RECIPE

HOT BUTTER FOAM ADAPTED FROM FERRAN ADRIÀ

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg whites	45 g (about one large white)	18%	① Blend until smooth, and strain. ② Vacuum seal, and cook sous vide in 70 °C / 158 °F bath for 30 min.
Egg yolks	35 g (about two yolks)	14%	
Unsalted butter, melted	250 g	100%	③ Blend into egg mixture.
Salt	to taste		④ Season. ⑤ Transfer to 1 l whipping siphon, and charge with two cartridges of nitrous oxide. ⑥ To serve, warm siphon in 60 °C / 140 °F bath, and dispense foam. Serve with grilled bread or steamed potatoes.

(original 2003)

EXAMPLE RECIPE

BARBECUED EEL WITH WHIPPED CARAMEL

ADAPTED FROM WYLIE DUFRESNE

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	100 g	100%	① Cook together to 143 °C / 290 °F.
Sugar	100 g	100%	② Cool and refrigerate.
Water	300 g	300%	③ Deglaze caramel, and stir to dissolve. Reserve 300 g of caramel water, and chill.
Versawhip 600 (Kerry Bioscience brand)	3 g	3%	④ Disperse powders into reserved cold caramel water, and blend until fully incorporated.
Xanthan gum (Keltrol T, CP Kelco brand)	0.45 g	0.45%	⑤ Whip with electric whisk until stiff, beer-head-like foam is achieved.
Barbecued eel (store-bought)	200 g	200%	⑥ Broil for 2 min, skin side down. ⑦ Arrange on plates, and garnish with whipped caramel.

(original 2006)

EXAMPLE RECIPE

DAIRY-FREE WHIPPED CREAM

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water, or flavorful liquid	200 g	100%	① Dry blend powders, and disperse in cold water. ② Bring to boil for 1 min to fully hydrate. ③ Remove from heat, and blend over ice until set. ④ Puree until smooth to make fluid gel.
Cellulose gum (Cekol LVD, CP Kelco brand)	1 g	0.5%	
Propylene glycol alginate (Protanal Ester BV 4104, FMC BioPolymer brand)	0.8 g	0.4%	
Agar (Texturas brand)	0.4 g	0.2%	
Neutral oil, or any flavored oil or fat	60 g	30%	⑤ Combine, and heat to 65 °C / 105 °F to dissolve flakes. ⑥ Slowly drizzle warm oil mixture into fluid gel, blending constantly, until fully emulsified. ⑦ Cool completely, and pour mixture into 1 l whipping siphon. ⑧ Simmer for 2 min, and remove from heat. Cool. ⑨ Charge with two cartridges of nitrous oxide, and refrigerate until use.
Glice (Texturas brand) or glycerin flakes (Terraspice brand)	4.2 g	2.1%	

(2010)

EXAMPLE RECIPE

HORSERADISH FOAM INSPIRED BY WYLIE DUFRESNE

Yields 400 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	400 g	100%	① Blend.
Fresh horseradish, finely grated	150 g	37.5%	② Strain.
Horseradish water, from above	400 g	100%	③ Bring water to boil. ④ Disperse methylcellulose and xanthan gum in boiling water.
Methylcellulose F50 (Dow brand)	4 g	1%	⑤ Simmer for 2 min, and remove from heat. Cool. ⑥ Vacuum seal. Refrigerate for at least 6 h to fully hydrate.
Xanthan gum (Keltrol T, CP Kelco brand)	0.6 g	0.15%	⑦ Transfer to metal bowl.
Salt	to taste		⑧ Season, and set bowl over pot of simmering water. ⑨ Whip foam base with electric whisk until soft peaks form. ⑩ Serve with rib roast or Boeuf en Gelée.

(original 2006, adapted 2010)

For a recipe for Boeuf en Gelée, see page 163.

EXAMPLE RECIPE

INSTANT SWISS MERINGUE

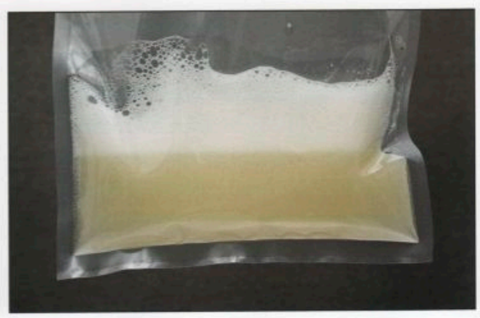
Yields 150 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg whites	100 g	100%	① Beat whites into sugar.
Sugar	100 g	100%	② Vacuum seal mixture. ③ Cook sous vide in 74 °C / 165 °F bath for 30 min. ④ Transfer to 1 l whipping siphon, and charge with four cartridges of nitrous oxide. ⑤ Dispense for use as soft meringues. ⑥ To set meringues, dispense on silicone mat, and bake in 150 °C / 300 °F oven for 1½ h.

(2010)

We developed this recipe to make a culinary classic more convenient. The meringue can be kept warm in the siphon at 60 °C / 140 °F for an extended period and then used to create instant meringue to order. The recipe as presented is flavorless, but you can add essential oils or other flavors. The same meringue can be made with 200 g of isomalt instead of 100 g of sugar.

1



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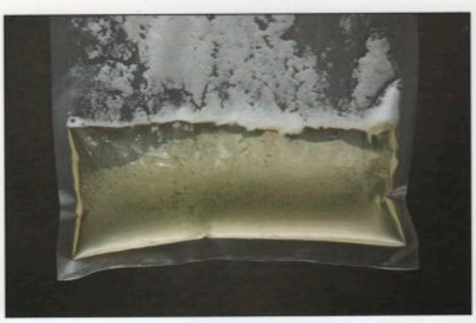

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EXAMPLE RECIPE

UNI WITH WHIPPED TOFU AND TAPIOCA ADAPTED FROM DAVID CHANG

Yields 3.85 kg (20 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Soft tofu	1.25 kg	313%	① Puree together until smooth.
Water	450 g	113%	② Pass through fine sieve.
Yuzu juice	80 g	20%	
Sugar	20 g	5%	
Yuzu kosho	15 g	4%	
Salt	10 g	2.5%	
Xanthan gum (Keltrol T, CP Kelco brand)	9 g	2.25% *(0.5%)**	③ Blend into tofu base until fully dispersed. ④ Pour mixture into 1 l whipping siphon. ⑤ Charge with two cartridges of nitrous oxide. ⑥ Reserve refrigerated.
Bonito flakes (katsuobushi)	20 g	5%	⑦ Toss together to make furikake (Japanese mixed seasoning).
Egg yolk powder	20 g	5%	
Nori powder	20 g	5%	
Puffed rice	20 g	5%	
Shrimp cracker puffs, crumbled	20 g	5%	
Toasted sesame seeds	20 g	5%	
Black tapioca pearls	1.25 kg	313%	⑧ Combine, and bring to simmer.
Apple juice (Mott's)	150 g	37.5%	⑨ Cool.
Elderflower syrup	100 g	25%	⑩ Place spoonful of tapioca pearls in bottom of each bowl. ⑪ Dispense large spoonful of whipped tofu onto each portion.
Santa Barbara sea urchin (uni) tongues	400 g	100%	⑫ Add three tongues to each bowl. ⑬ Garnish with furikake.

(original 2006)

(% of total weight of first six ingredients*)

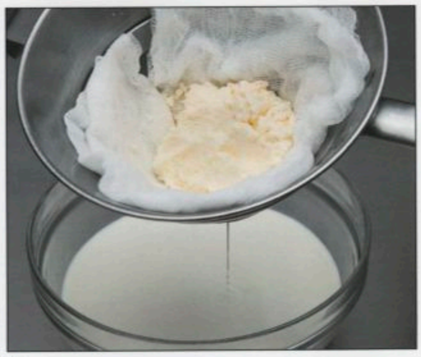
WHIPPED BUTTER

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Heavy cream (without stabilizers)	4 kg	400%	① Transfer to bowl of electric mixer. ② Whisk on high until fat is totally separated from liquid and small granules of butter begin to form, about 10 min. ③ Strain mixture through cheesecloth, discarding liquid. ④ Wring cheesecloth tightly to remove any remaining moisture from butter. ⑤ Measure 1 kg of sweet butter.
Sweet butter, from above or store bought	1 kg	100%	⑥ Whisk into soft butter. ⑦ Vacuum seal, and refrigerate for 24 h to mature butter flavor.
Lactic acid	1.5 g	0.15%	⑧ To serve, warm butter to 40 °C / 104 °F until fluid but not broken.
Delta decalactone (SAFC brand)	0.1 g	0.01%	⑨ Pour into 1 l whipping siphon, and charge with two cartridges of nitrous oxide. ⑩ Dispense to serve.
Salt	15 g	1.5%	

(2010)

2



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Whether you make your own butter or use store-bought butter, this incredible butter foam provides the essential taste of butter in a much lighter context. It may be held at 40 °C / 104 °F and foamed to order.

EXAMPLE RECIPE

YOGURT FOAM AND SWEET POTATO CHIPS

Yields 500 g

(HOMAGE TO AMERICAN SCULPTOR RICHARD SERRA) ADAPTED FROM JOSÉ ANDRÉS

INGREDIENT	QUANTITY	SCALING	PROCEDURE
160 Bloom gelatin	4 g	1.1%	① Bloom in cold water.
Heavy cream	150 g	43%	② Heat 50 g of cream.
			③ Add gelatin to dissolve.
Full-fat Greek-style strained yogurt	350 g	100%	④ Blend with gelatin mixture and 100 g of remaining cream.
			⑤ Transfer to 1 l whipping siphon, and charge with two cartridges of nitrous oxide.
			⑥ Refrigerate for at least 4 h.
Sweet potatoes, peeled	200 g	57%	⑦ Slice potatoes into sheets 1 mm / 1/32 in thick on Japanese rotary slicer.
Frying oil	as needed		⑧ Deep-fry in 190 °C / 375 °F oil until crisp and golden, about 3 min.
Salt	to taste		⑨ Season chips, and reserve.
Tamarind paste see page 5·99	100 g	28.5%	⑩ Blend well to form syrup, and transfer to squeeze bottle.
			⑪ Dispense yogurt foam into serving bowls.
Clear honey	40 g	11.5%	⑫ Drizzle syrup over foam, and serve with sweet potato chips on side.
Star anise powder	0.2 g	0.05%	

(original 2008, adapted 2010)

This "chips and dip" dish from Bazaar, the world's largest Modernist restaurant, is an excellent casual appetizer. We took a more formal approach here by shaping the chips in waves like those used by Richard Serra in his metal sculptures.

PARAMETRIC RECIPE

SET FOAMS

A set foam is simply a foam in which the liquid between the bubbles has solidified. The texture can vary from soft and sticky, like marshmallow, to dense and chewy, like bread, to dry and crisp, like meringue. Many traditional set foams, such as frozen soufflés and mousses made with gelatin, solidify simply by chilling. Others, such as meringues and baked soufflés, rely on heating to set the structure by coagulating proteins and swelling starch granules (see page 20). Still others exploit the fact that certain other hydrocolloids will set or that some oils solidify into fat when they cool.

By using foaming agents, such as purified albumin, and foam stabilizers, such as isomalt or another savory sugar, you can make novel set foams, like a beet meringue that has a delicate, crisp texture and an intense flavor when dehydrated.

Many of these techniques can be applied under reduced pressure in a vacuum chamber to achieve spectacular effects. As the pressure falls, the bubbles in the foam swell, and the solidification of the surrounding liquid can then capture the unique texture.

Best Bets for Set Foams

Serving temperature and bubble size	Foaming agents	(scaling)*	Hydrate (°C)	Hydrate (°F)	Hydrate (min)	Foaming method	Set Method	Set (°C)	Set (°F)	Set (h)
cold, fine	160 Bloom gelatin	3.00%	60	140	5	electric whisk	refrigerator			1
	xanthan gum	0.25%								
	160 Bloom gelatin	4.0%	60	140	5	stand mixer	refrigerator			3
	albumin powder	10%								
	heavy cream	200%	60	140	5	siphon with two cartridges of nitrous oxide	refrigerator			4
	egg yolk at 65 °C / 148 °F	30%								
	albumin powder	5%								
	160 Bloom gelatin	3%								
	xanthan gum	0.25%								
	albumin powder	18.0%	cold-soluble			stand mixer	vacuum oven	60	140	2
	glucose, syrup DE 40	16.5%								
	maltodextrin DE 19	5.0%								
	xanthan gum	0.3%								
hot and cold, fine	egg white	100.0%	n/a			electric whisk	steam oven	75	167	14 min
	lemon juice	10%								
	salt	1.3%								
	albumin powder	14.0%	cold-soluble			electric whisk	steam oven	78	172	16 min
	Maltrin M100	17.5%								
	egg yolk	27.0%								
	tartaric acid	0.2%								
hot and cold, coarse	egg white	104.0%	cold-soluble			siphon with two cartridges of nitrous oxide into perforated paper cup	microwave	full power		1 min
	nut butter	100.0%								
	egg yolk	67.0%								
	sugar or isomalt	67.0%								
	all-purpose flour	16.7%								
	160 Bloom gelatin	2.8%	100	212	5	electric whisk	blowtorch or broiler	high heat		1 min
	methylcellulose F50	1.4%								

(set weight of liquid to 100%)

MAKING A SET FOAM

1 **Select bubble size and foam temperature.** The table Best Bets for Set Foams below offers multiple options for foams to be served cold or hot, with or without fat.

2 **Measure ingredients carefully, and disperse the foaming agents in the liquid.** Set the weight of the liquid to 100%. For example, to make passion fruit marshmallows, add 6.25 g of 160 Bloom gelatin and 2.5 g of albumin powder for every 100 g of passion fruit base.

3 **Hydrate, using the time and temperature given (not required for cold-soluble foaming agents).**

4 **Cool liquid completely.**

5 **Aerate with an electric whisk or mixture, or expand by using a 1 l whipping siphon, as indicated.**

6 **Heat or chill the foam to set its structure.** Setting methods, temperatures, and times are listed in the table.

Examples	Note	See page
gelatin sponges, soy sauce cloud	keep liquid very cold when whipping	299
delicate marshmallow, passion fruit marshmallow	cool before whisking with albumin powder	next
savory parfaits and mousses	best cast directly in serving vessel	
very light savory meringues, green olive meringue	vacuum at 19 mbar / 0.28 psi; meringue base can also be dehydrated or baked	298
blanc manger	ideal pH around 8.7; add more acid to older egg whites	296
light soufflés	whip albumin and water with tartaric acid, and then fold in remaining ingredients	301
pistachio sponge cake	allow batter to rest for 1 h, refrigerated, before using; the container in which the sponge is cooked must have bottom ventilation	294
hot apricot marshmallow	best used with fruit or vegetable purees; use same day; see page 170 for details on methylcellulose	293

PASSION FRUIT MARSHMALLOW WITH CHORIZO POWDER

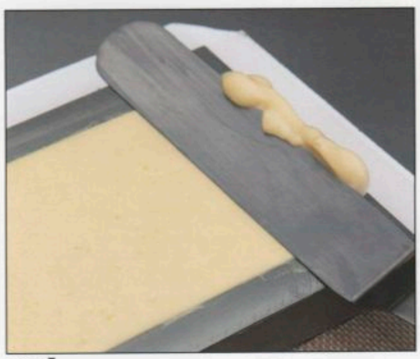
Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chorizo (dry cured), very thinly sliced	300 g	150%	① Place in even layer on dehydrator tray. ② Dehydrate at 55 °C / 131 °F for 12 h. ③ Pat off any excess oil.
N-Zorbit M (National Starch brand)	50 g	25% (*16.7%*)*	④ Add to dried chorizo, and grind to fine powder.
160 Bloom gelatin	8 g	4%	⑤ Disperse gelatin into juice.
Passion fruit juice	200 g	100%	⑥ Heat juice and sugar to 60 °C / 140 °F until gelatin and sugar dissolve.
Fructose	75 g	37.5%	⑦ Remove from heat. ⑧ Cool completely.
Albumin powder	20 g	10%	⑨ Whisk into cooled passion fruit juice mixture. ⑩ Whip until stiff peaks form, about 10 min. ⑪ Cast in 2.5 cm / 1 in layer on nonstick mold. ⑫ Refrigerate until fully set, about 4 h. ⑬ Cut resulting marshmallow into 2.5 cm / 1 in cubes. ⑭ Toss cubes in chorizo powder to serve.

(2010)

**(*% of total weight of chorizo*)

11a



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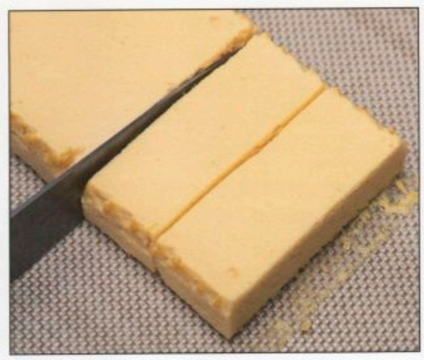

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EXAMPLE RECIPE

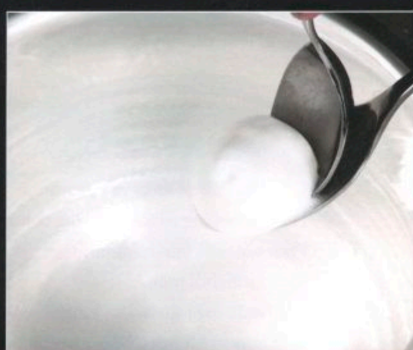
CRYOPOACHED GREEN TEA SOUR ADAPTED FROM HESTON BLUMENTHAL

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sugar	124 g	17.5%	① Combine.
HM pectin (Brown Ribbon HV, Obipektin brand)	11 g	1.5%	② Pass through tamis.
			③ Reserve sugar mixture.
Water	710 g	100%	④ Combine, and add sugar mixture.
Lime juice	133 g	19%	⑤ Hand-blend until sugar is completely incorporated.
			⑥ Bring to boil while whisking.
			⑦ Pass through chinois.
			⑧ Chill over ice to 4 °C / 39 °F.
Gunpowder tea	21 g	3%	⑨ Add to chilled mixture.
			⑩ Refrigerate infusion for 2 h.
			⑪ Pass through chinois lined with double layer of cheesecloth or 70 micron sieve.
Matcha green tea powder	1.5 g	0.2%	⑫ Blend into tea infusion.
			⑬ Pass through chinois to remove any lumps.
Egg whites	100 g	14%	⑭ Whisk into infusion to make meringue base.
Vodka	50 g	7%	⑮ Transfer meringue base to 1 l whipping siphon, and charge with two cartridges of nitrous dioxide. Store refrigerated.
			⑯ To serve, dispense small ball of meringue base onto spoon; transfer to Dewar flask filled with liquid nitrogen.
			⑰ Poach, turning meringue constantly until frozen on outside but still soft inside, about 30 s.
Matcha green tea powder	as needed		⑱ Dust over frozen meringue, and serve immediately.

(original 2001)

17a



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17c

EXAMPLE RECIPE

WHIPPED YOGURT CRISPS ADAPTED FROM AKI KAMOZAWA AND H. ALEXANDER TALBOT

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Full-fat Greek-style strained yogurt	480 g	100%	① Whisk together until yogurt is completely incorporated. ② Set aside yogurt base.
Water	270 g	56.25%	
Water	300 g	62.5%	③ Bring water to simmer.
Isomalt	50 g	10.4%	④ Stir in isomalt, Maltrin M100, and salt until dissolved.
Maltrin M100 (GPC brand)	25 g	5.2%	
Salt	5 g	1%	
Methocel K100 (Dow brand)	11.3 g	2.35% *(1.08%)**	⑤ Whisk into water until fully incorporated. ⑥ Remove from heat, and add to yogurt base, from above.
Xanthan gum (Keltrol T, CP Kelco brand)	2.26 g	0.47% *(0.22%)**	⑦ Cool in bowl set over ice-water bath. ⑧ Place bowl over hot water bath, and whip cooled mixture until consistency resembles whipped egg white meringue. ⑨ Transfer to pastry bag. ⑩ Pipe desired sizes onto tray lined with silicone mat. ⑪ Dehydrate in 95 °C / 205 °F oven until crisp, about 1 h.

(original 2007)

(% of total weight of first three ingredients*)

EXAMPLE RECIPE

GREEN TEA CAKE ADAPTED FROM JOHNNY IUZZINI

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sugar or isomalt, powdered	150 g	100%	① Blend until creamy.
Unsalted butter	85 g	57%	
Eggs, blended	150 g	100%	② Whisk into sugar mixture until smooth.
Vanilla seeds and pulp, scraped from pod	1 g	0.67%	③ Add.
Water	155 g	103%	④ Combine water and milk powder.
Skim milk powder	20 g	13.3%	⑤ Heat to boiling while whisking constantly. ⑥ Pour hot milk into blender.
Methocel SGA 7C (Dow brand)	3.5 g	2.3% *(2%)**	⑦ Blend into hot milk. ⑧ Chill milk over ice-water bath. ⑨ Add milk to blended sugar, butter, eggs, and vanilla seeds.
Cake flour	150 g	100%	⑩ Combine, and sift together.
Matcha green tea powder	8 g	5.3%	⑪ Fold into liquid ingredients to form batter.
Salt	4.5 g	3%	⑫ Load batter into 1 l whipping siphon, and charge with three cartridges of nitrous oxide. ⑬ Dispense into perforated paper cups. ⑭ Microwave on high for 1 min to cook through. ⑮ Unmold and serve.

(original 2009)

(% of total weight of water and milk powder*)

EXAMPLE RECIPE

HOT APRICOT MARSHMALLOW INSPIRED BY FERRAN ADRIÀ

Yields: 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Apricot puree see page 2·424	250 g	100%	① Combine methylcellulose with 200 g of apricot puree. Set aside remaining 50 g puree. ② Bring to boil, and hold for 2 min to fully disperse. ③ Cool completely. ④ Vacuum seal. ⑤ Refrigerate for 12 h to hydrate methylcellulose.
Methocel F50 (Dow brand)	3.5 g	1.4%	
160 Bloom gelatin	7 g	2.8%	⑥ Disperse gelatin in remaining 50 g of apricot puree. ⑦ Simmer to dissolve. ⑧ Combine with Methocel mixture. ⑨ Whip with electric whisk for 7 min, until light and airy. ⑩ Transfer to pastry bag. ⑪ Pipe small mounds onto center of ovenproof plates. ⑫ Cover plates with plastic wrap. ⑬ Refrigerate until set, about 4 h. ⑭ Remove plastic wrap.
Olive oil	100 g	40%	⑮ Combine.
Jasmine essential oil	1 g	0.4%	
Dried apricots, finely diced	40 g	16%	⑯ Bake apricot marshmallows at 120 °C / 250 °F for 3 min. ⑰ Garnish. ⑱ Drizzle a little infused olive oil over each meringue, and serve.
Marcona almonds, finely chopped	20 g	8%	
Chives, finely minced	5 g	2%	
Lemon balm leaves	5 g	2%	

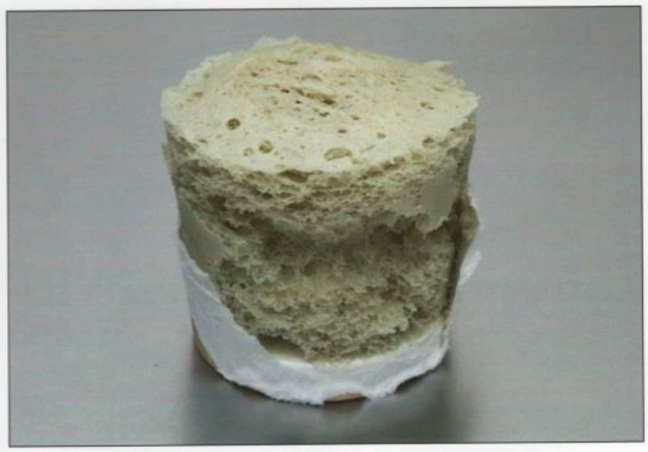
(original 2010)

MICROWAVED PISTACHIO SPONGE CAKE ADAPTED FROM FERRAN ADRIÀ

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg whites	250 g	104%	① Blend until smooth.
Green pistachio butter see page 2·418	240 g	100%	② Refrigerate for 2 h to rest.
			③ Strain.
Egg yolks	160 g	67%	④ Transfer cake base to 1 l whipping siphon, and charge with one cartridge of nitrous oxide.
Sugar or isomalt	160 g	67%	⑤ Perforate bottoms of 10 paper cups to allow for air circulation.
All-purpose flour	40 g	16.7%	⑥ Dispense cake base into cups, filling each about half full.
			⑦ Microwave each cup separately at 900 W for 50 s.

(original 2004)



EXAMPLE RECIPE

BEET MERINGUE ADAPTED FROM FERRAN ADRIÀ

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beet juice see page 2·336	120 g (from about 250 g of beets)	100%	① Bring to simmer, and remove from heat. ② Skim top. ③ Cool completely.
Isomalt	24 g	20%	④ Blend first three ingredients into cooled juice.
Albumin powder	15 g	12.5%	⑤ Season with salt.
Ascorbic acid	1.2 g	1%	⑥ Refrigerate for 12 h to rehydrate.
Salt	to taste		⑦ Whip rehydrated meringue base until stiff. ⑧ Pipe meringue base into mold, 5 cm / 2 in high. ⑨ Dehydrate in 90 °C / 195 °F oven for 2 h. ⑩ Cut into desired shapes. ⑪ Reserve in cool, dry place.
Spray-dried yogurt powder see page 2·438, or store-bought	15 g	12.5%	⑫ Combine. ⑬ Dust over meringues before serving.
Citric acid	1 g	0.8%	

(original 2005, adapted 2010)

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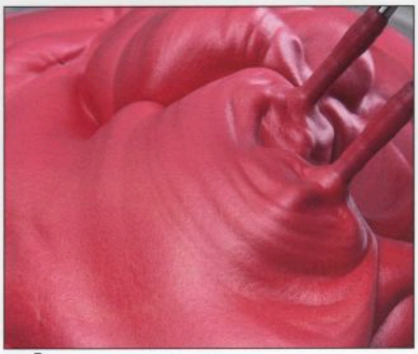

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STEAMED BLANCMANGE ADAPTED FROM JEAN-FRANÇOIS PIÈGE

Yields 200 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg whites	120 g	100%	① Whip together until stiff peaks form.
Lemon juice	12 g	10%	
Salt	2 g	1.7%	
Chives, finely minced	4 g	3.3%	② Fold in gently.
Black pepper, crushed	0.8 g	0.67%	③ Transfer to pastry bag.
Unsalted butter, room temperature	as needed		④ Grease four 10 cm / 4 in metal ring molds lightly. ⑤ Pipe egg white mixture into molds, filling each halfway full. ⑥ Press down in center of molds with back of wet spoon, making small depressions.
Egg yolks, whole	four whole		⑦ Add one yolk to center of each mold. ⑧ Fill molds with remaining egg white mixture, covering yolks. ⑨ Scrape off tops of each blancmange with offset spatula to flatten. ⑩ Flash sides lightly with blowtorch to tighten structure. ⑪ Brush plastic wrap with butter, and cover each blancmange. ⑫ Steam in 75 °C / 165 °F combi oven for 14 min. ⑬ Let rest in molds at room temperature for 2 min. ⑭ Transfer to serving plates.
Sauce vin jaune see page 5·116	120 g	100%	⑮ Warm sauce and pour over each blancmange at table.

(original 2005)

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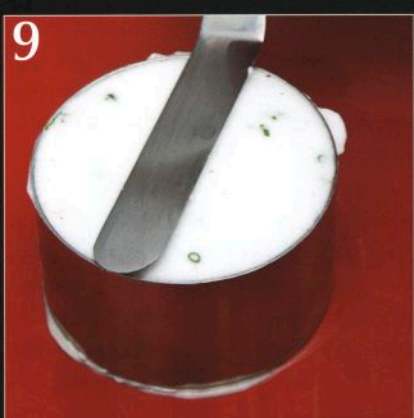
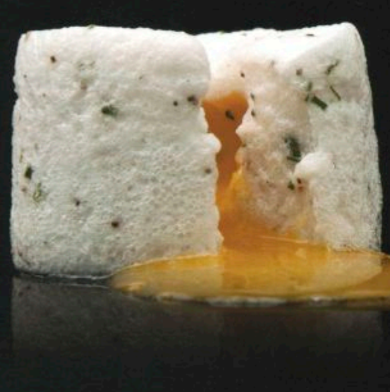




EXAMPLE RECIPE

SIPHONED SOUFFLÉ À LA LORRAINE

Yields 200 g (four individual soufflés)

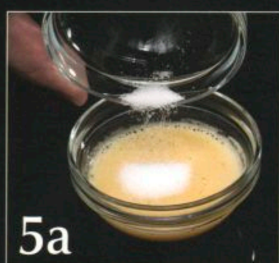
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	150 g	150%	① Vacuum seal together, and cook sous vide in **90** °C / **194** °F bath for 1½ h.
Bacon, rendered and drained	100 g	100%	② Remove from bag, and strain; measure 78 g of milk, and cool.
Sweet onions, thinly sliced	40 g	40%	③ Combine with infused milk, and blend until smooth.
			④ Cook sous vide in 78 °C / **172** °F bath for 30 min.
Egg whites	100 g	100%	⑤ Dust sugar over egg yolks, and let stand for 20 min at room temperature.
Infused milk, from above	78 g	78%	⑥ Blend whites, salt, butter, and infused milk with sugar dusted egg yolks until smooth, and cook sous vide in 78 °C / **172** °F bath for 30 min to make egg base.
Egg yolks	20 g	20%	
Unsalted butter, melted	14 g	14%	
Salt	3.6 g	3.6%	
Sugar	1.1 g	1.1%	
Corn starch	13.5 g	13.5%	⑦ Dry blend, and whisk into cooked egg base until dispersed evenly.
Propylene glycol alginate (Propanal Ester BV, FMC BioPolymer brand)	0.31 g	0.31%	⑧ Pour into 1 l whipping siphon, and hold in 55 °C / **131** °F bath until ready to bake.
			⑨ To bake, charge with two cartridges of nitrous oxide, and shake well.
			⑩ Line the sides of four ramekins with parchment collars.
Maltrin M100 (GPC brand)	3.1 g	3.1%	⑪ Brush inside of ramekins with oil or melted butter, and dust with flour.
Cream of tartar	0.7 g	0.7%	⑫ Dispense soufflé base two-thirds up sides of ramekins.
			⑬ Put in oven pan, and fill pan with enough water to cover bottom halves of ramekins.
			⑭ Bake in 190 °C / **375** °F oven for 20 min.

(2010)

For a cheese version of the soufflé, add 54 g (54%) of grated Gruyère cheese, and dissolve it with 0.4% sodium citrate in the warm milk. Cool completely, and proceed with the remaining instructions. Use only 1.8 g (1.8%) of salt.

For a chocolate version of the soufflé, replace corn starch with 7 g (7%) tapioca starch, whisk 39 g (39%) of grated semisweet chocolate into the warm milk, and omit the Maltrin, PGA, and 1.8 g of the salt. Cool completely, and proceed with instructions.

Sous vide cooking time of eggs will vary according to the size of the batch.



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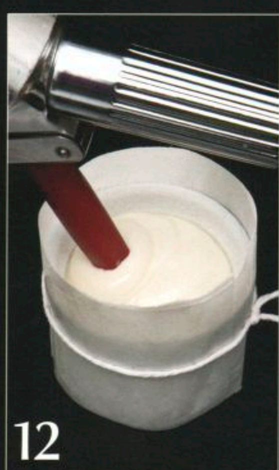

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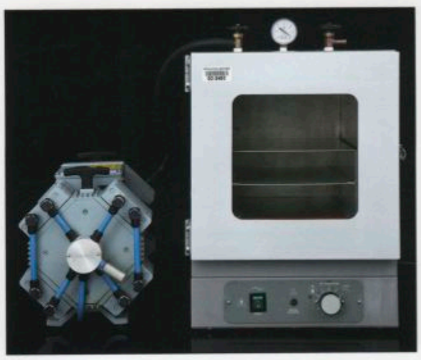
GREEN OLIVE MERINGUE INSPIRED BY PIERRE GAGNAIRE

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Green olives, pitted, bulk	900 g	300%	① Blend to fine puree.
Water	500 g	167%	② Strain through cheesecloth to extract juice.
			③ Measure 300 g of juice.
Green olive juice, from above	300 g	100%	④ Whisk together.
Albumin powder	54 g	18%	
Glucose syrup DE 40	50 g	16.5%	
Maltrin M100 (GPC brand)	15 g	5% *(3.7%)**	⑤ Fold into olive juice mixture.
			⑥ Whip in stand mixer until dense foam forms, about 5 min.
Xanthan gum (Keltrol T, CP Kelco brand)	0.9 g	0.3% *(0.2%)**	⑦ Pipe 5 cm / 2 in spheres of green olive meringue onto silicone baking mat.
			⑧ If available, bake in 60 °C / 140 °F vacuum oven at 19 mbar / 0.275 psi for 2 h.
			⑨ Otherwise, bake in 77 °C / 170 °F oven for 8 h, or 150 °C / 300 °F oven for 1½ h.
Green olives, pitted	100 g	33%	⑩ Dehydrate at 55 °C / 131 °F for 12 h.
			⑪ Grind to fine powder in food processor.
N-Zorbit M (National Starch brand)	40 g	13.3%	⑫ Whisk into powder.
Salt	to taste		⑬ Season.
Extra-virgin olive oil	30 g	10%	⑭ Whisk slowly into powder until fully incorporated.
			⑮ Dust over meringues to serve.

(original 2003, adapted 2010)

(% of total weight of green olive juice, albumin powder, and glucose*)



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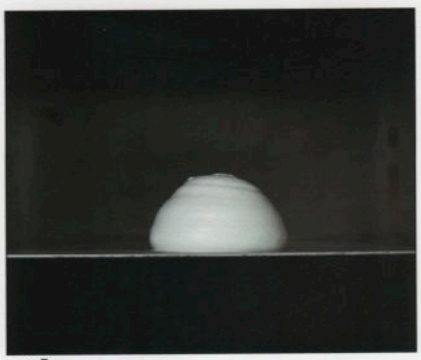

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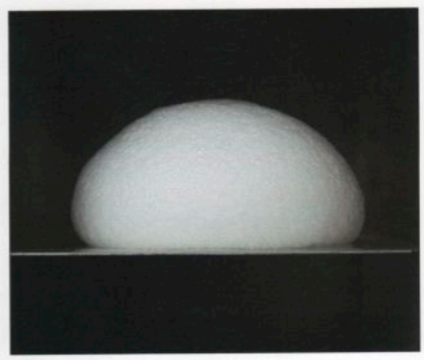

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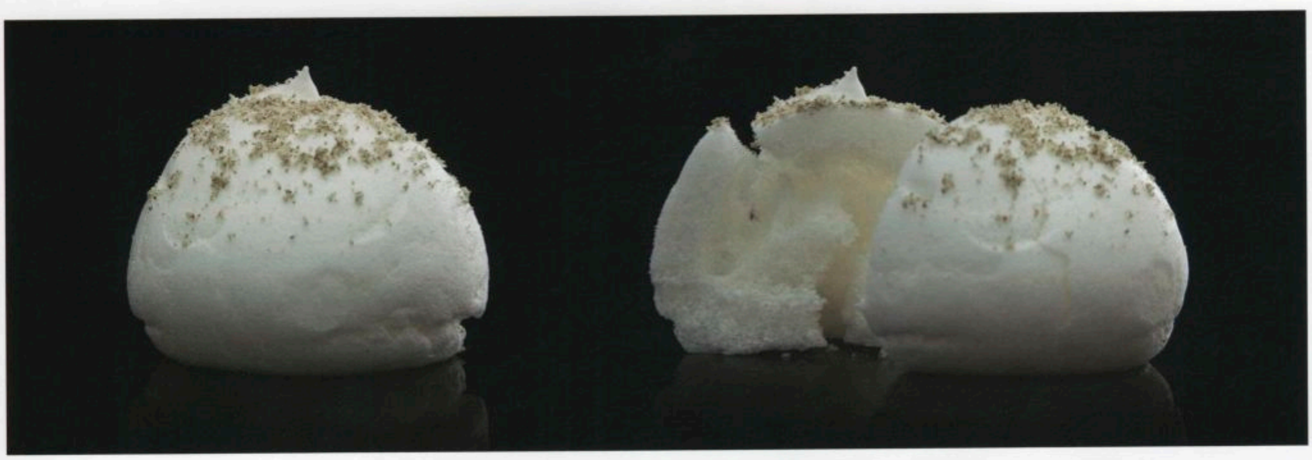

EXAMPLE RECIPE

SOY SAUCE CLOUD ADAPTED FROM FERRAN ADRIÀ

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water, cold	100 g	100%	① Place empty stand mixer bowl or stainless steel bowl in freezer for 25 min.
160 Bloom gelatin	6 g	6% (*3%*)*	② Hydrate gelatin in water. ③ Bring water to simmer until gelatin is just dissolved. ④ Cool quickly. Do not allow gelatin to set.
Soy sauce	100 g	100%	⑤ Combine, and whisk into gelatin mixture.
Xanthan gum (Xantana, Texturas brand)	0.5 g	0.5% (*0.25%*)*	⑥ Place in freezer-chilled bowl. ⑦ Whip with electric whisk attachment or handheld automatic whisk until liquid becomes very dense and forms tight foam, about 15 min. ⑧ Cast foam into nonstick mold, 1.5 cm / ⅝ in thick. ⑨ Freeze mold for 2 min to firm. ⑩ Transfer to refrigerator, and chill at least 2 h before using. ⑪ Cut into desired shapes, and serve as garnish for foie gras or monkfish liver terrine.

(original 2000, adapted 2010)

(% of total weight of water and soy sauce*)

6

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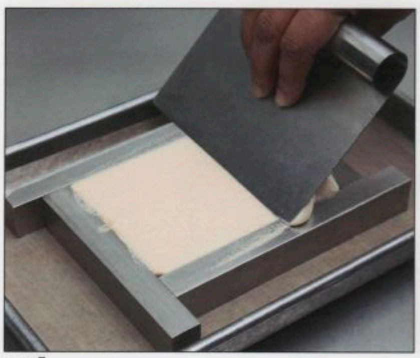
8a



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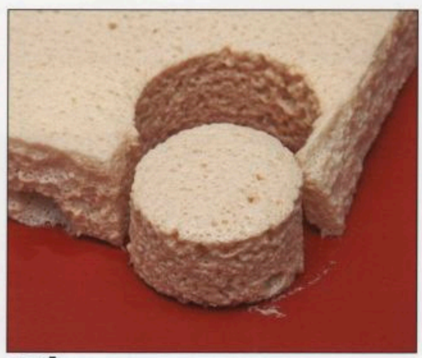


11b

FREEZE-DRIED CARROT FOAM ADAPTED FROM FERRAN ADRIÀ

Yields 200 g

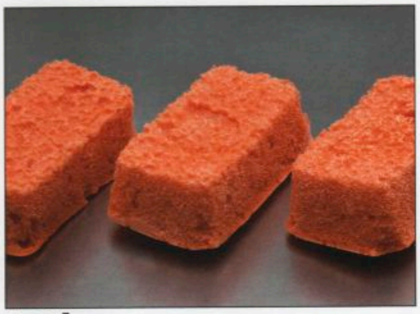
INGREDIENT	QUANTITY	SCALING	PROCEDURE
160 Bloom gelatin	15 g	3%	① Bloom gelatin in cold water.
Carrot juice see page 2·336	500 g (from 800 g carrots)	100%	② Warm 250 g of juice. ③ Dissolve gelatin in warmed juice.
Xanthan gum (Keltrol T, CP Kelco brand)	1 g	0.2%	④ Blend with remaining 250 g of juice. ⑤ Combine with gelatin mixture. ⑥ Cool. ⑦ Transfer to 1 l whipping siphon, and charge with three cartridges of nitrous oxide. ⑧ Refrigerate for at least 3 h. ⑨ Dispense foam in 2.5 cm / 1 in thick layer into desired mold. ⑩ Freeze-dry for 48 h to create carrot meringue.
Honey Sugar Unsalted butter	200 g 180 g 50 g	40% 36% 10%	⑪ Combine. ⑫ Heat to 170 °C / 338 °F. ⑬ Pour hot mixture onto silicone mat. ⑭ Leave at room temperature to harden completely. ⑮ Break honey caramel into pieces, and measure 210 g.
Honey caramel, from above N-Zorbit M (National Starch brand)	210 g 65 g	42% 13% (*31%*)*	⑯ Grind together in food processor to fine powder.
Freeze-dried mint powder see page 3·372	5 g	1%	⑰ Break carrot meringue into large pieces. ⑱ Garnish with honey caramel and mint powders.

(original 2005)

(% of total weight of honey caramel used*)

9

10a



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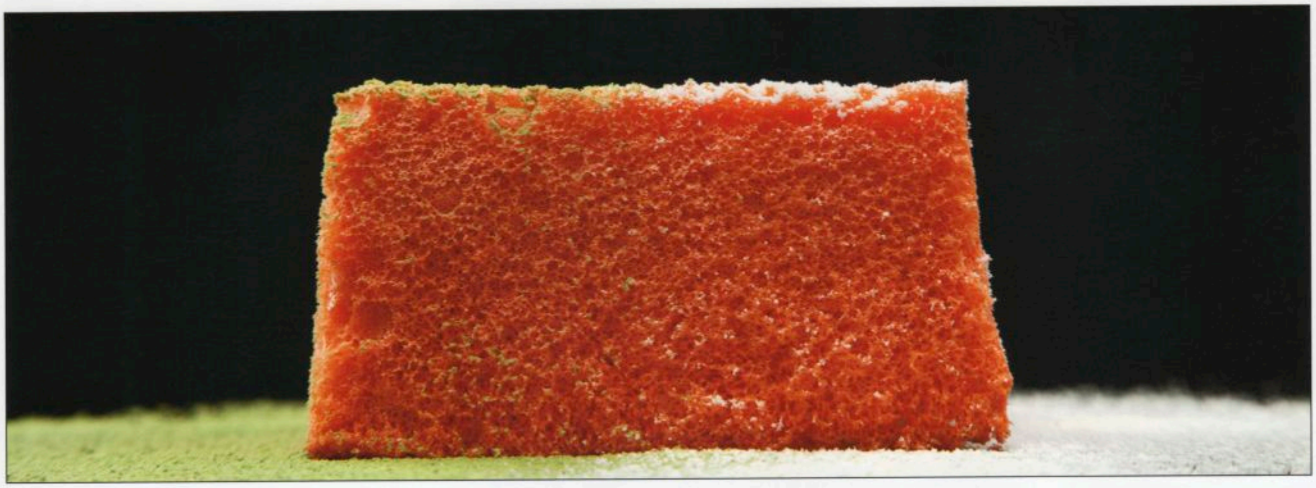

EXAMPLE RECIPE

GRUYÈRE SOUFFLÉ

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	250 g	111%	① Combine, and bring to simmer.
Sodium citrate	8 g	3.5%	
Salt	2.5 g	1%	
Gruyère cheese, finely grated	150 g	67%	② Blend in hot water until completely melted.
			③ Centrifuge at 27,500g or higher for 1 h.
			④ Strain, and measure 225 g of cheese water.
Gruyère water, from above see page 2·310	225 g	100%	⑤ Blend until powder dissolves.
Albumin powder	32 g	14%	
Tartaric acid	0.4 g	0.18%	⑥ Add, and whip to stiff peaks.
Egg yolks, blended	60 g	27%	⑦ Add and rewhip.
Corn maltodextrin (Maltrin M100, GPC brand)	40 g	17.5%	⑧ Cast into desired mold.
			⑨ Steam at 77 °C / 170 °F until fully set. Cool cheese soufflé.
Gruyère, finely grated	120 g	53%	⑩ Spread on silicone mat.
			⑪ Bake in 190 °C / 375 °F oven for 15 min, until crisp and golden.
			⑫ Cool completely.
N-Zorbit M (National Starch brand)	8 g	3.5%	⑬ Combine with cooled cheese.
			⑭ Grind in food processor to fine cheese powder.
Cauliflower crème anglaise see page 89	100 g	44%	⑮ Warm vacuum-sealed crème anglaise at 70 °C / 158 °F for 15 min.
			⑯ Toss cold cheese soufflé in cheese powder until evenly coated.
			⑰ Reheat in oven at 250 °C / 480 °F until outside is crisp, about 2 min.
			⑱ Serve with warmed crème anglaise.

(2010)

This recipe is incredibly versatile. Any cheese can be used for this preparation. But, more importantly, the soufflé base can be molded and cut into any shape and reheated for service, thereby allowing you to make a square soufflé with a hollowed center that can accommodate a custard filling.


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16a


16b

PARAMETRIC RECIPE

PUFFED SNACKS

You might not think of them as foams, but that is exactly what puffed snacks are. They are made by creating a dense starch gel, and then mostly dehydrating it. When it is deep-fried or cooked in a microwave oven, the residual water expands as it turns to steam and transforms the starch gel into a set foam.

Getting puffed snacks to work properly requires a consistent moisture content. A dry matter analyzer can be used to measure this.

1. **Select a food that puffs well.** The table Best Bets for Puffed Snacks below lists our recommendations and any prep steps.
2. **Parcook (optional).** Many foods puff better if first dehydrated by parcooking. See the table for methods, times, and temperatures.
3. **Dehydrate.** Dry the food until it is 11%–15% water by weight as measured by a moisture analyzer. Dehydration times in the table are given as a guide and will vary. Whole grains do not need a dehydration step because they are already dehydrated.
4. **Fry or microwave at 100% power.**

Best Bets for Puffed Snacks

		Parcook				Dehydrate			Deep-fry			Microwave at 800 W	See
Ingredient	Preparation	Method	(°C)	(°F)	(min)	(°C)	(°F)	(h)	(°C)	(°F)	(s)	(s)	page
legumes (chickpeas, lentils, and mung beans work best)	whole	cover with water and pressure-cook	1 bar / 15 psi		15	50	120	50 min	190	375	40	60 (in paper bag)	307
floury potatoes (for pommes soufflées)	sliced to 2 mm / 1/16 in thick	blanch in oil	157	315		n/a			195	380	30	n/a	306
pregelatinized starch cracker	roll to 1–2 mm / 1/32–1/16 in thick	n/a				65	150	1	200	390	15	35	305
processed grains (white rice and pearl barley work best)	whole	boil until tender	100	212	25	55	130	10	205	400	45	30	5·32
rice crisp (white rice)	spread in a layer 2 mm thick after cooking	boil to a porridge (falling apart)	100	212	1 h	50	120	3	200	390	12	40	304
tapioca starch cracker	roll before cooking or slice after cooking to 1–2 mm / 1/32–1/16 in thick	steam	100	212	70 (for loaf) 30 (for prerolled)	50	120	1	205	400	12	45	next
dried wheat pasta	whole	boil	100	212	35	55	130	10	205	400	45	2 min	
whole grains (corn, wild rice, and barley with husk work best)	whole	n/a				n/a			200	390	15	90 (in paper bag)	307

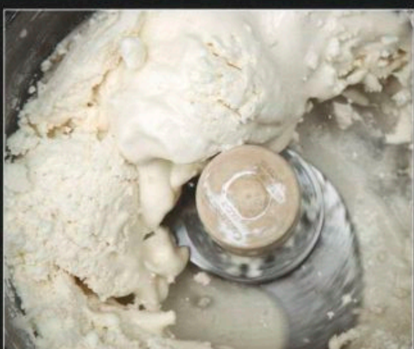
EXAMPLE RECIPE

TAPIOCA STARCH CRACKER

Yields 125 g

INGREDIENT	QUANTITY	SCALING
Warm water (or flavorful liquid)	120 g	60%
Tapioca starch	200 g	100%
Ground meat or shellfish (optional)	65 g	32.5%
Salt	5 g	2.5%
Frying oil	as needed	

(2008)



1 **Blend all ingredients to make very fluid, thixotropic dough.** Use food processor, if available, or wet hands and flexible spatula.

2 **Roll dough in plastic wrap into tight cylinder, and tie ends firmly.**

3 **Steam 40–50 min until dough turns gray and slightly translucent.**

4 **Chill for at least 5 h.** Dough will harden as it cools.

5 **Cut into slices 1–2.5 mm / 1/32–1/8 in thick, using meat slicer, if available.** Thin chips will be light and crisp. Thicker chips will be firm, with Styrofoam-like crunch similar to the prawn crackers that Vietnamese restaurants often serve.

6 **Dehydrate at 50 °C / 122 °F until chips attain dry, yet flexible, plastic-like texture, about 3 h.** Their residual moisture content should be 11–14%. To preserve for later use, vacuum seal under light pressure.

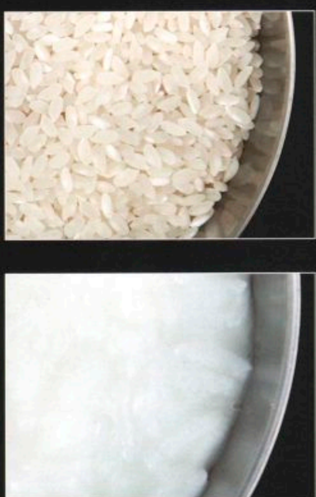
7 **Deep-fry in 198 °C / 390 °F oil until fully puffed, 20–30 s.** Remove from oil, and drain on paper towels.

BLACK SESAME RICE CRISPS INSPIRED BY FERRAN ADRIÀ

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White long-grain rice	320 g	100%	① Boil until rice is overcooked and achieves porridge-like texture, about 1 h. ② Puree with hand blender until nearly smooth but with small fragments throughout.
Water	1 kg	313%	
Black sesame seeds	75 g	23%	③ Mix into rice. ④ Spread in layer 1.5 mm / 1⁄16 in thick on a silicone mat. ⑤ Dehydrate at **50** °C / **120** °F until dry but still pliable, about 3 h. ⑥ Break into large fragments, and reserve in dry environment.
Frying oil	as needed		⑦ Heat oil to **190** °C / **375** °F. ⑧ Deep-fry rice crisps until crisp and slightly puffed, about 12 s. ⑨ Drain on paper towels.
Salt	to taste		⑩ Season.

(original 2003, adapted 2010)



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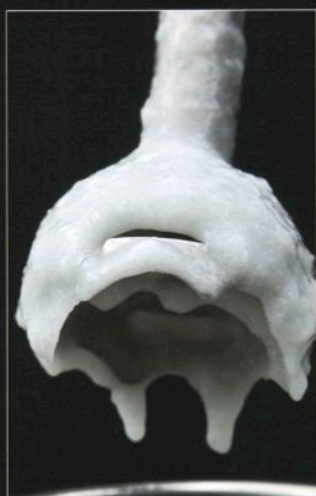

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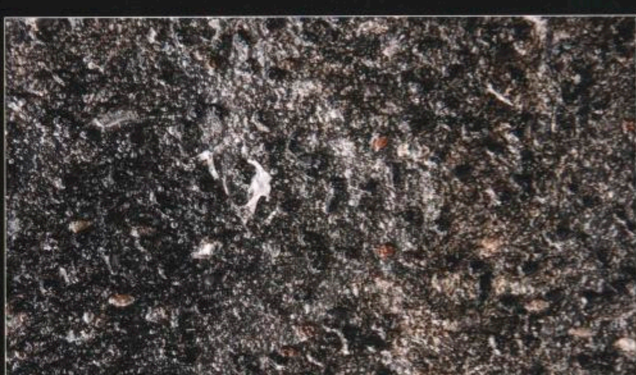


EXAMPLE RECIPE

CHEESE PUFFS INSPIRED BY WYLIE DUFRESNE

Yields 170 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
N-Zorbit M (National Starch brand)	50 g	16.7%	① Blend until smooth paste. ② Spread thinly on nonstick sheet.
Thin cheddar cheese sauce see page 223	25 g	8.4%	③ Dehydrate at 50 °C / 122 °F for 8–12 h until completely dry. ④ Grind to make cheese powder.
Crisp Coat UC (National Starch brand)	66 g	22%	⑤ Dry blend powders.
Ultra-Sperse M (National Starch brand)	16.5 g	5.5%	
Salt	4 g	1.3%	
Cheddar cheese water see page 2·310	300 g	100%	⑥ Whisk cheese water into powder mixture to form paste. ⑦ Spread onto silicone mats in one layer, 3 mm / ⅛ in thick. ⑧ Dry in 65 °C / 150 °F oven for 1 h. ⑨ Break into desired shapes.
Frying oil	as needed		⑩ Fry shapes for 10–15 s at 200 °C / 390 °F. ⑪ Drain on paper towels. ⑫ Dust cheese powder over puffs.

(original 2007, adapted 2010)


6a


6b


7

POMMES SOUFFLÉES

This is one recipe for which the freshest ingredients are not what you want. Freshly harvested potatoes will most often have too much moisture to puff properly. Potatoes that are so old that they have become soft, on the other hand, will be too dry. Select slightly aged, starchy potatoes that are not too heavy and have clear, firm skin. The ideal moisture content ranges from 12% to 18%. Russets usually work well, but perfection with any given batch of potatoes will require some experimentation. **See page 3·330 for a puffed potato chip made from a batter.**

Yields 325 g

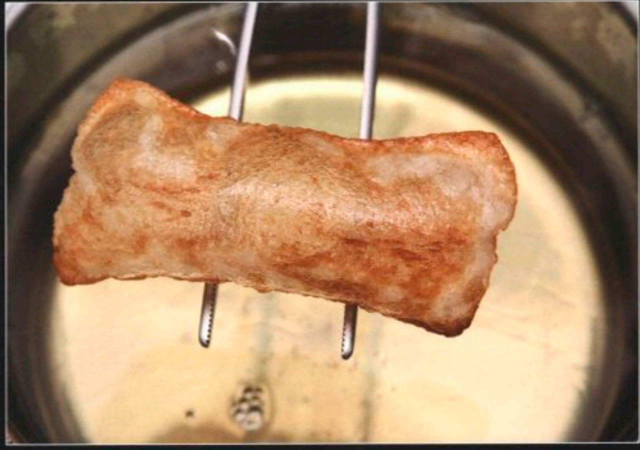
INGREDIENT	QUANTITY	SCALING
Russet potatoes, peeled and sliced into ovals or rectangles 3 mm / ⅛ in thick to 3.5 mm / 5⁄32 in thick	400 g	100%
Frying oil	as needed	
Salt	to taste	

(2009)

1 **Preheat two fryers or pots of oil.** Bring oil in first pot to 145 °C / 290 °F and oil in second pot to 195 °C / 390 °F.

2 **Soak potatoes in ice water for 30 min.** Dry slices after they have firmed.

3 **Blanch in 145 °C / 290 °F oil.** Slices will blister in 7–8 min; cook them for another 60 s, and then drain, and pat dry. Rest for at least 5 min and for up to 4 h before puffing.



4 **Puff in 195 °C / 390 °F oil for 1–3 min, moving potatoes constantly.** Do not overcrowd pot. Remove each slice as soon as it has fully puffed and turned evenly brown.

5 **Drain gently on paper towels.** Season with salt.

EXAMPLE RECIPE

PUFFED CHICKPEAS

The classic puffed grain or seed is popcorn, but many beans, legumes, grains, and seeds will puff in a microwave or deep fryer. Grains can usually be puffed from the raw state—they are already dried and puff directly. Beans work better if hydrated, pressure cooked, and dried before deep-frying.

Yields 200 g

INGREDIENT	QUANTITY	SCALING
Water	500 g	200%
Dry chickpeas	250 g	100%
Frying oil	as needed	
Salt	to taste	

(original 2007, adapted 2009)

1 **Cover chickpeas with twice their volume in cold water.** Soak, refrigerated, for 12 h. Drain.

2 **Combine soaked chickpeas with water in pressure cooker, and cook at a gauge pressure of 1 bar / 15 psi for 15 min.** Rest chickpeas for 5 min, and then drain and cool.

3 **Spread cooked chickpeas evenly on dehydrator tray, and dehydrate at 50 °C / 120 °F for 50 min.**

4 **Deep-fry dried chickpeas in 190 °C / 375 °F oil until puffed and golden, about 40 s.** Season.

This process can also be applied to puff whole grains such as forbidden rice and barley (both pictured above before and after puffing) or others such as wild rice, amaranth, and corn. Simply omit the cooking step, and deep-fry in 200 °C / 390 °F oil until they puff, about 15 s—or instead coat them with oil and microwave them at 800 W for 90 s in a sealed paper bag.

SCALLOP MOCHI

Yields 60 g

INGREDIENT	QUANTITY	SCALING
Water	100 g	200%
Dried scallops (store-bought)	20 g	40%
Mochi flour	50 g	100%
Scallop infusion, from above	50 g	100%
Glucose syrup DE 40	25 g	50%
Salt	1.2 g	2.4%
Frying oil	as needed	
Freeze-dried scallops, ground to fine powder see page 2·450	5 g	10%

(2009)

1 **Vacuum seal dried scallops with water.**

2 **Cook in 90 °C / 194 °F bath for 1½ h.**

3 **Remove from bag, and strain.** Measure 50 g of scallop infusion, and cool.

4 **Mix mochi flour, scallop infusion, glucose, and salt into smooth paste.**

5 **Microwave dough for 2½ min on full power.** The dough will turn opaque and become very elastic.

6 **Roll out mochi dough to 2 mm / 3⁄16 in thick.** Place dough between two silicone mats and use rolling pin.

7 **Remove top mat, and dehydrate dough on bottom mat in a 107 °C / 225 °F oven for 10 min.**

8 **Flip dough over, and dehydrate for 10 min more.**

9 **Run dough through pasta machine to 1 mm / 1⁄32 in thickness.**

10 **Cut with round cutter into scallop shapes.**

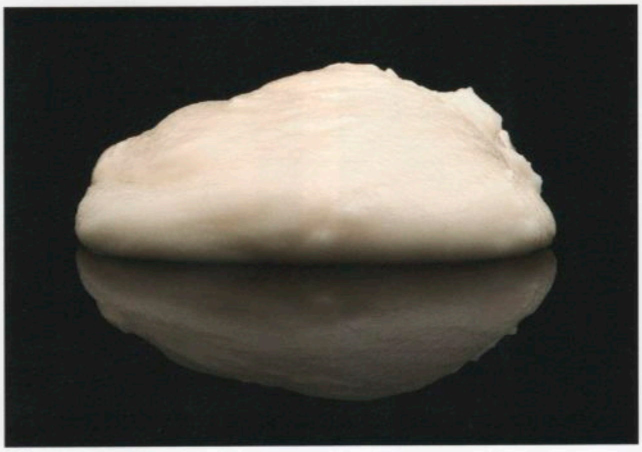
11 **Lay each pair of cut shapes on top of each other, and laminate by running them together through pasta roller.**

12 **Repeat lamination process with remaining dough.**

13 **Dehydrate mochi discs at 60 °C / 140 °F until leathery and pliable, about 30 min, to make light puffs.** Dehydrate at same temperature for up to 5 h until very dry to make very crispy, denser puffs.

14 **Deep-fry dehydrated discs in 200 °C / 390 °F oil until fully puffed and golden brown, about 1½ min.**

15 **Dust with scallop powder.**



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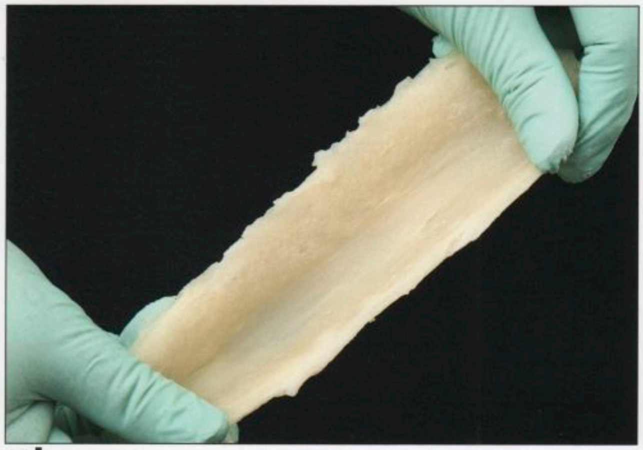
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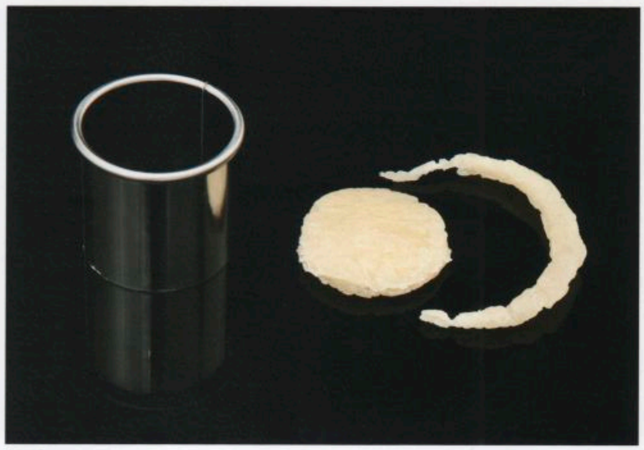
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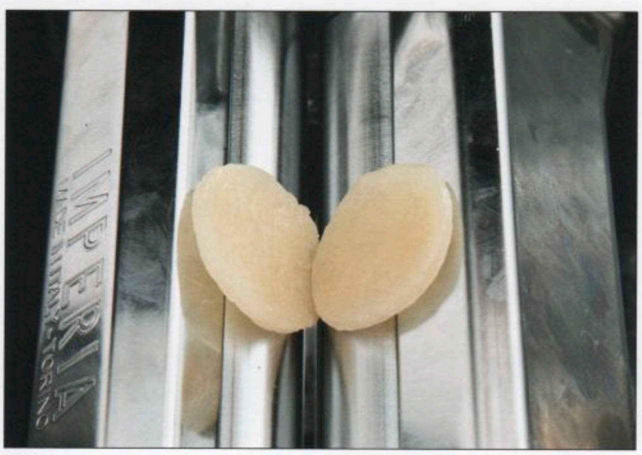

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13

VACUUM-SET FOAMS

Vacuum-set foams start with a liquid with either small bubbles or some dissolved gas in it. Once a vacuum is applied, the bubbles greatly expand and any dissolved gas emerges from the solution. Both effects help to inflate the foam.

One class of vacuum-set foams sets through cooling. These foams are best made by using a vacuum container and a vacuum-packing machine (see page 2·222). The former can be either plastic storage containers or stainless steel hotel pans with special vacuum lids. Another approach is to put a pan into a chamber vacuum machine (see page 2·214). A vacuum desiccator can be also be used as a vacuum chamber.

Vacuum-set foams can also be heat-set in a vacuum oven. One example of a heat-set foam is vacuum-enhanced meringue, a recipe for which is on page 298.

Before the vacuum is pulled, the liquid is a dense foam.

Sucking air out of the container with a vacuum pump expands the foam greatly, and it can now set in this expanded state.

EXAMPLE RECIPE

AERATED MANGO SORBET

Yields 700 g (17 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sugar	280 g	56%	① Whisk together in pot, and cook to **102** °C / **216** °F; syrup density should reach 75 °Brix.
Water	120 g	24%	② Measure and reserve 208 g of syrup.
Mango flesh, frozen	500 g	100%	③ Puree until very smooth and slightly foamy.
Syrup, from above	208 g	41%	④ Place in bowl set over salted ice water, and stir until very cold and viscous.
Citric acid	10.4 g	2%	⑤ Pour 40 g of mango base into 1 pt mason jars; repeat until all base is used (up to 17 jars).
			⑥ Attach lids and rings, and close until just snug.
			⑦ Place in vacuum chamber, and pull vacuum until sorbet reaches top of jar.
			⑧ Freeze for at least 5 h.
			⑨ Remove from freezer, and open while frozen solid.
			⑩ Replace lid, and allow sorbet to soften slightly at room temperature for 5 min before serving.

(2010)

EXAMPLE RECIPE

AERATED FOIE GRAS ADAPTED FROM WYLIE DUFRESNE

Yields 425 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Simplesse (CP Kelco brand)	5.5 g	1.7% (*1.25%*)*	① Dry blend powders.
Agar	1.7 g	0.5% (*0.4%*)*	
Konjac gum (TIC Gums brand)	0.7 g	0.2% (*0.16%*)*	
Xanthan gum (Keltrol T, CP Kelco brand)	0.3 g	0.1% (*0.07%*)*	
Foie gras torchon see page 3·176	315 g	100%	② Microwave in bowl until melted, about 2 min.
			③ Add gum mixture, blending until completely incorporated.
Water	105 g	33.3%	④ Heat water in microwave for 1½ min.
Egg yolk	20 g (one large)	6.3%	⑤ Combine hot water slowly with yolk to temper, using hand blender.
			⑥ Mix in gum and terrine mixture, emulsifying fully.
			⑦ Blend emulsion with hand blender to whip in air as mixture cools.
			⑧ Cool mixture to **36** °C / **97** °F.
			⑨ Transfer to one-sixth-size hotel pan.
			⑩ Place in vacuum chamber, and pull vacuum until mixture rises to top of pan.
			⑪ Place pan over ice-water bath, and allow foie gras to set for 2 h.
			⑫ Break into uneven pieces, and serve.

(original 2009)

(% of total weight of last three ingredients*)

EXAMPLE RECIPE

AERATED GRUYÈRE

Yields 360 g

INSPIRED BY H. ALEXANDER TALBOT AND AKI KAMOZAWA

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Skim milk	180 g	100%	① Blend until powders are incorporated.
160 Bloom gelatin	3.6 g	2% (*1%*)*	② Bring to boil over medium heat.
Agar (Texturas brand)	1 g	0.55% (*0.28%*)*	③ Remove from heat.
Locust bean gum (POR/A2 Powder, TIC Gums brand)	0.1 g	0.05% (*0.03%*)*	
Gruyère cheese, grated	180 g	100%	④ Add to hot milk mixture, and stir until cheese has melted.
Salt	3 g	1.6%	⑤ Pour into blender, and process until completely homogenous.
Cayenne pepper powder	0.2 g	0.1%	⑥ Transfer to 1 l whipping siphon, and charge with two cartridges of nitrous oxide.
			⑦ Dispense into four 235 ml / 8 fl oz Mason jars.
			⑧ Seal with lids immediately.
			⑨ Refrigerate for at least 5 h before opening.

(original 2009, adapted 2010)

(% of total weight of cheese and skim milk*)

EXAMPLE RECIPE

AERATED COFFEE ICE CREAM

ADAPTED FROM ALEX STUPAK

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole milk	500 g	100%	① Combine, and vacuum seal. Infuse, refrigerated, for 24 h.
Coffee beans	50 g	10%	② Strain.
Sugar	122 g	24.4%	③ Whisk into warm milk until dissolved.
Dextrose	97.5 g	19.5%	
Egg yolks	24.5 g (from two eggs)	4.9%	④ Pour warm milk over yolks, and whisk to temper.
Propylene glycol alginate (Protanal Ester BV 4830, FMC BioPolymer brand)	4.9 g	1% (*0.5%*)*	⑤ Transfer mixture to blender, and mix in PGA on low speed. ⑥ Increase to high speed, and blend for 1 min.
Cream cheese	80.5 g	16.1%	⑦ Add to blender, and continue blending until smooth.
Unsalted butter	73 g	14.6%	⑧ Cool completely over ice water.
Salt	1.95 g	0.4%	⑨ Churn in ice cream machine according to manufacturer's instructions, or freeze in Pacojet beaker and pacotize.
			⑩ Transfer ice cream to piping bag, and pipe layer 1 cm / ½ in thick into bottom of Food Saver canister; or pipe into mason jars, and cover with lids.
			⑪ Place container or jars in vacuum machine, and pull vacuum until foaming ice cream reaches top of container.
			⑫ Remove from machine, and freeze for at least 8 h before opening and serving.

(2010)

(% of total weight of milk, sugar, dextrose, yolk, cream cheese, and butter*)

Ice cream is a foam. Air bubbles, called overrun for ice cream, typically make up 33%–50% of ice cream by volume. Alex Stupak increases that percentage by using a vacuum to expand the foam.

The British Aero candy bar was the original inspiration for Heston Blumenthal's aerated chocolate, which we have adapted for this book.

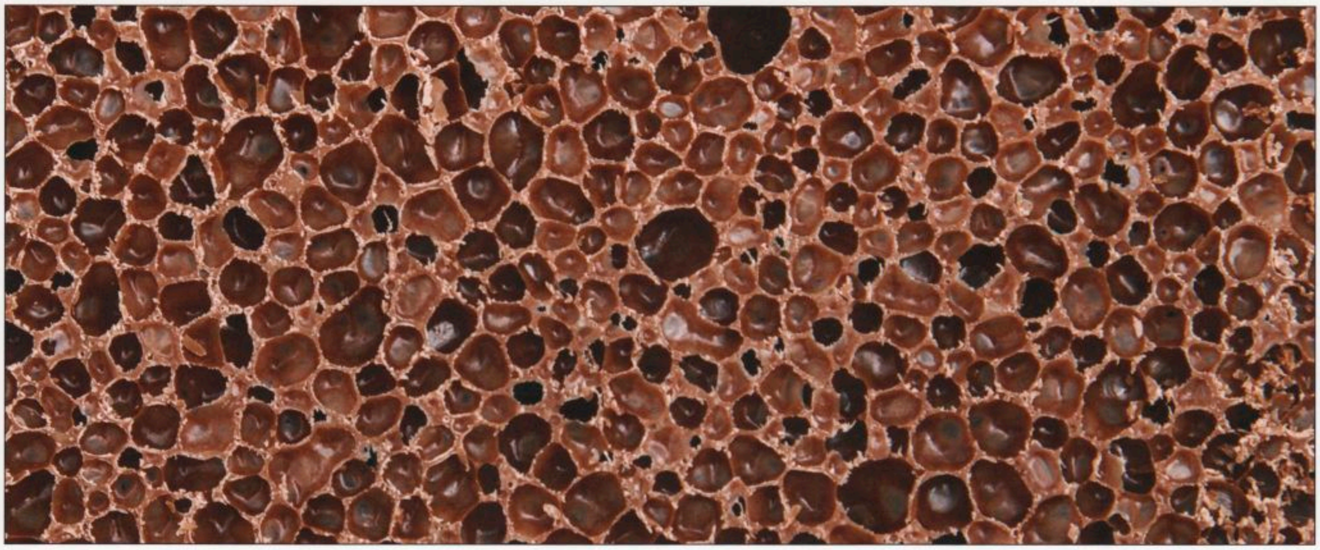
EXAMPLE RECIPE

AERATED CHOCOLATE ADAPTED FROM HESTON BLUMENTHAL

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Milk chocolate (33% cocoa solids)	500 g	100%	① Combine, and vacuum seal. Place mold in bottom of vacuum chamber. ② Transfer melted chocolate to metal or glass bowl. ③ Melt sous vide in 53 °C / 127 °F bath for 12 h. ④ Place layer of aluminum foil on bottom of mold 1.5 cm / ½ in deep, measuring 11 cm by 6 cm / 4¼ in by 2⅜ in.
Mycryo spray-dried cocoa butter (Callebaut brand)	10 g	2%	⑤ Cool to 40 °C / 104 °F, and stir in Mycryo. ⑥ Stir constantly until cooled to 28 °C / 82 °F. ⑦ Place bowl of chocolate over simmering water, and stir constantly until chocolate reaches 32 °C / 90 °F. Remove from heat.
Mandarin essential oil (optional)	5 g	1%	⑧ Stir in PGPR and essential oil until fully incorporated. ⑨ Transfer to warmed 1 l whipping siphon, and charge with two cartridges of nitrous dioxide.
Polyglycerol polyricinoleate (PGPR)	1 g	0.2%	⑩ Dispense quickly into foil-lined mold set inside vacuum chamber. ⑪ Pull vacuum, and allow foam to rise to top of mold. ⑫ Turn off vacuum machine, but hold foam under vacuum for 1 h to set. ⑬ Remove aerated chocolate from chamber, and store in cool, dry environment.

(original 2005)



HOW TO Make Edible Prune Coals

We set out to make edible ashes for our Autumn Harvest Pork Roast plated-dish recipe, which you can find on page 5·17. We were inspired in part by the faux coals made from yucca root by chef Andoni Luis Aduriz (see page 3·395). In this case, we started with stewed prunes, a classic pork garnish, and added a black sugar glass caramel foamed with baking soda, and then expanded the pieces in a vacuum chamber. The result is a crisp coated "coal" (or lava rock) that is both astonishingly realistic and very good to eat.

Yields 300 g

INGREDIENT	QUANTITY	SCALING
Dried prunes	200 g	100%
Prune juice	100 g	50%
Armagnac (or cognac)	60 g	30%
Salt	1 g	0.5%
Water	20 g	10%
Gum arabic	10 g	5%
Sugar	75 g	37.5%
Trehalose	75 g	37.5%
Glucose, syrup DE 40	40 g	20%
Water	30 g	15%
Carbon black powder (natural food coloring)	5 g	2.5%
Baking soda, sieved	10 g	5%
Spiced ash see page 5·22	20 g	10%

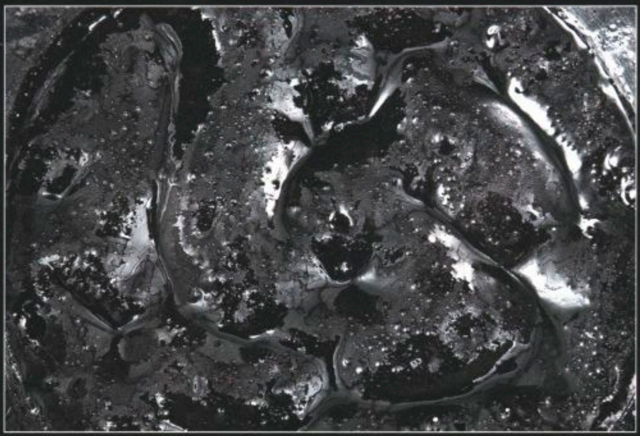
(2008)

1 **Boil the dried prunes, with prune juice, Armagnac, and salt (not shown).** After the prune mixture has come to a boil, remove it from the heat, and let cool.

2 **Vacuum seal the prunes and liquids together.** This is an excellent way to marinate prunes and store them easily until needed. Refrigerate the bag for 12 h, and then remove the prunes from the marinade.

3 **Arrange the prunes on a nonstick baking sheet, and brush them evenly with gum arabic solution.** Gum arabic acts as a moisture barrier and prevents the black syrup coating (in a later step) from becoming sticky.

4 **Dry the prunes in a 190 °C / 375 °F oven for 6 min, turning them every 1½ min to ensure even drying.** As a quicker alternative, use a blowtorch to lightly flash each prune's surface. Hold a low flame 10 cm / 4 in away from each prune. Roll the prune while flashing until its surface is uniformly leathery.

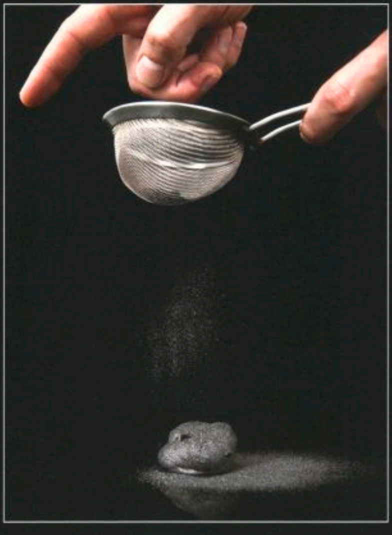


5 **Whisk the sugars and water together to create the black coating syrup.** Caramelize it by heating it in a pan to 170 °C / 338 °F. Remove the mixture immediately from the heat, and then whisk in the baking soda and carbon black powder. Be careful—the hot syrup will bubble violently.

6 **Skewer the dried prunes, and dip them immediately into the hot, black, foamy syrup.** Coat all surfaces evenly, and place the coated prunes on a silicone-lined baking sheet. Then place the sheet immediately in a vacuum chamber.

Vacuum pressures (equivalent altitude):

Sea level | 1,525 m / 5,000 feet | 4,575 m / 15,000 feet | 9,145 m / 30,000 feet | 13,715 m / 45,000 feet



7 **Pull a vacuum for 20 s.** As pressure in the vacuum chamber decreases, the higher pressure of the carbon dioxide inside the bubbles causes them to swell. A sugar coating will form. Turn off the machine, and maintain the pressure. Allow the sugar foam to harden for 10 min before opening the machine. The sugar should transform into a rigid glass that resists collapse when the vacuum is released. Store the prunes in a dry chamber, for no more than 8 h.

8 **To serve, dust edible ash over the prepared prunes.** Dusting the prune coals with ash made from pain d'épices powder blended with food coloring provides a final touch of realism.

17 WINE

WINE

One of the most familiar beverages in the world is also one of the most complex and confounding creations in gastronomy. At first glance, wine seems disarmingly simple: grapes are juiced, and the juice ferments. But the potential variations, influenced by soil, geography, time, environment, science, and the human hand, make wine endlessly fascinating.

Wine has captivated humanity since antiquity, when wine was a great deal safer to drink than water and was quaffed on a daily basis. Ancient wine writers classified it and critiqued it, often in bawdy terms.

But modern winemakers succeeded, with help from an international medals regime and an opinionated media, in casting great wine as a rarefied creation—one closer to art than science. Prices rose, along with public respect, for what was increasingly perceived as a near-mystical process. Some bottles today trade in the tens of thousands of dollars, with the status of the label as well as the quality of the wine factoring into the price.

Inexpensive regional wines exist, however, that can bowl you over. Meanwhile, the prestige of famously good wines leaves many consumers convinced that their untrained, unsophisticated palates are incapable of discerning and appreciating them. There's a disconnect between the perception of wine and the actual experience of drinking it.

Legends of the great vineyards of the world, the promise of what constitutes a great wine, the artful pairing of food and wine ... these myths persist in a way that, instead of endearing wine to its drinkers, often does the opposite. They foster an elitism that gets in the way of enjoying one of life's great pleasures.

Many elements make one wine-drinking experience different from the next. Fundamental differences arise from the variety of grapes used, the land in which the grapes were grown, the climate of the region (in general), and the weather of the harvest year (in particular). Nature—not only weather and climate but also elevation, sunlight hours, incline, and soil and rock structure—directs much of the grape's development. Then the factors related to a specific winery come into play: the style of wine, the enologist's influence, the targeted audience of wine drinkers, and the quality and size of the equipment. All of these variables and more produce a wide spectrum of outcomes. In fact, the potential variations in taste, bouquet, density, tannin content, and color are infinite.

Amazingly, a grape is the sole ingredient a winemaker has to play with. Sure, it comes in dozens of colors, sugar levels, skin thicknesses (which affect the amount of tannins), sizes, and so on. But still, the winemaker is limited to that key ingredient and a handful of tools, such as presses,

Any source of sugar can be fermented into an alcoholic beverage similar to wine. Mead, fermented from diluted honey, has been made for thousands of years. Hard cider is fermented from apple juice; other regions of the world have their own fermented-fruit traditions. But no source of fruit sugar has captivated our taste buds in quite the way that fermented grapes have.

Decanting a wine is more than just a ritual: it helps the wine take on oxygen, and it removes dissolved gases. For an updated approach to decanting, see page 343.

barrels, fermenting tanks, and temperature control. It's astonishing that a simple cluster of grapes can end up as so many gradations of wine. Yet fans of wine seem to hunger for evidence of consistency. They codify regions, vineyards, winemakers, and vintages, indicating some sort of reliable standard among those various categories.

This can work, to a degree, especially when wine comes from an area with a strong regional style. White wines from the Loire valley or big reds from the Rhône are likely to have some similarities. Regional winemakers may purposely develop some intrinsic feature that is characteristic of their area's wine or may consciously attempt to follow a regional style. But as whites and reds branch out across regions and countries, and as modern winemaking techniques come into play, matching taste to geography becomes a strain.

Wine comes in many colors, from nearly clear to inky red-black. The primary determinant of the hue of the wine isn't the color of the grapes; it is how long the wine is left in contact with the grape skins, which contain most of the color components. The skins also contain most of the tannins.

The truth is that wine is a living, breathing creation. It's in constant evolution from the time the grapes are first crushed. Experience tells the winemaker, and the well-trained wine drinker, generally what to expect, but winemaking still is fraught with unpredictability.

The variables that now come into play, including microbes that may have been introduced into the wine before the cork went into the bottle (or perhaps because of the cork; see page 348) are legion.

When that wine leaves the winery, the number of variables grows further. How the wine is stored, and for how long, and at what temperatures, and even what is served with the wine—these all ultimately affect the perceived quality, sometimes dramatically. The range of potential perceptions—and pleasures—is enormous.

WHAT MAKES A GREAT WINE

This question has consumed many a wine expert: what factors make one wine sublime and another mediocre or even awful? Surely, between centuries of experience and decades of scientific research, experts should by now have satisfactory answers.

They don't. Despite certain established facts, the area is still rife with controversy. Traditionalists are loath to let go of long-cherished assumptions, and the community of scientists unraveling wine is relatively small.

We do know that at least a germ of truth resides in many long-standing beliefs about what makes the great wines of the world great: the gentle slope of the vineyard, the early-morning or late-afternoon sun, the cool evenings that moderate grape development, the pebbly soil that promotes good drainage. But which factor is most important—or is there some magical combination that unlocks the greatest potential of the grapes? The final answer remains elusive.

The traditional explanations of what determines wine quality fall into several broad categories. The first involves the agricultural characteristics of the vineyard, the so-called terroir. The second category is the variety, the breeding and family history of the grapevines themselves. Then there are the vagaries of weather, superimposed on the background of climate. Let's consider each of these categories in turn.

Terroir

"Terroir" is a favored term in the wine lexicon. A French word derived from *terre* (earth), it connotes the environmental characteristics—soil chemistry, microclimate, and other special attributes—that define an agricultural region. Many oenophiles hold to the theory that the taste of a wine is governed by these unique combinations. Such connoisseurs use "terroir" with

Famous vineyards produce some amazing wines. But there is no general agreement as to which factors are responsible. Is it the soil or the skill of the winemaker? Or, as some suggest, is it just the marketing power of famous brand names?

confidence, as if they can discern the very dirt where the grapes of a wine grew. An expert may tell you, for example, that he can taste the distinctive terroir of a lush château-produced grand cru Cabernet Sauvignon, and that terroir explains why you can't make a wine that tastes like a Montrachet anywhere but on one small plot of land in Burgundy.

But of course you can taste the terroir of a young Long Island Merlot as well. Terroir is everywhere. It doesn't make wine intrinsically good or bad; it simply is. And although nutrients, water runoff, and other physical conditions certainly matter in growing any plant, grapevines included, the argument that tiny variations in terroir make a detectable difference in wine quality is much harder to accept. So is the implicit corollary that terroir varies less than this threshold within the boundaries of the great vineyards of the world. Indeed, Britain's Royal Economic Society released a study in 2005 whose French and Belgian authors concluded that terroir plays no role in the production of great wines; rather, they contend, winemaking technologies and good enologists are the determining factors.

Some of the most celebrated vineyards in the world are quite small. La Romanée-Conti, for example, covers less than 2 hectares / 4.5 acres in the Burgundy region of France. The plots of land across the road look quite similar, yet they have their own distinctive names and reputations. A staunch believer in the terroir theory will tell you that the soil in one vineyard can be quite different from that in another that lies a mere 30 meters / 100 feet away. Or perhaps the drainage is different. Or maybe what matters is the slightly different time in the morning that the mist clears and the first rays of the sun kiss the grapes.

On the other hand, it's hard not to notice that, almost without exception, these vineyard plots are rectangular. They do not follow the natural contours of the land, or the drainage, or the shadows, but rather lines picked arbitrarily by a surveyor.

If the vines do, in fact, tell the story of the soil below, it is hard to believe that a man-made fence defines that terroir. Soil chemistry, drainage, mist dispersal—none of these natural variables follow right angles and straight lines. If terroir is so crucial, winemakers would study the borders of their vineyards closely, one vine at a time, sampling the resulting wines to see at what point the character and quality of the wine clearly change. Over time, this process would lead to plots of uneven shape that effectively map regions of constant terroir. Yet that isn't what one typically sees on visits to famous wineries.

Curiously, too, some great wine estates are very large indeed. A well-regarded estate in Bordeaux may be nearly as large as the entire growing region of Burgundy. Were Bordeaux growers just lucky that they got good terroir in large chunks, while their cousins in Burgundy were less blessed with fragmented terroir?

The economics of shipping plays a surprising

Famous wine appellations are often incredibly small. The justification for the premium prices they command is that they have unique terroir—properties of the soil and the microclimate that make it special, even compared to land that is just a stone's throw away. Yet the fields are rectangular. How could soil and climate properties honor such straight lines?

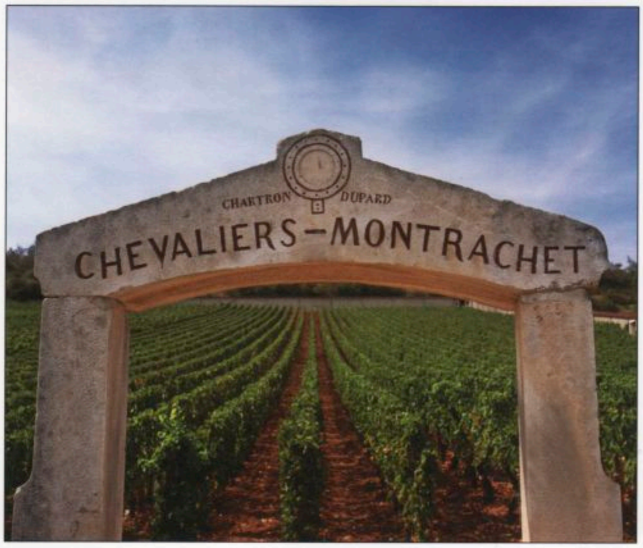
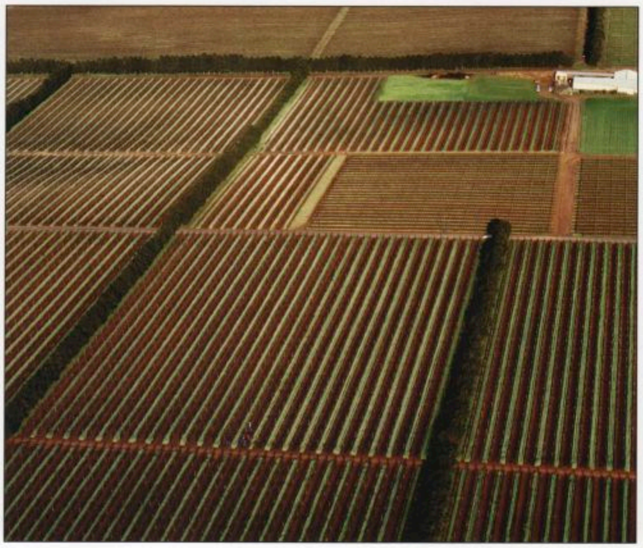


Photo by Ian Shaw / Cephas



role. Most of Europe's traditional wine-making regions lie near rivers. Waterways were the most practical way to transport goods before highways were built. Boats carried ancient vines or root-stocks—along Greek and Roman trading routes north from the Mediterranean—to riverside villages. Vineyards sprang up nearby because that was convenient, not because these areas were necessarily the best locations for grapevines to flourish. In time, vintners used the rivers to ship their wine to consumers far away, estates were consolidated, and some of the bigger ones thrived.

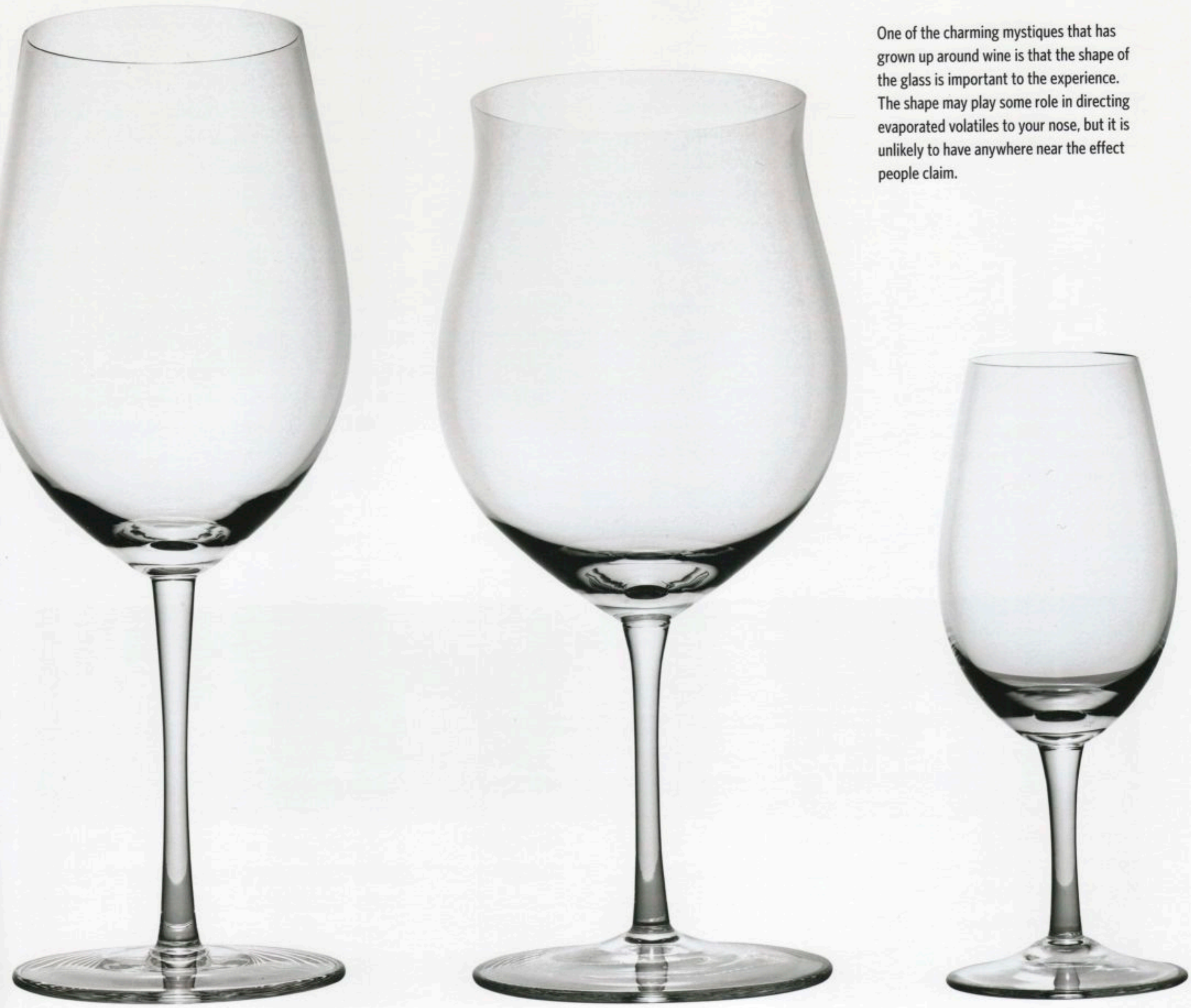
École de La Varenne, the cooking school that one of us (Myhrvold) attended in France, was located on a château property in northern Burgundy not far from Chablis. The château once had 2,000 hectares / 5,000 acres of vines. The grapes were pressed onsite, using a 250-year-old wine press, and the wine was aged in barrels stored in caves on the property. When the wine was ready to sell, the barrels were simply rolled down the hill to the Yonne River, which leads to the Seine and eventually to Paris.

As transportation channels opened and more and better wine came from farther afield, these

vines fell out of favor. They produced their last vintage sometime in the late 1800s. Other riverside winemaking regions probably still produce grapes out of habit and tradition. It wouldn't be surprising if a little exploration turned up other sites in the area that could grow better grapes.

So is Montrachet the best place in the world to grow the Chardonnay grape and make a stunning white wine? Or is it simply the best place within a few miles of a river? Trial, error, and historical contingencies over more than 2,000 years of French winemaking have identified a few special places like Montrachet. But we have to believe that many other ideal grape-growing areas exist, and many of them are probably not near any navigable body of water.

The rise of great new wines from Australia, Chile, New Zealand, and South Africa proves that other countries can make top-quality wines according to all the precepts of traditional French winemaking. Those gentle, moderately sunny slopes, gravelly soils, and cool evening temperatures occur in many places around the world. It may well be that the very best place on Earth to grow grapes for wine has yet to be discovered.



One of the charming mystiques that has grown up around wine is that the shape of the glass is important to the experience. The shape may play some role in directing evaporated volatiles to your nose, but it is unlikely to have anywhere near the effect people claim.

Grape Varieties

Most plants and animals are categorized by scientists into species; think *Escherichia coli* or *Homo sapiens*. You may be surprised to learn that the species designation is not very important for most domesticated plants and animals. Dogs, for example, are all part of the same species, *Canis familiaris*—even the Saint Bernard and the Chihuahua. What we recognize as different "breeds" of dogs can (at least in principle) interbreed. For that matter, they can breed with closely related species, like *Canis lupus* (wolves), resulting in a hybrid. Indeed, some biologists classify domestic dogs and wolves as subspecies—*Canis lupus familiaris* and *Canis lupus lupus*—of the basic wolf species.

Biologists usually define a species as a group of organisms that can interbreed and produce viable offspring.

In a domesticated setting, interbreeding is constrained by the decisions of farmers, ranchers, and other breeders. In the case of dogs, breeders have selected for certain traits in a Saint Bernard and others in a Chihuahua. They won't allow interbreeding with other dogs, to maintain the purity of the breed. The same is true for cattle and other domestic animals.

With plants, farmers have even more control, because grafting and asexual propagation allow them to select a single genetic example, and then clone it. Most varieties of fruit are propagated by cloning. Recent successes with the cloning of animals in laboratories make us think of cloning as a high-tech process of molecular biology, like that which produced the famous cloned sheep, Dolly. Animal cloning is a high-tech process, which is still too difficult and costly to be used for agriculture. But plant cloning is easy. With many perennial plants, if you cut off a shoot and stick the end in the ground, it will likely grow roots. These days, you dip the cutting in root-stimulation hormone first to increase your chances of success.

Although cloning is often associated with biotechnology and the dark visions of science fiction, it has been practiced in agriculture for thousands of years.

Grafting is even easier: you cut off a branch from a plant, wedge it into notches made in a different plant, and then tape it up. Often the host plant is simply cut off at some point a bit above the ground so that only the roots are left; this is the rootstock. The roots of one plant thus support the top of another. It hardly seems fair to make a set of roots labor to bring water and nutrients up to an unrelated plant stuck on top of it, but such is the case with grafting. It works so easily because plants lack the complicated immune systems that animals have.

In some cases, grafting binds strange bedfellows. Watermelons, for example, can be grafted onto the rootstocks of squash or pumpkins. The plants are closely enough related that this works—and even makes for better fruit under many conditions.

Grafting is thought to have first developed thousands of years ago. Ancient records show gardeners grafting in China and Mesopotamia about 2000 B.C. The practice could be even older, given that the earliest known wine production occurred 5,000 years earlier in the Zagros Mountains flanking Mesopotamia. Grafting was practiced extensively in ancient Greece, possibly beginning in the Bronze Age, before fanning out to Western agriculture.

Grafting is particularly useful for taming fruit

THE HISTORY OF

Sleuthing Out Zinfandel

Zinfandel was something of a mystery wine grape. Grown on the East Coast since the 1820s and then in California vineyards since the Gold Rush, Zinfandel was used to make everything from lush, elegant estate bottlings to that unfortunate pink-wine legacy known as "white zin." This red grape with its clear juice is a powerhouse of the California wine industry. Going by acres planted, it was California's third leading wine grape variety in 2009.

For many years, people thought it to be something of an original regional variety; there were no clear clues to the genetic origins of the grape. But DNA testing in 1994 found Zinfandel to be genetically identical to the Primitivo grape long grown at the heel of Italy's boot. Both Zinfandel and Primitivo, which bear clonal differences, are thought to be offspring of the same parent vine from Croatia. Researchers discovered in 2001 that Zinfandel has the same DNA as the ancient Crljenak Kastelanski variety, discovered on Croatia's Dalmatian coast.

trees and vines because they vary so much genetically. If you plant seeds from an apple tree that pollinates and breeds naturally, the saplings will not necessarily share the properties of the parents. In fact, they are almost guaranteed to bear fruit with vastly different taste, texture, and yield.

Early orchardists learned that it is better to find one really good tree that produces the fruit you want. You can then graft branches from that tree onto other rootstocks. The ancient Greeks, for instance, grafted cultivated olive twigs onto "wild" stocks. Granny Smith apples and Marcona almonds are just two examples of the thousands of varieties, or cultivars, that are propagated by grafting. Table grapes, including the widely planted Thompson Seedless, are cultivars of the species *Vitis vinifera,* which accounts for 90% of the world's grape production. A seedless fruit is the crowning glory of propagation by grafting; it is unable to reproduce except with human help.

These days, the rootstock is also propagated from cuttings, again because of the variability that comes from natural reproduction. Just about every traditional fruit you've ever eaten is a surgically joined composite of two asexually propagated clones. They are the direct ancestors of a single plant that caught an orchardist's eye.

Most wine grapes in the world also belong to the species *V. vinifera,* which is native to the Mediterranean region. Over thousands of years of cultivation by grafting, growers have developed well over 10,000 cultivars, sometimes called varietals. Of those, about 230 feature prominently in world wine production. Among the most commonly grown varietal wine grapes are Cabernet Sauvignon, Chardonnay, Merlot, Sauvignon Blanc, and Riesling.

We might not have these so-called noble varieties today if it weren't for grafting, which saved *V. vinifera* from extinction in the last half of the 19th century. Nursery cuttings from the eastern U.S. made their way to France about 1860, carrying with them *Phylloxera,* a rapacious aphid that feeds on and destroys grape roots. It nearly destroyed *V. vinifera,* in France and throughout Europe, until European varieties were grafted to resistant American rootstocks such as *Vitis labrusca.* To this day, replanting with resistant stocks remains the only effective defense against this scourge.

All of the world's Chardonnay, for example, comes from clones of a single primordial vine that a French vintner thought was worth grafting, likely more than 1,000 years ago. Recently, scientists have used the techniques of molecular biology to understand the origins of Chardonnay. Chardonnay, it appears, sprang from a spontaneous crossbreeding of the Gouais Blanc and Pinot Noir varieties. Gouais Blanc is the source of the popular varietals Gamay Noir and Aligoté. Ironically, Gouais Blanc has long been considered an inferior variety that from time to time has actually been banned from some wine-making regions in Europe.

Many of the varietal grapes used in winemaking today originated in rare cases like this, in which normal sexual reproduction via pollination was allowed to occur—either as crossbreeding of two cultivars or within the same one. Once such a success occurred, a vintner noticed it and propagated the result via grafting. DNA analysis found that all white grapes come from a very rare set of gene mutations that likely arose in a single vine, which gave rise to more than 55 cultivars of grapes that have white berries rather than red. DNA analysis also solved the mystery of Zinfandel, which is used to make a varietal wine popular in California (see previous page).

You might think this means that all Chardonnay grapes are identical. If they are all related to one mother vine, which has been grafted and cloned, then they should all be the same. That's almost true. Mutations do occur in the vines themselves, so a given branch (called a cane) might have slightly different genes from other canes on the same plant. When the cane is cut and grafted, the resulting vine has the genetic characteristics of the source cane.

Mutations of this kind are usually subtle, with much less variation than you'd get from pollination, but the results can still be important. Over many years, vintners have selected the best canes to graft, and that has given rise to distinct variations of the basic cultivar. The variants are now known as clonal variations, or clones.

Scientists have used DNA fingerprinting to identify hundreds of clones. So it is not enough to say that you are growing Chardonnay; these days, you want to know which clones of Chardonnay you have. The University of Burgundy has identified

34 clones of Chardonnay, but worldwide there may be many more.

Naturally, that leads to the question: what is the best clone? It's unclear whether that question has a single answer. Some people think that much of the quality in famous vineyards comes not just from the terroir but also from the particular clonal varieties present in the vineyard. As a result, winemakers have tried "suitcase clones"—cuttings taken from the most famous vineyards, then smuggled back home in a suitcase.

These can be successful, but different clones have different needs for nutrients and water. They have berries that ripen early or late; they produce different yields. As a result, some clones do better in some vineyards, or even in some parts of a vineyard, than in others. It is not quite as simple as making off with cane cuttings from La Tâche or Montrachet; they may be ideal there but fail elsewhere.

Weather and Climate

One of the amazing things about the wine business is that producers have managed to turn unpredictability into something the customer accepts, even embraces. We all know that some vintage years are much better than others, and wine drinkers accept this as part of the mystery of wine. For the consumer, this often leads to a dilemma: what to choose from a wine list. It's hard to recall which vintage means what, especially if you want to keep track of how good specific wines are over the years.

Why such variations in quality? It's simple: the weather. Grapes are a temperamental product of nature, seriously affected by the temperature, precipitation, wind velocity, and cloud type that, over years, define a climate. The *V. vinifera* grapes that go into most wines, for instance, prefer a Mediterranean-type climate, with wet, moderately cold winters and warm, dry summers. Small

THE SCIENCE OF

The Bordeaux Equation

Orley Ashenfelter is a distinguished professor of economics at Princeton University who has made many contributions to the scientific analysis of wine. His landmark work has had far-reaching consequences. Ashenfelter studied which aspects of weather during a grape's development correlated mathematically with the prices the wine sold for 10 years after the release date. He conceived of his approach based on the weather-based analyses of Bruno Prats, proprietor of Château Cos d'Estournel in Bordeaux. Prats systematically charted average growing season temperatures and harvest rainfall levels to compare vintages.

As an economist, Ashenfelter figured that auction prices ought to be a good quantitative measure of what oenophiles think of wine. Waiting 10 years to check the prices allowed the wine to mature. That's important for Bordeaux wines, which typically must age in the bottle to be at their prime.

Ashenfelter considered every aspect of weather conditions across all months of growth, but in the end only three variables correlated to eventual price (and thus presumed quality). This led him to what is often called the Bordeaux Equation, a mathematical formula that predicts a wine's 10-year price based on winter rainfall, average growing season temperature, and harvest rainfall. Together, the variables in the equation predict about 82% of the variation in price from one vintage to the next, at least for the auctions Ashenfelter analyzed from 1952 through 2003. Of course, that still leaves 18% of variation that must be due to other factors, including differences among vineyards, winemaking techniques, and so forth.

In 1990, *The New York Times* reported that Ashenfelter had used his equation to predict that 1989 would be the vintage of the century—before critics had even tasted the earliest samples. Sure enough, this matched the judgment of most wine critics. Explaining the bulk of the differences with just a couple of variables is very impressive from a statistical standpoint. Unfortunately, analytical approaches don't sit well with traditionalists, and as a result this work has been controversial within the wine industry. Wine critic Robert Parker (who is no stranger to controversy himself—see page 330) has branded it "an absolute total sham" that was "so absurd as to be laughable." Perhaps. Or is dismissing hard statistics the absurd position?

For analyses of a variety of wine regions, the relative contributions of weather differ. In Burgundy, temperature is not as important as rainfall; in Bordeaux, it's the reverse. In California and Oregon, rainfall during harvest almost never happens, while in Burgundy it can ruin an otherwise promising vintage. In most parts of the world, similar simple weather correlations explain 50%–80% of the variation from year to year.

variations in temperature, humidity, or rainfall that are unique to a particular piece of land define its microclimate. In the wine world, a microclimate can apply to one vineyard, a group of vineyards, or parts of the same vineyard, depending on weather conditions.

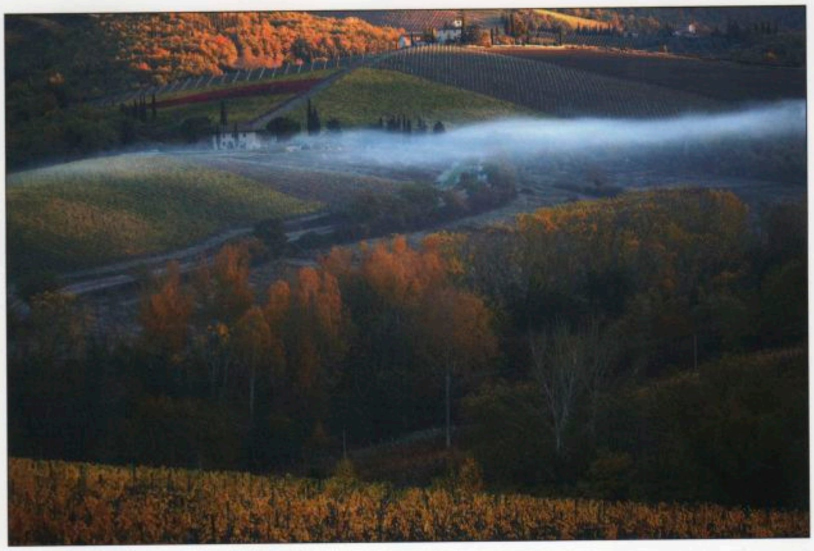
Weather, for all wine grapes, is important. Too little rain, or too much rain, or rain at the wrong time, or the wrong temperatures, can change the grapes quite a bit, which affects the wine.

Modern statistical analysis has yielded a surprising result in this realm. Most of the variation between one year's grapes and the next's can be determined mathematically (see The Bordeaux Equation, previous page). Orley Ashenfelter, an economist, contends that "evidence for the predictability of the quality of new vintages" is accumulating. Each wine region has key variables—winter rainfall, average growing-season temperature, and harvest rainfall—that signal whether a vintage is going to be good, great, or terrible, before the harvest is even finished. The indicators also shed light on which parts of the world might bear the next great wines.

Weather helps us understand which years are great and which are not. Can a similar analysis of microclimates—a vineyard's position relative to the sun, altitude, temperature fluctuations, wind exposure—tell us which vineyards are great and which are not?

Warm days with cool nights mean that grapes grow a bit slower than they would with warmer nights, so they spend more time on the vine and develop more character, structure, and sugar content before harvest. Grapes grown in a windy spot develop thicker skins to protect themselves; skins carry tannins that contribute to the complex flavors of wine. Perhaps the difference between great and ordinary vineyards isn't terroir. Perhaps it's how topography shapes the microclimate that makes the difference.

The determining impact of microclimate is a plausible theory, but so far there is little evidence to test it. The same statistical approaches Ashenfelter uses to predict the quality of red Bordeaux vintages have been used in regions like Bordeaux and Burgundy to see whether microclimate could be at play. So far there seems to be no correlation. What's more, *macroclimate* factors seem to explain more than 80% of the variation. This suggests that all of the other factors—terroir, microclimate, clonal variation, and winemaker—together add up to at most 20% of the effect.



Microclimatic variations are produced by local topography. They include factors ranging from the time of day the sun hits the grapevines to the presence of mist. Some believe that these variations are very important to wine quality; others say research suggests they are largely irrelevant.

Viticulture and Winemaking

Grape growers are farmers who tend a very valuable crop. They have every incentive to come up with new techniques to try to sidestep nature. The most dramatic, of course, is irrigation. Why worry about nature providing the right amount of rain at the ideal times? Today's vineyards in arid growing regions like Texas are served by computer-controlled drip irrigation systems that precisely determine the amount of water to release by using complex models of **evapotranspiration**—the rate at which water vapor leaves the grapevines.

Don't like the soil drainage? Well, that can be fixed, too. Same with the physical landform: terraces can be cut into steep slopes, and hilltops can be flattened (and have been for more than a thousand years in some areas). Worried about the soil chemistry? Careful analysis produces computerized maps showing nutrient levels so that growers can correct them. (Grapevines grow better in less fertile soil.) More mundane crops may get similar treatment, but when it comes to high-priced grapes, the sky is the limit on farming technology.

The technological advances extend to winemaking. Dozens of new techniques now correct once-frustrating problems. A classic example is too much rain near harvest time. Grapes become watery and bloated, so they lack the concentrated sugars and other molecules necessary to make great wine. What to do?

For more on concentration by freezing, vacuum reduction, and reverse osmosis, see Filtering, page 2·351.

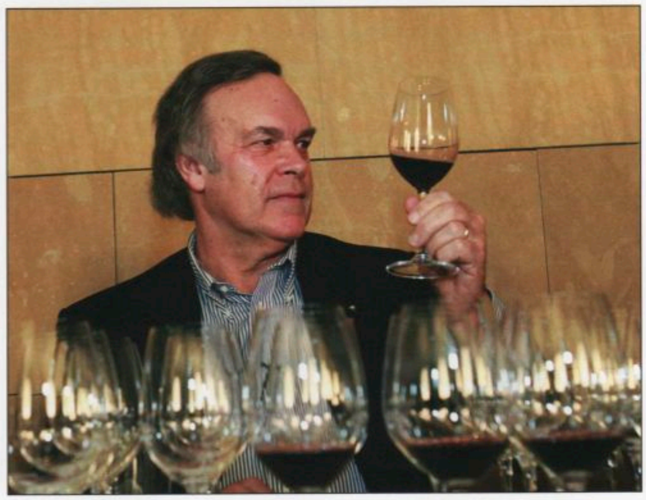
Enter **cryoconcentration,** in which freezing removes water. Cooks know this as freeze concentration (see page 2·396). It produces a close cousin of the ice wines made from grapes harvested and crushed while partially frozen. Another approach is **vacuum evaporation,** the winemaker's equivalent of the vacuum reduction technique used in Modernist kitchens. **Reverse osmosis** is one of the most powerful means of removing excess water without removing anything else from the juice.

Each technique allows a winemaker to modify the grape juice prior to **fermentation** to get the right concentration. The traditional fix for watery juice with insufficient sugar is adding cane or beet sugar to the wine. French chemist Jean-Antoine Chaptal popularized the technique, called **chaptalization,** around 1801, though adding sugar or honey to wine dates to the Romans.

Virtually every stage in the winemaking process has seen technological innovation. **Nanofiltration** can be used to remove large molecules associated with off-tastes and unwanted odors. **Microoxygenation,** or **MOX,** lets the winemaker control the amount and rate of oxidation in a given lot of wine

BIOGRAPHY

Robert Parker and "Parkerization"



You might think that one of the world's most influential wine writers and critics would have had an elite upbringing that set him on a path to become the standard-bearer for quality in wine. Instead, Robert M. Parker, Jr., had a classic American childhood in Maryland, as the son of a dairy farmer turned salesman. His family was more inclined to meatloaf and Coca-Cola than to beef Wellington and fine Bordeaux.

It was a girlfriend—now his wife—who had a major influence on the course of his career. Parker was studying law when his girlfriend went to France for a year of studying abroad. His first trip away from home was to visit her, and it was life-changing. Soaking up the culture of France, he sipped wines that opened up a new world to him. Parker went on to practice law for a decade, but by 1984 he had turned his professional attention fully to wine.

Parker—profoundly influenced in the 1970s by Ralph Nader and law professors who pounded into their students the evils of conflicts of interest—is dedicated to judging wine independently, by how it tastes. That may sound obvious, but at the time it was revolutionary. Parker criticized famous grand cru vintages and gave unknown wines high marks. Previous wine critics had avoided this. They helped feed the mystique and status of upper-echelon wines. Perhaps they did so unconsciously, or with such conviction in the wine that they never entertained the notion that it might not be great. Either way, few wished to upset the enological applecart.

Parker's approach to wine criticism completely upended the wine industry. And it made him the most influential man in the business. His now-famous 100-point scale for judging wines appears in his bimonthly newsletter, *The Wine Advocate,* which he launched as a free newsletter in 1978 and has been publishing since 1984 as a subscription-only periodical that does not accept advertising. In 2002, he began erobertparker.com, which has become one of the most-visited web sites devoted to wine.

The judgments of Parker's palate can make or break the success of a particular bottling of wine. Consumers, too, lean on him to direct them toward reliably good bottles. Some critics argue that Parker's influence has had a negative effect on the wine industry. Many of the world's winemakers craft their wines with Parker's palate in mind, working to please the taste of one man. They call this phenomenon the Parkerization of the wine world.

But most see this turn of events as a victory for consumers—and for new winemakers who can compete on quality, rather than on whether their vineyard was highly rated in 1855.

by microbullage—injecting precise amounts of oxygen into fermenting wine. Bordeaux winemakers use microoxygenation to soften a wine's tannins so that barrel samples are more appealing to critics.

Dealcoholization is used to create a more balanced wine. When grapes get overripe and have a high concentration of sugars, as they often do in sunny California, they can produce too much alcohol. If fermentation is stopped early, the finished wine can be too sweet. So why not ferment all the way and then simply remove some of the alcohol?

The technology doesn't make it easy to produce a great wine, however. Clark Smith, a pioneer of several of these techniques, cautions that extracting alcohol comes with a price. "My experience with dealcoholization is that it completely changes the structure and character of the wine, so you better know what you are getting into," he told *Wine Business Monthly* in 2005.

But each technique removes a barrier that once inexorably led to a product the winemaker regretted. Instead of having no way out, the winemaker now has options. So it's not surprising that these approaches are widely used in the wine industry.

Some people argue that modern technology will somehow remove the soul of wine—much the same way that people argue that sous vide cooking methods somehow take the soul out of cuisine. Others say, if you can produce better-quality wines more consistently and at lower prices, sign me up!

Names, Rules, and Laws

In some places, it's against the law *not* to make a great wine. That sounds silly, but the reality is that wine is heavily regulated in many parts of the world. Nowhere is that more true than in France. As former *New York Times* wine critic Frank Prial puts it: the laws governing France's stringent Appellation d'Origine Contrôlée (AOC) system determine "the amount of grapes that can be grown and the amount of wine that can be made from them," as well as many production details. For instance, a wine cannot qualify as grand cru, or "great growth," if its makers don't follow a list of rules. Conversely, if they do follow those rules, the wine can be called "grand cru" regardless of how it tastes.

The AOC system was established in France in the mid-1930s and created the prototype for legally defined and regulated wine regions around the world. This new standard for regulating regional wine production included such aspects as the region's geographic boundaries, what grape varieties can be grown and where, how the vines are tended, and what the yield per acre is, along with mandated superb expertise in fine wine production. According to the body governing the Côtes du Rhône region, a wine must undergo analyses and tasting for quality and local characteristics before being granted an AOC.

A French national body called the *Institut National des Appellations d'Origine* (INAO) has assumed responsibility for making all of these rules. The INAO also regularly verifies that the wines meet its criteria for yields, territorial extension, grape varieties, cultivation methods, and harvesting techniques. The AOC system is the foundation for the European Union's wine law.

The AOC regime began as a guarantee that a certain wine came from a certain geographic zone, to reassure consumers about what they're getting in that bottle of Sancerre or Aloxe-Corton. Prior to this there was little effort to regulate or classify wines at that level. The closest example is Napoleon III's mandate in 1855 that the best Bordeaux château wines be classified in a formal hierarchy. It was a system based on price. Wine brokers in the region assessed the values of the various Bordeaux estates and, based on that

Vintners worldwide now use high technology in wine making, but California and Australia are notable centers of wine innovation.

Modern wineries, like this one in Washington state, are full of gleaming stainless steel. This allows the hygiene of a hospital operating room, a necessary condition for repeatably making great wine.

France's Appellation d'Origine Contrôlée (AOC) system assures consumers that wine comes from where it says it comes from and that the winemaker followed certain rules. But it doesn't ensure that the wine is any good.

ranking, categorized them as being *premier grand cru classé* (first-growth) or *deuxième grand cru classé* (second-growth), on down to fifth-growth classification. And aside from Château Mouton-Rothschild's move from second- to first-growth status in 1973, the classifications remain unchanged in 150-plus years. Can the prices paid in 1855 really be the best guide today?

Italy created its own controlled naming system in 1963. Known as DOC (*Denominazione di Origine Controllata*), it is crafted along the lines of the AOC system. DOC is overseen by a national committee, which has granted DOC status to more than 300 Italian wines and is credited with substantially improving the wines of Italy.

In 1980, Italy established a superior classification of DOC wines called DOCG (*Denominazione di Origine Controllata e Garantita*), including Brunello, Montepulciano, Chianti, Barolo, and Barbaresco fine wines.

DOC and AOC also apply to regional food products, such as cheeses, sausages, hams, and other foods that rely heavily on regional influences, ingredients, history, and production methods.

Keep in mind that different regions have different rules. In some places, winemakers may be restricted to one type of grape (such as Pinot Noir for red wines from Burgundy), while in others (such as Châteauneuf-du-Pape) a winemaker can choose from as many as thirteen grapes for blending. In France it is legal to chaptalize wine because the grapes often were not ripe enough at harvest time. In California, this is illegal, in part because it is not commonly needed.

AOC is like the branding strategy used by major companies: it allows winemaking regions and traditional place-names to become powerful brands. Brands have value because consumers remember them and what they stand for. That's the good news.

The bad news is that AOC has, over the decades, come to stifle winemaking in many ways. The most expensive wines have been protected by their names, regardless of the quality of wine produced in their regions of origin today. Some producers have maintained a high quality, certainly, but some have not. So the idea that a certain French wine is always equated with a particular level of excellence has been eroded over time. Indeed, the failure of the old classifications to track quality is what gave critics such as Robert Parker (see page 330) an opportunity to rate wines by the way they actually taste, rather than by their address or their pedigree.

Winemakers broaden their perspectives and learn modern wine production methods during travels abroad. But they come home to old-world regulations that keep them from applying proven technical innovations or perhaps trying a grape variety that's different from what's legally allowed. Worst of all, new wine regions have had a hard time because they couldn't be marketed except as table wine, or *vin ordinaire*.

The rise of California, then Australia and Chile, and now dozens of other places opened up new territories where people could make whatever kind of wine they wanted. Their value to the wine world was not just creating another source of wine but also the fact that they could experiment. As soon as they became successful, most of those places adopted their own—if less stringent—versions of AOC laws.

Critics like Parker helped usher in a means for consumers to rely on wine critics' comments to assess quality rather than on legislated titles like "grand cru." In France, the restrictive regimes ultimately led to the rise of renegade winemakers, or *garagistes,* who made *vin de garage*—fine, limited-production wine, often literally made in a garage. Suddenly it became cool not to be famous.

A single train of bubbles rises from a flaw, or **nucleation site**, deliberately put in a Champagne flute (see page 1·332).

TASTING WINE

Too much tannin in a glass of red wine? Here's a dirty little trick: swirl a sip in your mouth and spit it—well, let it slip—back into the glass. Proteins in your saliva will react with the tannins and solidify them into precipitates that settle to the bottom of the glass.

Setting aside all the theories about what makes wine great, we can at least agree that some wine is great. Or can we? Tasting turns out to be another area that's surprisingly difficult to nail down.

A great many variables can influence, and in small ways negate, the validity of a taste test. Consistency of the findings can be altered by what the testers ate beforehand, for example, or whether they sucked in air when they tasted the wine. Results can be affected by how the wine was stored, and whether it was freshly opened or has been exposed to air for a while. The flavor and aroma of some wines can change a lot with just 10 or 15 minutes of exposure.

And then there's the glass. Some argue that the shape of a good wineglass—usually narrower at the mouth—matters, which is plausible given that the glass's shape influences the way the volatile aromatics rise from the glass to your nose. This can affect your perception of the wine's flavor, but it is unlikely that glass shape matters as much as people claim it does.

Our preferred test, one used in many situations for this book, is called a triangle test because it uses three samples to determine whether an overall difference exists between two products. The triangle consists of two samples that are identical and one that's different. According to Bruce W. Zoecklein, a leading enologist at the Virginia Polytechnic Institute and State University, these tests are particularly useful to winemakers who want to know whether slight production variations result in a perceptibly different product. The variables could include a five-degree difference in the temperature during six months of bottle-aging, for example, or the type of cork used for the same wine.

Color and Flavor

Sample some wine blindfolded (or served in an opaque black glass). There is no better way to see how heavily wine tasting depends on contextual cues. Believe it or not, it can be hard to tell red wine from white. Test after test confirms that even the simplest categorization of wine is difficult to do by taste and aroma alone.

This doesn't mean that any red wine can be confused with any white wine. Dramatic flavor indicators can set some wines apart. You would never confuse the highly tannic, full-bodied flavor that signals a red wine with the honey-like sweetness of a sauterne. If you take a diverse set of red and white wines with a variety of flavor profiles, however, you're in for a challenge.

One important series of tests, conducted in 2001 by Frédéric Brochet, a cognitive psychologist at the University of Bordeaux, used a tasteless and odorless red dye to tint white wine red. A panel of 54 expert wine tasters evaluated the phony "red" and described it in the vocabulary of red wines.

Not one noticed it was really a white wine. "About 2% or 3% of people detect the white wine flavor," Brochet said in an interview, "but invariably they have little experience of wine culture. Connoisseurs tend to fail to do so. The more training they have, the more mistakes they make because they are influenced by the color of the wine."

A 2003 study at the Monell Chemical Senses Center gave tasters three samples of wine—ostensibly a white wine, a rosé, and a red. All three were actually the same white wine dyed to the appropriate colors. Once again, the results matched the visual cues. The red-colored wine, for instance, was ranked highest in fullness, body, complexity, and maturity. Dyed-wine studies going back to the 1960s have reported similar results.

One study served dyed wine in both clear and opaque black glasses. Wine experts were much better at evaluating the dyed wine in the black glasses, in which the false color didn't throw them off. One theory suggests that the experts edited themselves based on "knowing" that it was a red wine. But an even more intriguing idea is explored in a 2003 research paper titled "The Nose Smells What the Eye Sees," which argues that at a deep, subconscious level our olfactory sense is biased by visual cues. In another study, experts who smelled but did not taste wines in opaque black glasses successfully distinguished red wines from white (but could not correctly classify rosé wines).

An even more amusing result came from a 2009 study in Germany, which found that the color of the ambient lighting affects perception of the taste of wine. The studies served white wine in environments that were red, blue, green, or white. Red and blue ambient lighting resulted in more favorable views of an identical wine; green or white led to less favorable perceptions.

People are often shocked to hear that red and white wines are difficult to distinguish by taste and smell alone, or that visual cues influence the perception of flavor. It contradicts the received wisdom of wine experts. Their next response is to reject wine expertise, the surmise being that expertise must be false if experts themselves can't tell red wine from white.

With further reflection, one can reach a compromise point of view. The color of wine is an

THE COGNITIVE SCIENCE OF

How Presentation Can Be Everything

Wine isn't the only food that yields surprising results in blind taste tests. A study sponsored by the American Association of Wine Economists fed duck liver pâté, pork liver pâté, liverwurst, Spam, and Newman's Own-brand dog food to subjects and had them rank their preferences. The college-educated, 20- to 40-year-old study subjects knew they would be eating pet food in the name of science—but they weren't told which sample was which.

Although, statistically, the dog food got the lowest average rank, the study participants fared no better than random chance when they tried to guess which of the samples was dog food. The researchers concluded that "although human beings do not enjoy eating dog food, they are also not able to distinguish its flavor profile from other meat-based products that are intended for human consumption." Of course, there is also another possibility: those folks at Newman's make damn good dog food.

HOW TO Set Up a Triangle Test

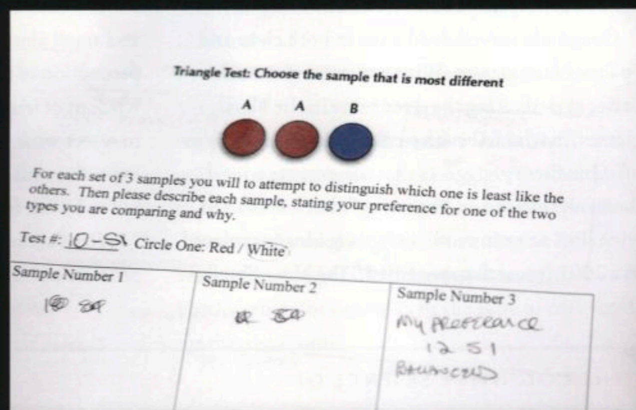
Tasting wines scientifically is real work. The rigorous method of testing is called a "triangle test." We also recommend using this kind of a test for comparing the taste of foods; for more details, see page 2·299.

1 **Establish a judging panel.** The more judges you can enlist, the more statistically meaningful the results will be. A minimum of 10 judges are usually required for sufficient statistical power. The judges may be aware of the products being tested but should not be given any clues about what samples they're testing in any given round.

2 **Give each judge three samples, two of the same product and a third of the comparison product.**

3 **Vary the order of the samples given to each judge to alleviate any prejudice that order of presentation may impose.** One judge might get A A B, the next A B A, the third B A A.

4 **Have the judges taste each sample and score it.** The goal is to determine which two of the samples are the same, thereby determining which one is the contrasting sample. Testers very often have to taste the samples several times to find the different one. To avoid taster fatigue, no more than two sets (six samples) should be evaluated in one tasting session.


Triangle Test: Choose the sample that is most different

A A B

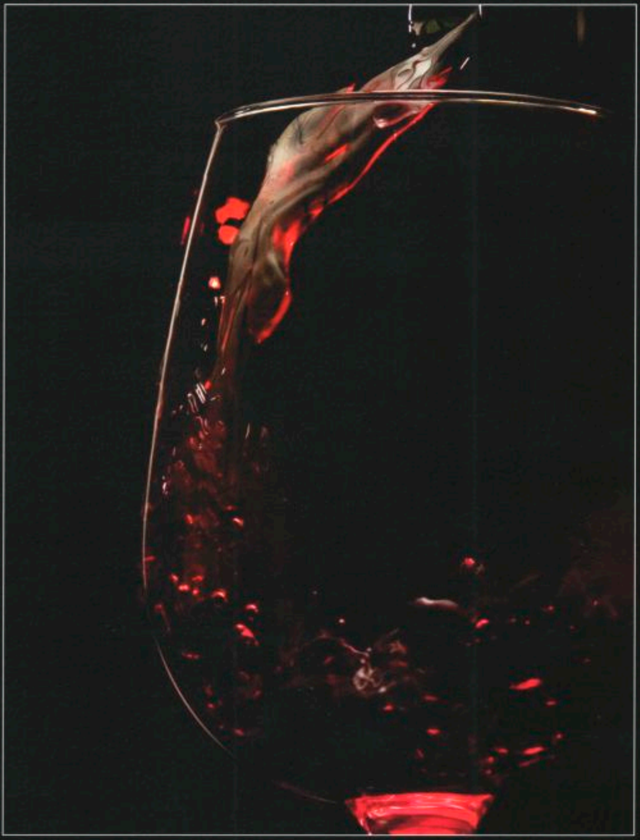
For each set of 3 samples you will to attempt to distinguish which one is least like the others. Then please describe each sample, stating your preference for one of the two types you are comparing and why.

Test #: 10–S1 Circle One: Red / White

Sample Number 1	Sample Number 2	Sample Number 3
		MY PREFERENCE 12 51 BALANCED

THE SENSORY SCIENCE OF

Wine Tasting Suggestions



Some devoted wine lovers keep diaries of virtually every wine they've tasted: what they drank, when and where they drank it, what they thought of the wine. The logs help refresh their memories the next time they need to choose a wine to go with a meal or a particular cheese.

For the rest of us, it can be hard to remember what we loved about one wine when it's enjoyed in isolation, without another wine to help pinpoint its distinct characteristics. This is why side-by-side wine tastings are handy. Wine flavors and aromas that in theory are familiar—like those of grass, spice, tropical fruit, leather—can in practice be much easier to detect when one wine is sipped alongside another that has a distinctly different flavor profile. This practical experience helps build a greater capacity for recall down the line.

When organizing a tasting, consider the audience. If all of the participants are oenophiles, something a little challenging is in order. Place each bottle in a paper bag to mask the variety, winemaker, and regional source. The tasters can then try to name each wine's provenance and grape variety as they compare it with the other wines side by side. For a group of more casual wine drinkers, just set the bottles out and let folks review the labels while they're sipping.

Here are some other tips for a successful tasting.

1 **Pick a theme to help narrow your pool of samples.** This also helps make the most of a side-by-side comparison; select wines that share some attributes but not others. If the tasting wines are all vastly different, it's more difficult to extrapolate a lesson—for instance, how much more earthy a French merlot tastes than one from Washington state—from the exercise.

2 **Feature no more than eight wines.** Professional tasters might go through a marathon tasting of 100 wines in a sitting, but even their well-trained palates begin to fatigue at the couple-of-dozen mark.

3 **Don't bother to use different glasses for different varietals, as you might at a dinner party; here, the consistency of tasting all of the wines in the same type of glass aids comparisons.** A simple, open-mouthed white wine glass is ideal. Lay everything out on a table big enough for all of the bottles, glasses, food, and spittoons. A white table surface or covering is useful as a background for comparing wine colors. Place paper and a pen at each setting so that tasters can take notes.

4 **Offer light food, both as a palate cleanser between wines and to provide a little sustenance to balance the alcohol.** Keep it simple. Pronounced flavors and oily foods will impede your guests' ability to taste wines clearly. Baguette slices or simple crackers are good choices.

5 **Begin sampling with the lighter wines, and then move toward the heavier, richer wines.** This ensures the big wine of the bunch doesn't dull the palate to the brighter, cleaner flavors of the lighter wines.

6 **Encourage guests to hold the glass up and look at the wine's color and clarity, and to then swirl it gently and breathe in the wine's aroma before taking the first sip.**

7 **To spit or not to spit?** If any of your guests are concerned about overconsumption, it doesn't hurt to have a bowl or pitcher where they can spit (or pour) wine they don't want to drink.

8 **Keep the sample pours small—one to two ounces—for a comparative tasting.** The quantities can easily add up to a couple of full glasses, particularly if tasters return to one or two of the wines for another sip.

9 **An hour or so is generally plenty for an informal tasting with friends.** Then encourage your guests to pour a glass of their favorite wine and proceed to the dinner table. Or bring out an array of flavorful snacks to enjoy. What's key is that the wine-tasting experience be low-key, focused, and tailored to the level of interest and expertise of your group.

important aspect of how we experience it. The deep red color of a Cabernet primes us for tasting it. Perhaps that is hardwired into our olfactory system, or maybe it is just human nature that people's thinking conforms to their expectations.

Of course, there are wine experts who scoff at the notion that people can't tell red from white; they argue that the tests are an aberration. But that's based more on opinion than on any formal test data they can show that contradict the studies. Our advice: try it yourself. The simplest way to do this is to buy some opaque black wine glasses and ordinary red food coloring. Use the dye to make some white wine red, or to turn some light red wine inky-dark. When we did this, we found the taste test to be astonishingly difficult.

Ratings and Gold Medals

Winning a prestigious award (or even a not-so-prestigious one) can significantly boost sales of a wine. Awards also allow wineries to add "award-winning" to their marketing material. So wineries invest a lot of money every year in competition entry fees. Interestingly, consumers don't seem to be particularly motivated by medals when they're buying wine in retail stores, according to a study by 10 universities around the world published in *Wine Business Monthly.* So any lifts in sales that awards bring may be due largely to their influence on restaurant purchases.

Wine ratings are a hot topic as well. Critic Robert Parker, *Wine Spectator* magazine, and others assign numerical rating points to wines, and this has become extremely popular as a way to help consumers choose wine. But how accurate or meaningful are these ratings?

Robert Hodgson, a retired professor of oceanography who runs a small winery in California, wondered why some of his wines won in some events and not in others. So he performed a statistical study of 4,000 wines entered in 13 U.S. wine competitions. His remarkable results, published in the spring 2009 issue of the *Journal of Wine Economics,* reveal that wines that won a gold medal in one competition had a no better than random chance of being judged gold in any other competition. In fact, the statistical distribution of gold, silver, and bronze medals *could not be distinguished from the result of random chance.*

This strongly suggests that the entire process is arbitrary, and that given a large enough number of competitions, every wine has an equal chance of being a gold medalist—or, conversely, that even a great wine may never win gold in a finite number of contests. Instead of going to all the work of tasting the wines, the judges could have produced the same quality results by pulling the names of the wines out of a hat.

It gets worse. An earlier Hodgson paper analyzed the patterns of judges' decisions at the California State Fair wine competition. Over a four-year period, Hodgson presented 16 panels of four judges each with four wines, each served in triplicate and poured from the same bottle. The triplicate glasses were interspersed randomly with a set of other wines being judged, and they were sampled in the same flight (tasting session). Hodgson's goal was simple—to find out whether the judges would give glasses of the same wine the same rating when they were tasted together.

Judges assigned the same rating about 10% of the time. In the remaining 90% of cases, they bestowed dramatically different ratings on *identical glasses of wine.*

How can this be? Well, for one thing, wine tasting is highly subjective. Despite taking their jobs as judges very seriously, these well-meaning people could not tell which of the samples were of the same wine. An Australian study of 561 experienced wine judges found a similar result. It, too, asked the judges to taste identical sets of wines on two occasions; their responses were highly inconsistent and statistically indistinguishable from what would occur merely by random chance.

In yet another test, one winery entered three bottles of the same wine—each with a different label—to one wine competition. One sample was deemed "undrinkable," while another sample of the same wine won a gold medal.

Hodgson advises consumers to "have a healthy skepticism about the medals awarded to wines from the various competitions" and to gain more confidence in their own opinions and tastes, as he told the *Los Angeles Times.*

Even Parker, who tastes about 10,000 bottles of wine a year, has said that in blind tastings he typically only gets within 3 points of his original rating. The California State Fair judges had a median span of about 8 rating points (both on a 100-point scale).

When it comes to wines, awards mean less than you might think.

This helps explain why competition results are random.

Wine ratings probably do mean something, but taking them too seriously is clearly a bad idea. Even with training and practice, it can be incredibly hard to consistently and reliably judge wines.

Wine Descriptions

It's almost too easy to make fun of the stilted, often flowery language used to describe the flavors and aromas of wine: it's quite a lexicon, encompassing everything from "blackberry jam" to "wet dog." Here's an experiment to try: take any food that you like—a strawberry, a piece of steak, a carrot. Taste it, then try to describe its flavors without using its name. Not so easy, is it?

Humans are visual storytellers; we have a great deal of language at our disposal to describe what we see—but not what we taste. Wine critics are attempting something that is fundamentally hard for us to do. Their poetic description of sensations is likely the best they can do, given the fundamental difficulty in describing flavors. The most extreme descriptions seem designed to be more evocative than literal. When was the last time you tasted a wet dog or piece of barnyard straw, after all? Yes, those aromas, or something like them, can occur in wine, and when we read these phrases we get a sense of what the critic experienced. But is that really useful? Or is it more like poetry, which is meant to evoke emotions rather than have a functional utility?

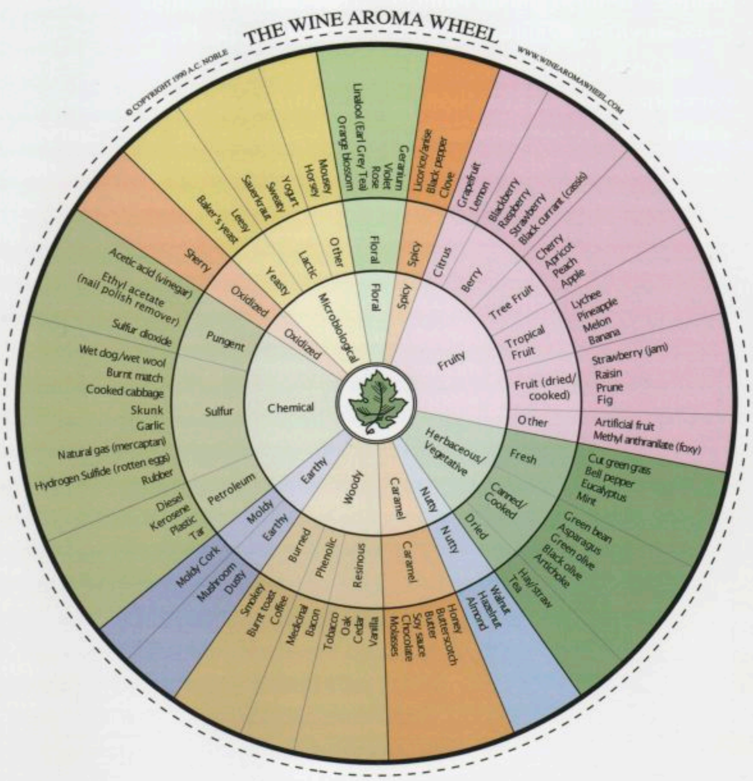
In a 2007 study, Roman Weil of the University of Chicago sought to find out whether expert wine descriptions are useful to nonexpert tasters. He paired similar wines from different makers in a triangle test. The tasters were given written descriptions, written by the same wine expert, of the two wines in the test. Here is an example of the descriptions (in this case by Robert Parker) from one of the pairs of wines from the study:

> Talbot—Admirable richness, layered texture, sweet tannin, abundant quantities of smoky cassis, licorice, herb, earth, and leather characteristics. Complex aromatics, blends power with elegance.
>
> Clos du Marquis—Dense, opaque purple-colored, with crème de cassis, vanilla, and cherry notes, medium to full body, an unctuous texture, low acidity.

It doesn't sound that hard to distinguish these two wines from each other. "Herb, earth, and leather" sounds pretty different from "vanilla and cherry notes." And nonexperts were reasonably able to tell the wines apart. In 800 triangle tests, 51% of results correctly identified the different wine. That's well below a perfect score but significantly higher than the 33% you'd get from random guessing. Nonexperts, as we'll see, were much better at distinguishing two "similar" wines than at distinguishing good years from bad or reserve bottling from regular.

The stunning thing, however, is that they did no better than chance at matching the expert review to the wine! So much for the value of wine reviews in telling nonexperts what the taste is like. Even

Wine Aroma Wheel copyright 1990, 2002 A. C. Noble; www.winearomawheel.com



Professor Ann Noble, an enologist at the University of California, Davis, created this wine aroma wheel, which draws analogies to other familiar scents, as a way to help people describe the complex flavors of wines. It groups aromas into families and then organizes them in tiers, with the more general terms—fruity or herbaceous, for example—toward the center and more specific descriptors—such as apple or cut grass—toward the outside of the wheel.

Written reviews of wines have two goals. One is to inform people about the product. The other is to be enjoyable to read in their own right, a kind of vicarious tasting for wine lovers. Weil's research indicates that the latter role may be the more important one.

For more on triangle tests, see page 336.

with the wines and the descriptions right in front of them, Weil's nonexperts couldn't match descriptions and wines any better than they would have by chance.

Cheap vs Expensive

Perhaps the most contentious issue in wine is expensive versus cheap. Is expensive wine worth what it costs? Of course, there are reasons other than taste to drink an expensive wine. Collectors can thrill to drinking a rare or old bottle in the same way that stamp collectors can thrill to seeing a rare or old stamp. Many attributes of expensive wine generate value for the consumer even though they have nothing to do with how the wine tastes. Nevertheless, one can set those aside and ask the question: does expensive wine taste better? Once again, the results are surprising.

Frédéric Brochet has done one of the most damning tests. He took middle-quality and medium-cost wine and poured it into two sets of bottles—one with the label of a famous and expensive top-ranked wine, and the other with that of a cheap *vin ordinaire*. A panel of 54 French wine experts rated the wines after seeing them poured from the bottles. None of the experts recognized the two as the same wine, and they rated the versions very differently, praising the wine in the expensive bottle and dismissing and criticizing the wine in the cheap bottle. This study speaks to the same issue as the dyed wine: experts are highly influenced by things other than taste and aroma.

Functional magnetic resonance imaging (fMRI) is a technology that can sense to working of a human brain and create images showing which specific regions in the brain are active during a mental task. Perhaps the most sophisticated approach to understanding cognitive processes, fMRI has been used extensively for improving our understanding of how the brain works. Neurologist Hilke Plassman and colleagues performed a series of fMRI tests, reported in 2008, on nonexperts tasting a series of wines. The tasters thought they were tasting five different wines, but in fact there were only three wines; two of them were duplicated. The subjects were told false prices for the wines before the tests: $10 per bottle for one, $90 per bottle for another. As in Brochet's test, the "expensive" wines were rated more highly by the tasters. In addition, regions of their brains associated with pleasantness lit up in the fMRI. The subjects weren't just making up a high rating to match their expectations—their brain scans seem to show that they really did like it better. Plassman concludes that expectations may play a deep role in how we perceive things like the taste of wine.

Other studies tested expert wine tasters. When not fooled by the wrong bottle, the experts' ratings do tend to correlate with price. But what about nonexperts? Can they actually taste the difference?

In a 2001 study, Weil tested the same wine in different vintages—one rated "excellent" and the other rated "appalling" by Robert Parker. The tasters were nonexperts, and the triangle test consisted of three unlabeled glasses, two of which held the same wine. The study focused first on whether the tasters could tell which wine was different from the others, and second on how they ranked the wines. Randomly guessing in a triangle test produces the correct answer 33% of the time. The nonexpert subjects in Weil's study correctly distinguished the vintage 41% of the time, hardly higher than random chance. Moreover, nonexperts preferred the "appalling" vintage just as often as the "excellent" one.

It was the same story with reserve bottling vs. ordinary bottling. As an example, one of Weil's tests put Chateau Latour up against Les Forts de Latour—wines made by the same winery in the same year, but whose prices differ by a factor of four. The tasters could distinguish between reserve and ordinary bottling only about 40% of the time, and again they were split randomly as to whether they preferred one versus another. If you're having non-wine experts over for dinner, it would seem that Les Forts has an edge over its more expensive cousin. Very few will notice the difference, and even if they do, they may prefer the cheaper one.

The studies we've discussed so far look at specific issues that cast doubt on whether wine price reflects quality. Experts and nonexperts alike can be fooled in various interesting ways. But what about the core issue: do people like expensive wine more than cheap wine?

A large 2009 study took on this question directly, with data from more than 6,000 blind tastings by more than 500 nonexperts. The tests were **double-blind**, meaning that neither the people administering the test nor the tasters

CONTROVERSIES

Myths About Taste and Flavor

For a while in the 20th century, it seemed as if Western science had the mystery of taste licked. As children, we were taught that there are four basic tastes: sweet, salty, bitter, and sour. Each is perceived by specialized taste buds in a different region of the tongue—bitterness in the back, for example, and sweetness on the tip. Flavor is a simple combination of taste and smell.

Now we know that this cartoon-like picture is not just wildly oversimplified but just flat wrong. More recent neuroscientific research reveals that flavor is arguably the most complex human sensory experience. A nearly infinite number of possible flavors can delight the palate. Cooking presents many things to worry about, but a shortage of room for innovation is not one of them!

So where did the simplistic notion about taste come from? The map of specific taste regions on the tongue began with a study published in 1901 by the German scientist Dieter Hanig. Writing in the journal *Philosophische Studien*, Hanig plotted the wide range of locations on the tongue where study subjects said they experienced a variety of tastes most intensely.

Those results might have been relegated to obscurity had it not been for Edwin Boring, an experimental psychologist and historian of psychology at Harvard University. In a 1942 book on sensory science, Boring recast Hanig's data in a simplistic way that implied that different parts of the tongue are sensitive exclusively to one particular taste and are completely insensitive to the others. Boring's simple taste maps infiltrated the public psyche, even though the maps do not reflect what really happened in the subjects studied.

It wasn't until about 40 years later that psychologists and neuroscientists began to question these ideas and—for the first time—to actually subject them to rigorous tests. They found that the taste-sensitive cells in taste buds often do respond best to one taste, such as sweet or sour, but that these cells also are widely responsive to other tastes, regardless of the cells' position in the mouth.

We now know that taste is an emergent phenomenon. The perception of a taste arises gradually from an overall pattern of responses of taste-sensitive cells as the gustatory centers of the brain process these responses. A large amount of research published in the past 25 years indicates that human taste buds contain dozens of distinct taste receptors, including some for savoriness (particular kinds of amino acids and peptide fragments sometimes called umami) and possibly even some for fats. "Bitter," it turns out, is not a single taste but a class of at least two dozen tastes, each with a different receptor encoded by a different gene.

What's more, it's not just the tongue that's doing the tasting: although taste receptors are concentrated in the roughly 10,000 taste buds of the tongue, large numbers also have been found in the roof of the mouth, the epiglottis, and the throat. Even the lining of the intestine has taste receptors! These newly recognized internal taste receptors may play roles in tuning the digestive system's biochemistry to different foods. And the malfunctioning of these receptors may lead to obesity, diabetes, and other digestive diseases.

It's important to appreciate, too, that taste is just the foundation of the many-layered perception we experience as flavor. Odors, conveyed from mouth to nose by an internal airway, add another rich component—as a stuffy nose dramatically reveals. The burning sting of a spice or the cooling tingle of evaporating alcohol or menthol modulates flavor as well. Even the way food sounds as it's chewed and the way it feels in the mouth contribute crucial inputs.

You can thank the part of your brain known as "the nucleus of the solitary tract" for initially processing the signals from your taste cells, then shunting that neutrally coded taste information to higher brain centers. There, all the wildly different flavor cues are integrated into what, to you, seems to be a singular experience that can provoke delight or disgust. Undoubtedly, science still has plenty to learn about how taste and flavor actually work. As that new knowledge emerges, it may suggest ways for cooks to stimulate our most sophisticated sense in delightful and fascinating new ways.

knew which wines were which. Wines in the study ranged from $1.65 per bottle to $150 per bottle. Tasters registered their preference on forms, and the data were tabulated. Statistical analysis showed a small correlation of rating to price. But it was a *negative* correlation: more expensive wines actually had slightly lower ratings overall than the cheaper wines did.

Of course, none of these studies can tell you the most important thing for your own personal wine decisions—do *you* like the wine? It doesn't matter what panels of experts or nonexperts think. You are the only important case for your own wine-drinking decisions. The point of the studies is to show the considerable subjectivity in wine tasting. Nobody can figure out your own likes and dislikes better than you can.

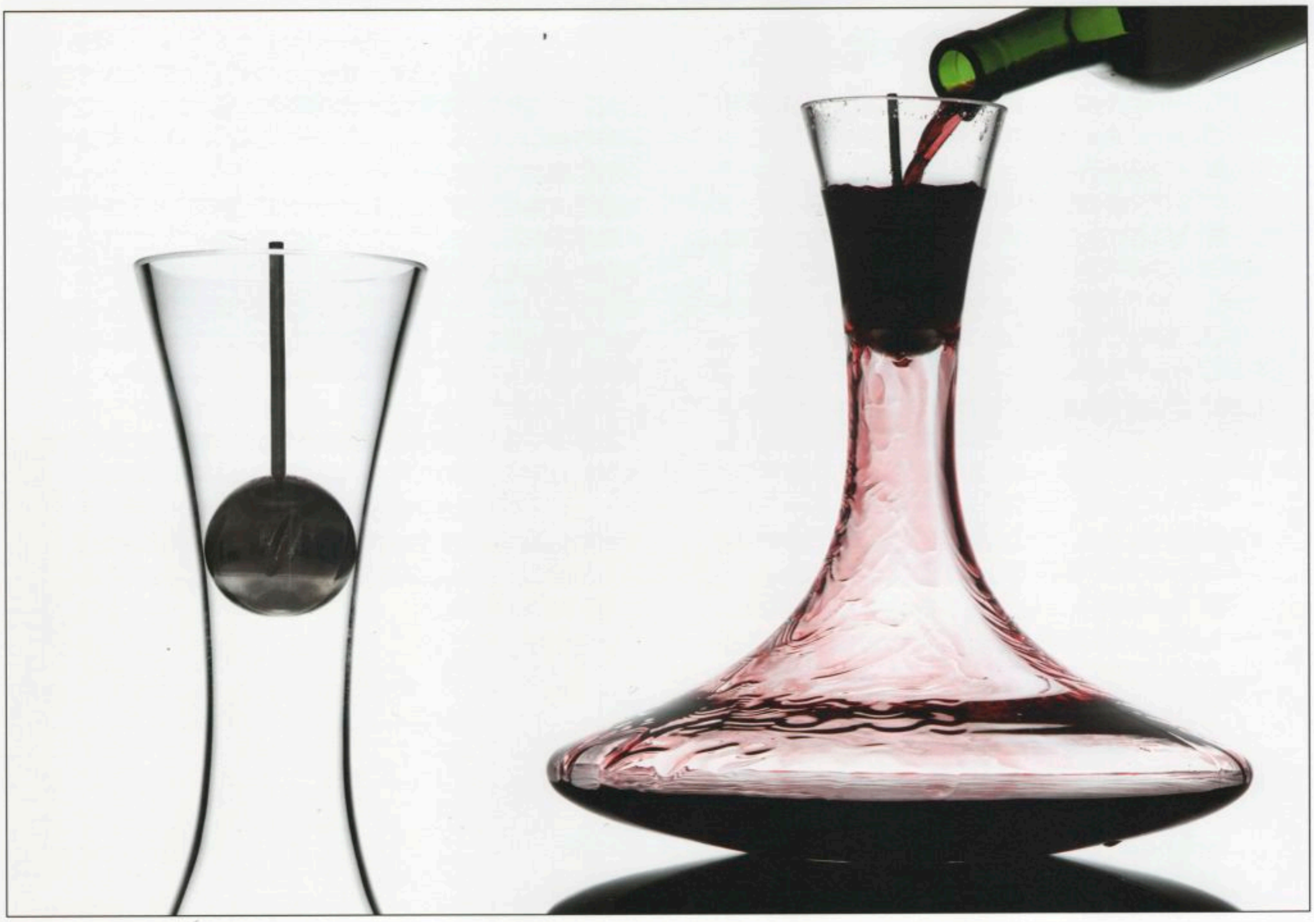
As you explore your own tastes, it is important to be aware of the ways that expectations can easily influence people. The context of the tasting matters. Indeed, it is probably more important to nonexperts than the intrinsic aspects of the wine. But "What matters to most people?" isn't the question you should be asking. Find out what matters to you.

Decanting and Hyperdecanting

One of the rituals of serving certain wines that probably does actually matter is decanting. Before serving wine, consider decanting it. Decanting accomplishes three things. The first is simply to separate sediment from the wine, which frankly is better done with filtration (see page 2·351). The second and third are oxygenation and outgassing.

Wine decanters are designed to allow the wine to flow in a thin sheet across a broad surface of the decanter's interior, thus exposing more of the wine to air. Oxygenation occurs when oxygen from the air dissolves in the wine. When oxygen reacts with flavor molecules, the taste of the wine can change.

Many kinds of wine paraphernalia claim to improve decanting. Some of these tools are expensive, and their efficacy is questionable. We think the best tool for the job is the common blender (see next page).



Outgassing releases bad odors and flavors; it occurs when dissolved gases and volatile compounds vent into the air. Most often these are sulfur compounds, but outgassing can occur with many off-flavors.

It is unclear which of these two processes does more to improve the wine. Our experiments using pure oxygen and nitrogen suggest that outgassing is the dominant effect, but much more work needs to be done to arrive at a conclusive answer.

Wine experts describe the combination of oxygenation and outgassing by saying that the wine "breathes." The analogy is apt, as breathing involves both bringing in oxygen and exhaling other gases.

We developed the technique of hyperdecanting, using a blender, to take decanting to the next level of intensity (see How to Hyperdecant Wine, below). After 30–60 seconds of blending, a layer of foam forms at the surface, not unlike the head that appears on a just-poured beer. After a few moments, the foam subsides, and the wine is ready to serve.

Like regular decanting, this method works best on wines that are young or harsh. In our own tests, we have never found a red wine that wasn't improved (at least a little) by hyperdecanting—as judged by multiple people in blind tastings. Even legendary wines, like the 1982 Château Margaux, benefit from a quick run through the blender. We haven't tried it on every wine, of course, and it is certainly possible that it would degrade the drinkability of an older wine that is at or past its prime. White wines tend to benefit less, as one would expect from the fact that they are not usually decanted; some do not come out better at all.

Several devices on the market claim to speed-decant. They tend to be pricey, with the exception of the Vinturi, a clear funnel that hyperaerates as you pour wine into a glass. We find that these aids are all weak compared to hyperdecanting.

One possible objection to hyperdecanting is that it stirs up the sediment found in older wines. Indeed, one of the stated reasons for ordinary decanting is to remove sediment. A better way to remove

Sellers of some wine "improvement" devices claim the gadgets use the properties of metals as catalysts, or make other claims that smack of pseudoscience. We haven't tried all of these products, but we remain skeptical of such claims.

HOW TO Hyperdecant Wine

Many fancy gadgets are on the market for aerating wine, but you probably already have in your kitchen the ideal tool for this job: a blender. Perhaps the best part about hyperdecanting is the shocked reaction that you'll get from old-fashioned wine "experts" and connoisseurs when you pour wine into a blender at the table and frappé it into a froth. Their reaction alone makes the effort worthwhile! The second-best part is that, in blind tastings, the same shocked people tend to prefer hyperdecanted wine.

We find that this process tends to be most effective on younger red wines, but it can improve some white wines as well. At least two phenomena are at play here. The first is oxygenation, which increases the reaction of oxygen with flavor molecules in the wine. The second is outgassing, which releases gases dissolved in the wine. We tried putting pure oxygen or nitrogen into the blender, and while the tests are not fully conclusive, it appears that outgassing is the more important of these two effects.

1 Pour the wine into an ordinary kitchen blender.

2 Use the highest-power setting to blend for 30–60 sec.

3 Allow the froth to subside (it dissipates quickly), and serve.

sediment is to vacuum filter the wine. This requires a Büchner funnel and filter setup (see page 2·356) and either laboratory filter paper or a paper coffee filter. Vacuum filtration does a perfect job of removing sediment, and it wastes very little wine. Conventional decanting, on the other hand, can easily waste half a glass if there is a lot of sediment. You can vacuum-filter wine either before or after hyperdecanting, or on its own for wine with sediment.

We learned about vacuum filtration of wine from technology entrepreneur Jim Clark, who is an enthusiastic wine collector.

Closures

Corks, though classic, are losing favor among winemakers. One key reason: they can leak in two directions. Because cork is porous, it allows air to migrate through the closure over time, oxidizing the wine in small doses as it ages. And if a bottle is poorly handled or stored, wine can leak through or around the cork. This evaporation or leakage, known as "ullage," creates an unfilled space (also called the "fill level") of air between the wine and the top of the bottle. The lower a bottle's fill level, the more space for oxygen, which speeds aging. Low fill levels can cause a wine's value to plummet by as much as 50%. Leakage often happens with wine bottles held at inconsistent temperatures. Temperature changes force the cork to expand and contract, which compromises the seal that it forms in the neck of the bottle. Slight channels can form, allowing seepage.

Poor results from storing and aging often can be blamed on a poor seal. Even in antiquity, Romans added resin to cork-topped amphorae to reinforce the seal. Modern-day ports long have been sealed with wax, adding security beyond the cork itself, and these wines consistently have proven to hold up better than those with cork-only closures. It's why many wineries are moving from cork to synthetic and screw-top closures. Another benefit is that no cork in the bottle means no risk of corked wine (see The "Corked" Effect and Other Calamities of Wine, page 348).

Screw tops first appeared on inexpensive, low-end wines, but their more reliable seal has seduced the wine trade and, in recent years, consumers. By early 2009, screw cap sales had increased 25% over the previous year, to take 15% of the worldwide wine closure market.

The leading screw cap closure, Stelvin (made in France), offers various liners for the screw cap that allow either no oxygen or various limited amounts of oxygen to pass through. This allows optimization of aging, refuting the notion that screw caps can't be used for fine red wines that are meant to be aged.

Courageous winemakers have begun putting screw caps on high-quality wines. In Australia and New Zealand, where winemakers have a tradition

Although cork (the bark of a Mediterranean tree) is the traditional material for making wine closures, it has a surprisingly high failure rate. Synthetic corks (center) and screw-top closures (right) have become increasingly popular with winemakers and wine drinkers alike. What they lack in tradition and class, they make up for in consistent performance.

of being renegades, screw caps dominate the wine market. In the United States, screw caps are far less common but are appearing on high-end wines from some makers, including Bonny Doon wines, made by the legendary maverick Randall Grahm, and the wines of PumpJack Winery, makers of Oakville Estate Cabernet Sauvignon.

Synthetic (plastic) corks first appeared on the U.S. market in 1993, a result of winemakers' searching for a lower-cost closure that wouldn't suffer cork taint. But they don't provide a tighter seal than natural cork, and they are not biodegradable. About 8% of the 13 billion corks produced in 2009 were synthetic.

The main resistance to new closures comes out of cultural inertia and tradition. Screw caps are a far better technological solution than cork, but people associate them with fruit juice, soda pop, and cheap jug wines. There is nothing rational about this; it is simply a set of customer expectations. Synthetic corks are a middle ground: for those too timid to move to the technical superiority of the screw cap, they provide some of the comfort of the past, with a bit of modern improvement.

Storing Wine

Age can be both a friend and a foe of wine. Age is not simply the time wine spends in a bottle; it is also exposure to external influences—light, heat, and oxygen—that occurs over the months or years the wine is stored. How you store your wines from the time you purchase them to the time they're consumed is an important influence on the drinking experience.

Virtually all chemical reactions occur faster at higher temperatures, and the aging of wine is no exception. Aging is a set of slow chemical reactions between the flavor molecules in the wine. Most, but not all, of these reactions involve reaction with oxygen that gets in past the cork. There are also complicated interactions among the thousands of flavor chemicals in wine.

You've probably heard that the optimum temperature to store wine is generally 10–15 °C / 50–59 °F. One reason for this is chemical: the low temperature slows reactions. How much? Many sources say a temperature increase of 10 °C / 18 °F speeds aging by a factor of two, but that is based more on a rule of thumb than on hard science. It is quite likely that the numerous chemical interac-

Chinese wine scientists have explored using electric fields to accelerate the aging of wine. They pump the wine past titanium electrodes to which a high-voltage alternating current is applied. The scientists say that this improves many of the properties of aged wine, including color change and taste. So far the technique is not in widespread use, but it may be in the future.

THE PHYSICS OF

Why Wine Cellars Are Underground

People figured out long ago that the earth is a good place to store wine (and root vegetables) because of the consistent temperature underground. Dirt and rock have an insulating effect that extends the time it takes for temperature changes at the surface to penetrate.

At depths below about 2 m / 6½ feet (depending on the type of dirt and rock, and ground water, if any), it takes six months or more to reach thermal equilibrium. That's because heat conduction is a slow, diffusive process. Every doubling in thickness increases the time to reach thermal equilibrium by about a factor of four (see page 1·277).

As a result, the temperature at that depth tends to be nearly constant—at the average temperature for the year—even though the surface temperature fluctuates with the seasons.

This consistency is more important than the temperature itself. When a wine bottle changes temperature, it undergoes thermal expansion and contraction. Extreme expansion can force wine out of the bottle, a process called "ullage." Older wines that have been poorly stored often have a wine level down at the shoulder of the bottle.

Even small temperature changes can cause problems. As a bottle goes from 10 °C to 20 °C / 50 °F to 68 °F, for example, air in the neck increases in volume by about 3.5%. If the bottle is sealed with a cork, air pushes past (not so with a screwtop). When the bottle cools, thermal contraction causes a partial vacuum, and new air is sucked into the wine. Only 3.5% of the air is exchanged in one cycle in this example. But after 20 of these cold-hot-cold cycles, half of the air in the neck will be fresh air. That provides a substantial amount of new oxygen to react with the wine.

So, even if you can't store your wine at the supposedly "ideal" temperature, try to keep the temperature constant. A basement is usually a good bet, or, failing that, a room without windows. Sunlight, besides providing solar heat, can also affect reaction rates and degrade wine—one reason that wine bottles traditionally are made from dark glass.

tions each have their own reaction rate, so there is no single answer.

The primary reason for the optimal-temperature recommendation, however, isn't chemistry—it is history and geography. Underground wine cellars maintain a constant temperature at the average annual temperature for a region (see previous page). Prior to thermostats, cellars were the only option for maintaining constant temperatures. In Bordeaux, the average annual temperature is 13 °C / 55 °F. The rest of France is similar: as low as 10 °C / 50 °F in Strasbourg and as high as 15 °C / 59 °F in Nice. Similar ranges prevail in other European wine regions. Our wine traditions come from a time when the annual average was the only temperature at which wine could be consistently kept—and from places that have average temperatures of 10–15 °C / 50–59 °F. So that is what many have come to think of as "best."

Wine experts now advise, however, that any reasonably constant room temperature is fine for wine. The wine will age somewhat faster at higher temperatures, but for most wines this is not a big factor. For long-term storage, the consistency of the temperature is more important than the actual temperature.

The size of the bottle is another factor in aging. The rate of aging reactions depends on the rate of oxygen exchange, which depends in turn on the surface area of wine exposed to air in the bottle. Half bottles have a much higher fraction of wine exposed to oxygen than standard bottles do, and large-format bottles have a smaller fraction exposed. The smaller the bottle, the faster the wine in it benefits or suffers from the effects of aging.

The bottle closure matters as well. Cork can be not only an imperfect seal but also a demanding one. Cork must be kept damp to maintain a hermetic seal to the best degree possible. As cork dries, it shrinks and allows more oxygen to enter the bottle and interact with the wine. Bottles with corks are always stored on their sides so that the wine keeps them moist. Synthetic or screw closures have no such requirement. Nor do the "corks" in Champagne bottles. In fact, these mushroom-shaped corks are compromised over time if they're in constant contact with the wine, so Champagne bottles should always be stored upright.

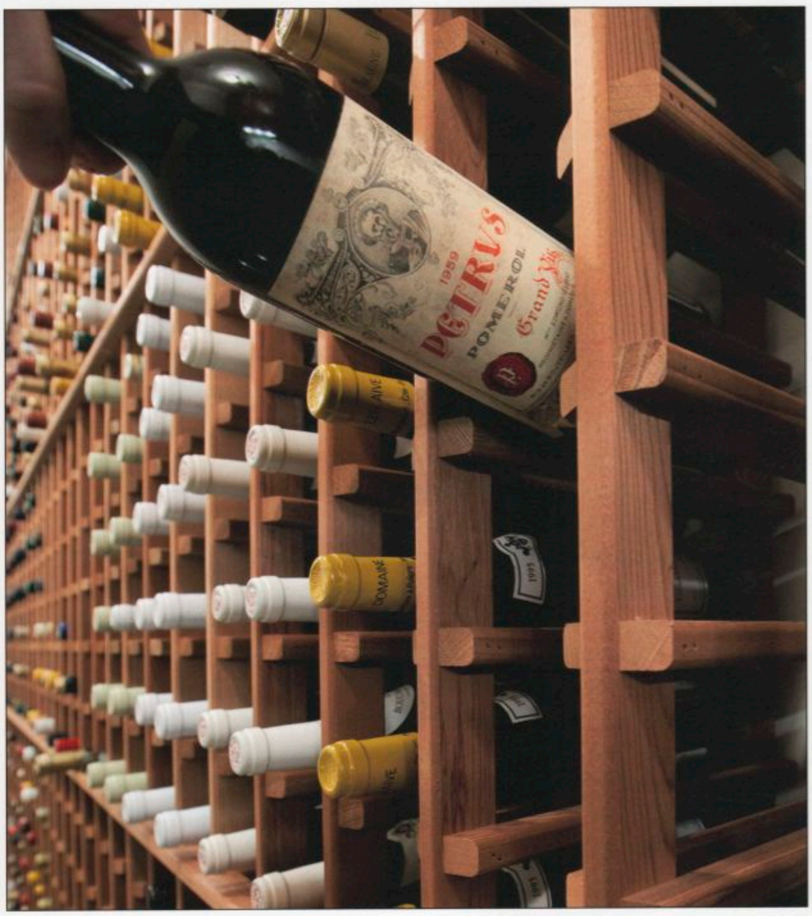
In short, keep still wines with cork closures on their sides and sparkling wines with corks upright; bottles with screw caps or synthetic corks can be stored either way.

One dilemma in storing wine is what to do with an unfinished bottle. Fresh air has been brought into the bottle, and because the level of the wine is much lower, the fraction of the wine exposed to the air is larger.

First, refrigerate the wine because the low temperature will slow the reactions. Second, remove the oxygen, preferably by topping off the bottle with an inert gas. Commercial systems, used for serving wine by the glass, do a good job of this, and you can do the same thing yourself at home.

Nitrogen is widely used for this purpose. It already makes up 78% of air, but putting more into the bottle, using an aerosol can or tank, will help

Wine bottles are rested on their sides to keep their corks damp, which creates a better seal. Cork closures are very much part of tradition, but they allow ullage and extra air flow. Screw caps are simply superior.



The Perlage Champagne preservation system works by repressurizing the bottle with carbon dioxide, much as you would when carbonating a liquid (see page 2·468). Instead of trying to seal the top, you put the entire bottle into a clear plastic pressure vessel and then pressurize it. Each time you open it to pour, you must repressurize it, but carbon dioxide cartridges are cheap compared to Champagne or sparkling wine.

The company also makes the Perlini carbonation system (at right) for creating fizzy drinks.

preserve the wine. You must put enough in to displace all of the air: the goal is to get 100% nitrogen above the wine in the bottle. If you have liquid nitrogen in the kitchen, add a few drops to the wine to achieve the same effect. Just be sure to let the bottle sit for five minutes before you seal it, or it could explode. Argon gas, the third major component of air, is another good (some would say better) choice. Heavier than oxygen, it tends to form a layer above the wine that keeps oxygen out, while nitrogen tends mainly to dilute the oxygen.

After putting in the gas, add a tightly sealing cap—any of those on the market that replace the cork—or just screw back on the screw cap.

Champagne and other sparkling wines have an even bigger problem when opened: the carbon dioxide that makes them sparkle disappears once the pressure is released. Various products try to address this, but the only successful one we have seen is the Perlage system (see previous page), which uses a carbon dioxide cartridge to repressurize the whole bottle.

The "Corked" Effect and Other Calamities of Wine

"Corked" wine is one of the banes of the wine industry. When a wine is said to be "**corked**" or have "cork taint," it indicates the wine has been contaminated with 2,4,6-trichloroanisole, or **TCA.** The natural cork itself or the winery equipment can harbor TCA, passing it to the wine on contact. The wine is still safe to drink, but the impact on its aroma can be pretty powerful: musty in small doses, like piles of old wet cardboard in the worst cases. TCA is an equal-opportunity affliction; it can be carried in the highest-grade corks used in the world's best wines.

How much wine becomes corked each year? Exact figures are hard to come by, but a common wine industry reference is about 5%. The Portuguese Cork Association claims a 0.7%–1.2% taint rate, while *Wine Spectator* found 7% of bottles afflicted in a 2006 blind tasting. That is a very high loss rate. It is one of the reasons the wine world is moving to screw caps and synthetic corks.

Sulfur dioxide, a naturally occurring compound,

THE TECHNOLOGY OF

The Aroma Kit

Even wine professionals can use some help to sharpen their sense of smell. An aroma kit can include more than 50 small vials of colorless liquids, extracts of distinct scents that are meant to help train a person's nose to recognize certain aromas. It can be surprisingly difficult to differentiate between common aromas when sampled side by side.

Try this: have a friend select six spices or essential oils from your shelf. With a blindfold on, smell those spices or oils and see how easy it is to distinguish between ginger and cloves when you have no other cues. It's not so easy, is it? The ability to discern distinct aromas in a glass of wine must be developed; for most people, it doesn't come naturally. Unless, of course, you are Robert Parker, the wine critic whose "million-dollar nose" has always been hypersensitive.

For the everyday wine lover, the aroma kit is like a set of flash cards; it's a chance to learn aroma descriptors the way we learned vocabulary words in school. Terms used to describe the qualities of a wine are effective only when the audience has a clear understanding of the language of wine identification. If we all used aroma kits, it would be easier to talk about wine.

Photo courtesy of Jean Lenoir / Le Nez du Café is present in all wine to a very small degree. Many winemakers add additional sulfur dioxide because it offers dual benefits: it reacts with oxygen and so prevents oxidation, and it prevents bacterial growth. Judicious use of sulfur dioxide helps preserve wine's flavor and integrity. Too much will kill off yeasts, however, thus halting fermentation midstream. Some drinkers sensitive to sulfur dioxide can experience nasal or sinus irritation. Most winemakers use the minimum required to avoid such complications, but even the amounts naturally present in wine can cause off-aromas, or even medical symptoms in certain people (see page 1·238).

THE CHEMISTRY OF

Rescuing Corked Wine

Corked wine is one of the most confounding problems that winemakers and wine drinkers face. Winemakers have experimented with treating virgin corks to eliminate TCA—the chemical that causes the musty corked aroma—but no major strides have been made.

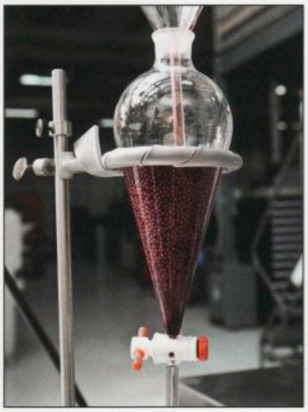
What can you do if a great bottle turns out to be corked? An emergency procedure can help. The TCA molecule is chemically similar to polyethylene and will adhere to it, dramatically reducing the sensory impression that the wine is corked. Some TCA will remain, but only at such small levels as to be nearly imperceptible. To eliminate the moldy smell of cork tainted by TCA, Andrew Waterhouse of the University of California, Davis, suggests pouring corked wine into a bowl with a sheet of polyethylene plastic wrap. The process is "very effective in just a few minutes," he says.

The trick is that the wine and the wrap need to make contact across a large surface area to make a significant impact. How large? We conducted a number of tests, comparing two manipulations and a control. One manipulation was simply shaking corked wine in a polyethylene bag for 10 minutes. The second treatment was a bit more complex.

To increase the surface area in contact with the wine, we poured it through about 250 ml / 1 cup of small balls (3.2 mm / ⅛ in. in diameter) made of high-density polyethylene. These plastic filter beads can be purchased from aquarium supply sources; they are used as floating filtration devices in some fish tanks. The wine was allowed to drip slowly through a separatory funnel with a mesh-filtered drain. It passed through the pile of beads in less than 10 minutes.

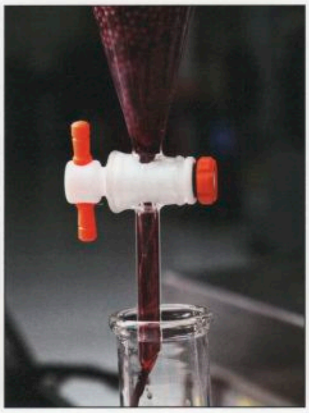
We had panelists compare these treatments in a triangle test (see page 336), and both treatments made great improvements in the badly corked wine. The corked wine that passed through the bead-filled funnel tasted slightly—but perceptibly—better than the wine shaken in the polyethylene bag.

It appears that either treatment would suffice. If you do use the bead-and-funnel approach, be sure to treat the beads after each use with hydrogen peroxide to remove the compounds that they have absorbed.

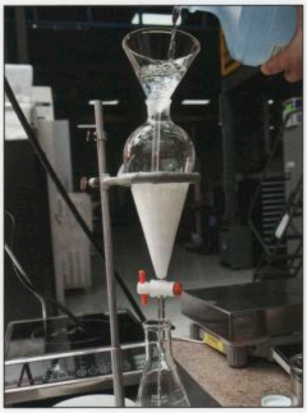


1 Close the stopcock of a separatory funnel, and then pour the corked wine into the funnel.

2 Swirl the wine with the beads for a few minutes.



3 Set a clean vessel beneath the funnel and open the stopcock to drain the treated wine.



4 Wash the beads with hydrogen peroxide until they appear clean and have no detectable aroma; they can then be reused.

Yeast is integral to the winemaking process, converting the natural sugars of the grapes into alcohol. But **Brettanomyces** (brett, for short) is a naturally occurring yeast that can run amok in wine. Held in check, this unicellular fungus can be a good thing, adding complexity to the wine. It's known for increasing the depth of character and flavor of Château de Beaucastel, one of the world's best wines, whose most successful vintages have been marked by high levels of brett. But most of the time, a little brett goes a long way. Too much, and the aroma profiles move into the rancid realm, with odors of stables, sweaty saddles, and barnyards—none too pleasing in the glass. Brett can easily spoil the whole party.

Vinegar is a good thing when it's on your kitchen shelf. But it's not what you want to encounter when lifting a wineglass to your lips. Too much oxidation can go really wrong. Prolonged exposure to oxygen-rich air robs wine of its layers of flavors and aromas, making it flat and bland. Oxygen can affect a wine at a number of stages during production and storage. The effects are amplified, of course, once the wine bottle is opened. In some cases, that oxidation can spur the growth of bacteria that produce acetic acid, adding an aroma—and sometimes a slight flavor—of vinegar to the wine.

Wine Pairing

For nearly as long as there have been food and wine, the two have been enjoyed together. Though they long were consumed with little or no thought as to whether they complemented each other, over

THE NEUROSCIENCE OF

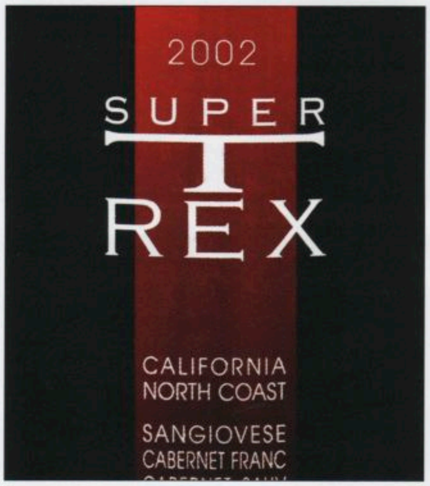
Why Some People Can't Smell Truffles

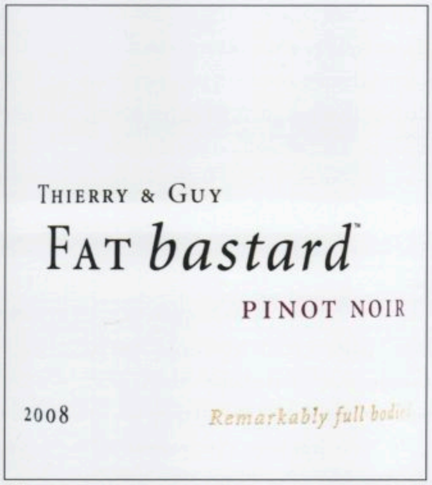
White and black truffles are delicacies that have been known to sell for more than $2,000 a pound. The dominant aroma note in truffle is that of the steroidal compound **androstenone**, also a key contributor to the smell of male underarm sweat. Some people describe it as pleasant, musky, and vanilla-like. Others think it reeks of urine; still others can't smell it at all. The latter two groups are presumably very disappointed when they order menu items that owe their high price to their truffle content.

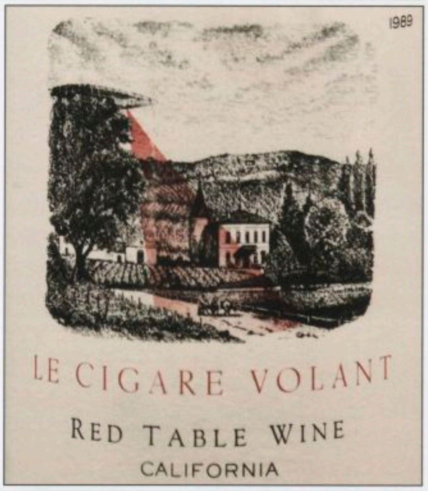
This wide disparity in aroma perception seems to be genetic. A gene encodes the **protein** on olfactory sensory cells on which androstenone docks. Truffle lovers have one set of the variants of this gene, whereas those who hate the delicacy or couldn't care less have other variants.

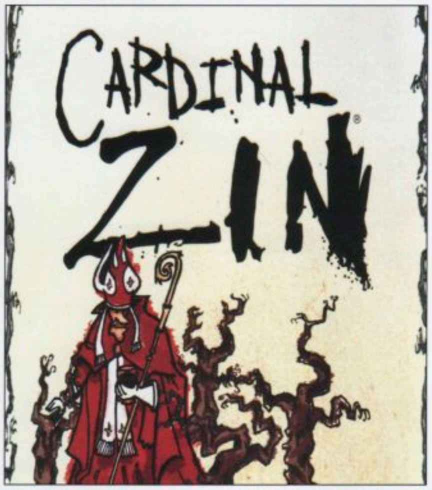
Some studies suggest that as many as one in four men perceive androstenone as odorless, but a 2003 study concluded that 2%–8% of all adults have no androstenone perception. Presumably, most of those who shell out for truffle dishes carry the gene variant that renders the smell of truffles alluring.

Asparagus presents another oddity of individuality in smell. Many of us are reminded of our recent meal of asparagus when we use the toilet: we pick up a strong scent of the methanethiol, dimethyl sulfide, and other chemicals produced during the digestion and metabolism of asparagusic acid. But some can eat mounds of the stuff yet detect no malodor at all in their urine. For years it was believed that this was due to differences in digestion. In the 1980s, however, studies in France, Israel, and China confirmed that all humans produce the chemicals, but only about 22% of the population has the genes that allow them to detect the odor.









You don't drink the label, but its effect on the marketing of wine is profound. A lot of creativity goes into wine names, from the whimsical—like Marilyn Merlot, Super T Rex, Cardinal Zin, or Fat bastard—to the obscure. Le Cigare Volant (French for "flying saucer") commemorates a 1953 UFO sighting in the village of Châteauneuf du Pape, which resulted in the townspeople enacting a local ordinance forbidding aliens from landing in vineyards.

In addition to names, artwork is a big part of wine labels. In 1945, Baron Philippe de Rothschild decided to have famous artists (including Picasso, César, Dali, Miró, Villon, Warhol and other masters) design a different label each year. This design worked so well that it inspired label art throughout the wine world, artistic to a sometimes ludicrous degree, ever since.

time it naturally became clear that some food and wine combinations sang, while others jarred.

Some traditional wine and food pairings grew out of the premise that products from the same region naturally partnered well on the dinner table. Provence's aromatic Rhône Valley Syrah loves the local lamb. Bright, crisp Sauvignon Blanc from the Loire works well with Brittany's briny oysters.

It's hard to know for sure when the practice of wine and food pairing made a formal debut in a restaurant setting. Celebrated chef Alain Senderens, who presided over the kitchen of L'Archestrate in Paris, has been a proponent of thoughtful pairings since the 1960s. The practice of offering specific pairing suggestions for many dishes on restaurant menus is common these days. When done well, it can produce an outstanding experience, the wine complementing and elevating the food—and vice versa. When done poorly, it can be a waste of both.

Pairing becomes a huge dilemma for the growing cadre of restaurants that offer Modernist cuisine. Some of the foods served can simply be very difficult to pair with wine. Carbonated foods have a sharp flavor on the palate, a challenge almost any wine will be powerless to stand up to—save, perhaps, a sparkling wine, though who wants double doses of carbonation at a fine meal?

Modernist meals also often feature 20—in some cases as many as 50—courses. You certainly can't pair a different wine with each course, unless you do so by the thimbleful. An alternative is to pour a glass to be sipped for seven or eight consecutive dishes, but given the breadth of flavors reflected in those dishes, it's unlikely that one wine will stand up well to the entire spectrum.

Sommeliers, Modernist chefs, and other experts are beginning to sink their teeth into this dilemma, but there's plenty of room for growth in our understanding of how fine wine and Modernist cuisine can happily coexist on the same dining table.

Pairing wine with cheese is an art. At Lucas Carton in the 1980s, the cheese course on the tasting menu featured four or five cheeses, chosen by the chef, each with its own paired glass of wine. After pouring, the sommelier would say, "Start here, and go clockwise," because even the order was considered important.

Among the myths of wine is the idea that the "legs," or "tears," that wine forms on the insides of a wineglass indicate the quality or viscosity of a wine. In fact, those rivulets running back into the glass are the simple result of the evaporation of alcohol. It evaporates more quickly than water, producing the Marangoni effect, which pushes water down the side of the glass in channels. The higher the alcohol content, the more legs there are.

18 COFFEE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MENTOS

COFFEE

Dining at a fine restaurant is such a special experience because so much attention is given to the smallest details of the meal: carefully chosen ingredients, artful dishes, sublime wines, classy cocktails, artisanal breads, refined cheeses.

Then comes the coffee, so often an afterthought—more like a generic commodity than a gastronomic event—that many people don't even realize what a transcendent experience the beverage can provide.

This is true even at Michelin three-star restaurants. These pinnacles of the culinary arts boast the finest food in the world, proffer encyclopedic wine lists, and go to every extreme to offer the best dining that money can buy. Yet a typical Michelin three-star restaurant serves coffee that wouldn't meet the standards of an ordinary street vendor in Seattle.

Coffee shouldn't be an afterthought. It can be a profoundly stimulating beverage, and not just because of the caffeine. Coffee cognoscenti have a phrase for the earth-moving experience that a perfectly pulled espresso can provoke. They call it the "God shot" (see page 375). It is a sip of espresso that exemplifies absolute perfection: lush consistency, reddish-brown crema, and flavor as powerful and balanced as the aroma of freshly roasted coffee beans.

A God shot is quite rare, but that fact just proves that the seeming simplicity of coffee is misleading. In fact, countless variables must be mastered to brew the perfect cup. The first steps include heeding a few basic principles and investing in a lot of practice. Amazingly, these are steps that some of the most vaunted restaurants fail to take. In practice, many otherwise excellent restaurants delegate the task of making espresso to the newest, least-trained member of the staff. Truly an afterthought. And a shame, too, because with just a bit of forethought and some basic understanding of the coffee bean and various brewing processes—basics that we provide in this chapter—anyone can make coffee that shows off the full potential of the roasted beans.

In pulling this information together, we have drawn on the wisdom of a cadre of dedicated fanatics who take very seriously the job of producing a perfect cup of coffee. The latest generation of baristas and other coffee professionals is building on the foundation laid by mentors in the craft and elevating the art of espresso to new levels. They share the passion of the young turks in today's Modernist kitchens, who are building on the innovations of trailblazers in Modernist cuisine by adding their own distinctive interpretations. Their enthusiasm for the craft of coffee and their thirst for perfection is so strong that they train like athletes to pit their skills against colleagues in major barista championships held each year. After watching one of these competitions, no one can come away believing that "coffee is coffee."

Talent, technique, and gear are central to success but are not the whole story. No amount of high-tech temperature controls, intuition for perfect grinding, and tamping technique will coax layered, lush, full-bodied flavor and aroma from a bean that is subpar. As with any other food we enjoy, the quality of what we consume in the cup begins in the field. Poor growing conditions, cultivation, harvesting, or production will strip coffee beans of their ability to provide a truly enjoyable coffee experience, let alone a transcendent one.

High-quality coffee beans, grown in subtropical regions around the world, are the foundation of great coffee.

FROM CHERRY TO BEAN

The ripe fruit of the coffee plant is a red fruit called a cherry, which contains a pair of pits: the coffee beans. Two species of coffee dominate the commercial trade: Arabica and Robusta. Both are grown in a band of subtropical zones that span the globe, but Arabica is by far the more common. It's a finicky plant that likes altitude and is less resistant to disease, but its beans produce flavor that is more complex and nuanced. Robusta beans, particularly when expertly cultivated, can lend body when blended with Arabica beans, but they can also contribute less-pleasing aromas and have higher doses of caffeine.

Myriad factors affect the quality of the beverage that ends up in the cup: whether cherries are harvested at optimal ripeness, what method is used to process the beans, how long they are roasted, and many others. The ideal combination varies from one variety and growing environment to the next.

Processing and roasting are distinct steps on the bean's journey from the coffee bush to your coffee maker. Processing happens immediately after harvest and comes in two principal forms. The "dry," or "natural," process is an age-old method in which whole coffee cherries are laid out to dry in the sun for up to four weeks. Once dried, the outer pulp and inner skin (called the mucilage) are removed to expose beans that produce coffee that's complex, full-bodied, and smooth.

Being too fresh might seem an unlikely problem, but coffee is not at its best until it has aged slightly. The beans need a chance to release most of the carbon dioxide that was created by the Maillard and other reactions during the roasting process. If they don't, the high levels of CO_2 will be carried through the process, causing excessive bubbling during extraction and adding a sour flavor to the coffee.

The "wet" process is a relatively recent innovation. In this case the pulp is stripped off mechanically. A fermentation step then removes the mucilage layer before the beans are put out to dry. Coffee processed this way tends to be bright and slightly acidic in flavor, with developed fruitiness.

A third method, called "pulped natural," is a hybrid of natural and wet processing. Pulps are removed mechanically, but the beans are dried without any intermediate fermentation, and the mucilage isn't removed until after drying. Beans thus treated have a good balance of sweet and acidic notes, with robust body.

Because of the many variables that affect bean quality, cooks and restaurant managers are wise to rely on skilled, trustworthy roasters. Then most of the work that goes into making an excellent cup of coffee has already been done for you. Passionate coffee roasters have scoured the globe for reliable sources of outstanding beans. They've scrutinized roasting options and matched the best roasting levels to each type of bean. Similarly, demanding coffee store operators have invested in state-of-the-art grinding and brewing equipment and have trained all of their staff to manipulate good beans to maximum advantage. To have a superlative coffee experience, all you need do is place an order at the right coffee shop.

Nevertheless, it pays to understand the hows and whys of outstanding coffee. If you know what goes on behind the scenes to yield that mind-blowing God shot from a humble sidewalk café, you can avoid serving an awful cup of coffee after an otherwise grand dinner.

Roasting for Flavor

A coffee bean in its innocuous, tender, parchment-wrapped state after the flesh of the cherry has been stripped off gives little clue to the complex character encased within. And no matter which of the processing methods was used to pulp and dry the bean initially, the coffee has little inherent flavor until the heat is turned up. The compounds that bring out the aroma, taste, and body we attribute to coffee develop only through roasting. Roasting brings the craft of the coffee world into play, displaying the roaster's stylistic preferences and intended outcome for the "green" (raw, dried) coffee beans.

Roasting coffee is simple in concept but complex in practice. An array of variables is already in effect by the time a heavy bag of green coffee

The long path from the coffee plant's fruit (called the coffee cherry) to the final bean involves many steps. One of the most important is roasting, which develops the flavor.


RICH

Various degrees of roasting have many names, but espresso is not one of them. In the U.S. and many other places, beans intended for espresso are given a roast called Northern Italian. The name itself gives away its origin. In this roast, beans are heated to 227–230 °C / 440–446 °F, just on the verge of the second crack stage and before the beans release their oils.

Although this roast has been a standard for many years, some roasters now prefer to pull the beans before they reach the level of a Northern Italian roast, in order to allow a bit more of their natural sweetness to persist and to ensure that the more delicate floral flavors don't get lost.

beans shows up at the roaster. Where they were harvested, how they were processed, and what variety or cultivar of coffee plant the beans came from are just a few influences. Geography, climate, altitude, and other factors affect the character of the plant and its fruit. These aspects of the raw ingredient, in turn, influence the roaster's approach, coupled with the ultimate goal for that batch of beans. Does the roaster intend a lighter, mellow, "clean" cup of coffee? Or does the roaster strive for robust, nutty, intense flavors?

There are no absolutes with coffee roasting. Rules and frameworks are all just starting points for the intended interpretation, based on the roaster's goals, the ambient temperature and humidity, and the character and quality of the bean at hand. Not all types of beans react the same way to each incremental rise in temperature. This is where skill and art come into play: the roaster monitors the roast's progress and adjusts the time at which beans are pulled from the drum.

The Maillard reaction that takes place in meats, seafood, and other high-protein foods (see page 3·89) also occurs in coffee roasting. Maillard reaction products contribute to the more than 800 flavor and aroma compounds that create the complexity, richness, and aroma of coffee. In wine, by comparison just a few hundred compounds contribute to the flavors and aromas of that complex beverage.

Roasting begins with a simple heating stage, in which the beans absorb the heat and give off excess water, in the form of steam. Until nearly all the water is gone, the temperature of the beans themselves can't rise above the boiling point of

THE SURPRISING PROVENANCE OF

Kopi Luwak

Paradoxurus hermaphroditus, the Asian palm civet, is an odd-looking creature that resembles a cross between a mongoose and a raccoon. If not for its particular taste for coffee, it might be just another entry in the book of exotic zoology. As it happens, these animals spend most of their time in trees in search of their favorite foods, which include the ripe cherry of the coffee plant.

Selective eaters, these civets prefer the ripest coffee cherries. It took a brave soul to realize that when excreted, these coffee beans have been processed in a way akin to the wet method that removes the outer pulp and involves slight fermentation. Fans of the beans think their flavor has also been refined.

The secrets may be in the animal's gut. Acids from the civet's stomach break down some of the proteins in the beans, which then leach out. These proteins contribute to bitter flavors, so removing them allows the natural sweetness and other more delicate flavors of the coffee to shine through.

Collectors gather civet scat, fish out the beans, wash them well (thankfully), and then air-dry them. The remaining thin skin on the beans is removed, and they are sorted and stored for roasting. The result is known as Kopi Luwak, a coffee that commands up to $600 per pound, making it the most expensive coffee in the world—and one that counterfeiters often attempt to mimic. Furthermore, because the authentic beans are so valuable, there are animal-rights concerns about the use of captive animals to increase production. As a result, many coffee experts strongly disapprove of Kopi Luwak; some even asked us to remove mention of it from the book.

Is it the most delicious? That is controversial, but it certainly is the most unusual.

water. The beans' color also begins to change from a dull green to a pale-to-medium yellow.

As roasting continues, the beans may go through two crack phases (depending on how long the batch is roasted and how hot the roasting temperature is). The first phase occurs when the beans reach a temperature of 150–180 °C / 300–360 °F and start making distinct popping sounds as gases escape from them (not unlike popping kernels of corn, though less dramatic). At this stage, the beans also roughly double in size. As the temperature increases, their color deepens, their surface texture becomes shinier as oils migrate to the surface, and their aroma continually changes until they hit the more sedate second crack.

During roasting, a fine line separates the development of the inherent flavor qualities of the coffee bean and the point at which the roast itself becomes the dominant flavor, overwhelming the bean's intrinsic character. Heavily roasted beans also relinquish more of their volatile compounds, which reduces the amount of rich, complex flavor that can be drawn from the bean during brewing. Those extricated oils can also oxidize and turn stale, further diminishing the quality of the eventual coffee in the cup.

Roasted coffee is at its peak 48–72 hours after roasting. Ideally, brew it before 10 days have passed post-roast. From that point forward, the quality of the coffee declines as volatile compounds escape from the beans, and the remaining oils begin to degrade and become rancid. Stale, older coffee is easy to notice when brewed in an espresso machine. Beans that are four or five days old make **crema**, the distinctive foam atop an espresso that is thick and lush; beans that are too old form crema that is thin and insipid.

THE ECONOMICS OF

Fair Trade Coffee

Home cooks and professional chefs alike have been working to reduce the number of hands through which food passes on its way from farm to kitchen. Just look at the number of farmers' markets around the world today. More and more, people are consciously buying locally produced foods and, where possible, putting their food dollars directly in the hands of growers.

This model is tricky to apply to coffee because it is grown in such remote parts of the globe. In addition, coffee cherries must be processed before they can be sold to average consumers. Still, many of us would like to know that we're getting quality, farm-direct coffee and that the farmers are earning at least a living wage.

In the 1980s, such widely felt desires led to Fair Trade certification, an admirable attempt to confirm that good economic and social practices are in place along the chain from coffee grower to consumer. If nothing else, the efforts helped make consumers more aware of the economic challenges that so many small coffee farmers face. That's good, right?

Yes, except that over the years Fair Trade certification (right) has become something of a marketing ploy. Critics of Fair Trade-certified coffee point out that certification applies only to commodity coffee, not specialty coffee because only regional cooperatives, rather than individual growing estates, are certified. Cases have been reported of growers selling illegally or unethically grown coffee to cooperatives, where it then became "certified." Furthermore, economic research has shown that very little of the premium price commanded by Fair Trade certified coffee actually makes it back to individual farm workers.

The most conscientious coffee importers and roasters have created their own means of working with individual estates, without going through Fair Trade-certified channels. For example, the small specialty roaster Caffé Vita, in Seattle, has developed a protocol the company calls Farm Direct to ensure an excellent product for buyers, prices to growers that exceed Fair Trade-certified levels, and good environmental stewardship at the source. Other independent specialty roasters, such as Counter Culture Coffee, in Durham, North Carolina, have taken direct trade a step further by using an independent auditor to verify that the economic and social standards are actually being met.

Ask your supplier questions, just as you do with other foods you buy, and know that a coffee doesn't have to be Fair Trade-certified to be one that is fairly traded.

FAIR TRADE CERTIFIED

100% FAIR TRADE CERTIFIED COFFEE
This excellent quality coffee has been Fair Trade Certified by TransFair USA, an independent non-profit organization which monitors and certifies Fair Trade products in the United States. Fair Trade raises incomes and living standards for small coffee farmers overseas while helping to protect the environment. Learn more at **www.fairtradecertified.com**

THE PRACTICALITIES OF
Storing Coffee

Ideally, use coffee beans once they have rested for two or three days after roasting. To store whole beans, simply keep them in a lidded container in a cool, dry place.

The most important consideration in storing beans is to avoid oxidation. Vacuum packing the beans with a vacuum-sealing machine helps. Adding a nitrogen flush while vacuum packing is even better. Under these conditions, the beans can be kept in a cool, dark place at room temperature for up to three weeks with minimal loss of flavor or development of rancidity. Although freezing further slows spoilage, freeze coffee only in a container that can be made airtight, and fully defrost the beans and allow them to come to room temperature before opening the bag. Otherwise, condensation will form on the beans as they thaw, making them much harder to handle when grinding and brewing.

As we will explain later in this chapter, coffee should be ground immediately before brewing. We prefer not to store ground coffee.

THE STAGES OF ROASTING COFFEE

Hard, knobby-looking green coffee beans go into the roaster (1); the beans dry (2) and begin to smell toasty (3); then the first crack begins, and the beans expand to nearly double their original size (4). At the end of the first crack, the beans are at city roast stage and go through **pyrolysis** (a heat-induced chemical change), which releases carbon dioxide and alters their chemical composition (5). The "full city" roast stage occurs just before beans hit the second crack (6); when the second crack is complete, the beans begin releasing their heat (7), oils begin forming on the surface of the beans (8), and continued roasting carries beans through ever darker roasting points, up to full French roast (9).

Raw

143 °C / 289 °F
6 min

164 °C / 327 °F
8 min

183 °C / 361 °F
10 min

THE SCIENCE OF

Decaffeinated Coffee

The term "decaffeinated coffee" may strike some as an oxymoron, but there is a cadre of drinkers who relish the taste of coffee but just can't tolerate the jolt from caffeine. Remember, however, that decaffeination only removes about 90% of the caffeine. Drinking 10 cups of decaffeinated coffee can, in principle, contain about the same amount of caffeine as in one cup of full-test coffee.

To make decaf, the caffeine is removed in the green bean stage, before the coffee is roasted. Originally done by means of chemical solvents that leached caffeine from the beans, decaffeination today generally relies on more neutral methods to extract caffeine. Although some high-volume companies still decaffeinate by using ethylacetate or methylene chloride, the process is regulated such that all the solvents are removed before the coffee is roasted.

Of the many methods for decaffeinating coffee, the best is extraction by carbon dioxide in a **supercritical** state, meaning that it is under high enough temperature and pressure to act as both a gas and a liquid (see page 1·302). Supercritical carbon dioxide can reach into the crevices of coffee beans like a gas but dissolve caffeine like a liquid. First the beans are soaked in water to expand cell structures and make it easier to extract the caffeine molecules; then they are exposed to supercritical carbon dioxide for several hours. The caffeinated carbon dioxide liquefies and evaporates, and the beans are then processed as for other coffees. Because the carbohydrates and proteins remain intact using this method, there is very little change in taste as a result of decaffeination. It's still difficult, however, to extract a good shot of espresso from decaffeinated coffee beans.

Not all of the caffeine ingested from a cup of coffee gets metabolized. Some caffeine ultimately exits the body in the urine. Scientists who studied the ocean water in Puget Sound, near coffee-mad Seattle, found that it contained tiny but measurable quantities of caffeine. Apparently sewage treatment plants do not remove it from the waste stream.

201 °C / 394 °F 12½ min | 210 °C / 410 °F 14 min | 219 °C / 426 °F 15½ min | 223 °C / 433 °F 17 min | 229 °C / 444 °F 18½ min

BREWING

Brewing coffee is all about **extraction.** Ground roasted beans meet water (typically, but not always, hot water), which leaches out the volatile aromas and nonvolatile taste compounds that create the sensory experience of coffee flavor.

This extraction can happen through **infusion** (steeping coffee in the water of a French press), **percolation** (passing hot water through coffee grounds), and **decoction** (extracting flavor by boiling, as in the cowboy coffee of yore or, to a more refined degree, Turkish coffee). Regardless of the method used, it takes care to produce a cup of coffee that perfectly exemplifies the character of the coffee bean.

Each brewing technique aims to extract 18%–22% of the soluble materials (components that contribute taste, aroma, body, and color) from the ground bean, which then flavor the water. The ratio of water to coffee, the temperature of the water used, the fineness of the coffee grind, and the total brewing time all affect the character of the coffee. When those various elements are properly controlled, they meld and form a flavorful, balanced cup of coffee.

Various methods applied to the same type of coffee can produce extractions with different balances of flavor and aroma compounds. As a result, the flavor can be quite different, and each can be excellent in its own way.

Determining the strength of coffee can be confusing. Many people who like strong coffee gravitate toward darker roasted beans, presuming they are the means to the desired end: strong coffee in their cup. In fact, a strong coffee can be brewed from beans roasted to any level. A lighter, medium roast with moderate sweetness and floral characteristics can be brewed as strong as a batch of dark, oily French roast. Strength is a factor not of the darkness of the roast but rather of the brewing ratio of coffee to water.

Many coffee drinkers confuse strength with bitterness or sourness, also a correlation that is indirect at best. Bitterness or sourness are characteristics of over- or underextraction, respectively, and extraction depends more on brewing time than on the roast or the ratio of water to beans. A strong or a weak cup of coffee can be sour, bitter, or well balanced—neither too sour nor bitter. The ultimate goal in brewing coffee is to yield a strong enough cup with a balanced taste.

Brewing temperature also affects the coffee extraction. Again, many variables come into play, and temperature can and should be adjusted in response to those variables. Too low a brewing temperature causes underextraction, which draws out the acidic flavors and little body from the beans; excessively high brewing temperatures bring out the more acrid, bitter characteristics.

Although there's a long-standing belief that the best way to serve coffee drinks is "fresh and hot" within moments of being brewed, there may be a bit of folklore at play here. It's true that espresso should be enjoyed immediately, before the highly volatile aromas dissipate, but that's not the case for brewed coffee. Think about a bowl of soup: if it's too hot, not only do you risk burning your tongue but you're also unable to taste the full complement of flavors in the soup. Brewed coffee similarly benefits from cooling slightly before that first sip, after which you are likely to capture more of the inherent flavor. Heat masks the positives in the cup as well as any defects the coffee may have.

That's why professional coffee tasters typically taste the coffee five or six minutes after the water was poured, when it is warm rather than piping hot. They get a more authentic representation of the flavor at a more moderate temperature. Because of these effects, the temperature of water used for brewing should be calibrated to remain consistent from one brewing cycle to the next.

HOW TO Taste Coffee Like a Pro

"Cupping" is a controlled tasting procedure that helps roasters, retailers, and connoisseurs judge the distinctive flavor of a particular batch of coffee, including its balance of acidity, aromas, body, and richness. The process below helps determine the ideal roasting level of the green bean, as well as whether it should be sold as a single-origin product or as part of a blend. Periodic cupping after roasting assesses how the flavor develops—or degrades—over time.

When performed with the aid of a brewing control chart (see next page), cupping also familiarizes the barista with how the coffee's flavor profile varies with brewing strength. The cupping exercise helps train a barista to learn which combination of brewing adjustments will improve a particular coffee.

1 **Prepare grounds.** Grind the coffee finer than for French press, coarser than for drip. Place the grounds in a small cup, typically a double shot glass. Most professionals use 55 g of coffee grounds per liter of water, or about 9.5 g for a 175 ml / 6 oz cup.

2 **Evaluate the raw fragrance.**

3 **Add hot water; steep for five minutes.** Allow a crust to form on top.

4 **Evaluate aromas.** For the first pass, hold your nose just above the edge of the cup, break the crust with the back of a spoon, and inhale. Leave your mouth open while inhaling through your nose to maximize the sensory impact. Judge the top notes: nutty, citrus, chocolate, flowers?

5 **Discard crust and reevaluate.** On the second pass, spoon the crust of grounds from the surface. Breathe in aromas from the coffee, which is now cooler.

6 **Steep for 7–8 minutes more, and then slurp a spoonful noisily.** Slurping sprays the coffee across your entire palate, which mixes the liquid with air, volatizes aromas, and increases the impact on your palate.

HOW TO Use a Brewing Control Chart

Most people can agree when brewed coffee is too sour or too bitter. But too often they go about fixing the problem in the wrong way. Adding more coffee will make it stronger but not less sour. Cutting back on the dose will weaken the brew but won't necessarily reduce the bitterness.

To help clarify the nonintuitive way in which the dosage (also called the brewing ratio), the grind size, and the brewing time interact to affect the flavor of brewed coffee, experts have created a graph called the **brewing control chart**. By using this chart, you can systematically improve the quality of your brewed coffee.

The goal is to optimize balanced taste and strength. Almost all brewing experts agree that, for a balanced taste, the extraction should pull 18%–22% of total soluble materials (by weight) from the grounds into the water. If this **extraction percentage** (also called **solubles yield**) is less than 18%, the coffee tastes sour and astringent, if over 22% the coffee tastes bitter.

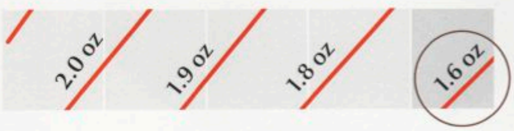
There is less agreement on the ideal strength, which is the ratio of coffee to water in the cup (also called the **solubles concentration**). Some cultures prefer stronger coffee than others. But most will judge the ideal proportions to fall somewhere within the range of 1.15%–1.40%.

The brewing control chart plots extraction on the horizontal axis and strength on the vertical axis, producing a box-shaped ideal zone in the middle that yields the "golden cup." Three tools will help you adjust the brew so that it falls within this zone. The first is a simple scale for weighing the grounds; to adjust the dosage, you must first measure the grounds and the water. The second tool is a **total dissolved solids** (TDS) meter; the least expensive varieties use electrical conductivity and read in parts per million (ppm), but varieties that make optical measurements and read in percentages are also available. The third tool is the brewing control chart itself.

1 **Weigh grounds and water, and prepare sample cups.** Make a note of the dosage—how many grams of coffee were used for each liter of water. The diagonal lines on the graph correspond to different dosages. Use a dosage that falls within the ideal zone.

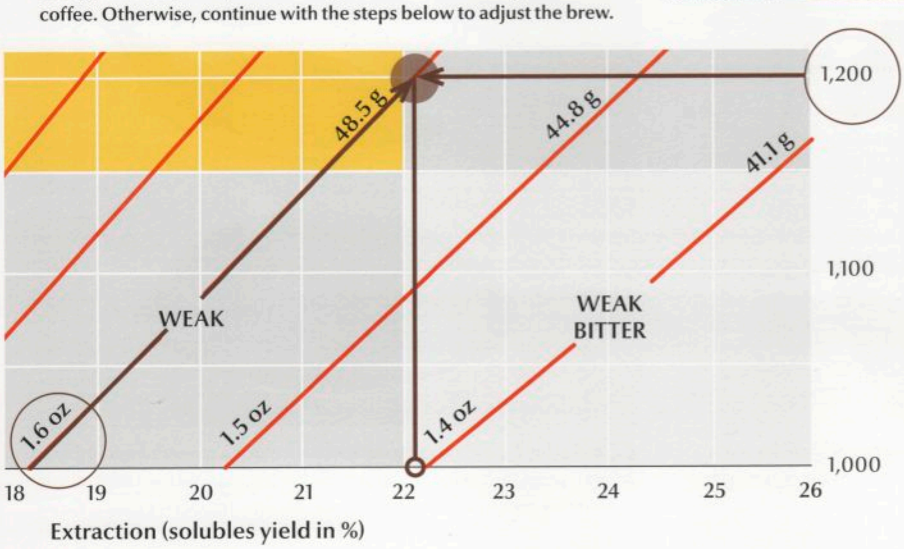
2 **Measure the total dissolved solids (TDS).** Follow the manufacturer's instructions for your TDS meter. If it presents measurements in percentages, use the vertical axis on the left side of the chart. If it gives readings in parts per million (ppm), use the vertical axis on the right side.

3 **Find the diagonal line on the chart that corresponds to the dosage used.**



4 **Find the horizontal line that corresponds to the TDS reading.**

5 **Find the intersection of the dosage and TDS lines.** Drop a vertical line from the intersection point to the horizontal axis to read the extraction percentage. If the intersection point falls within the ideal zone and the strength is acceptable, the brewing practices are working well for this coffee. Otherwise, continue with the steps below to adjust the brew.

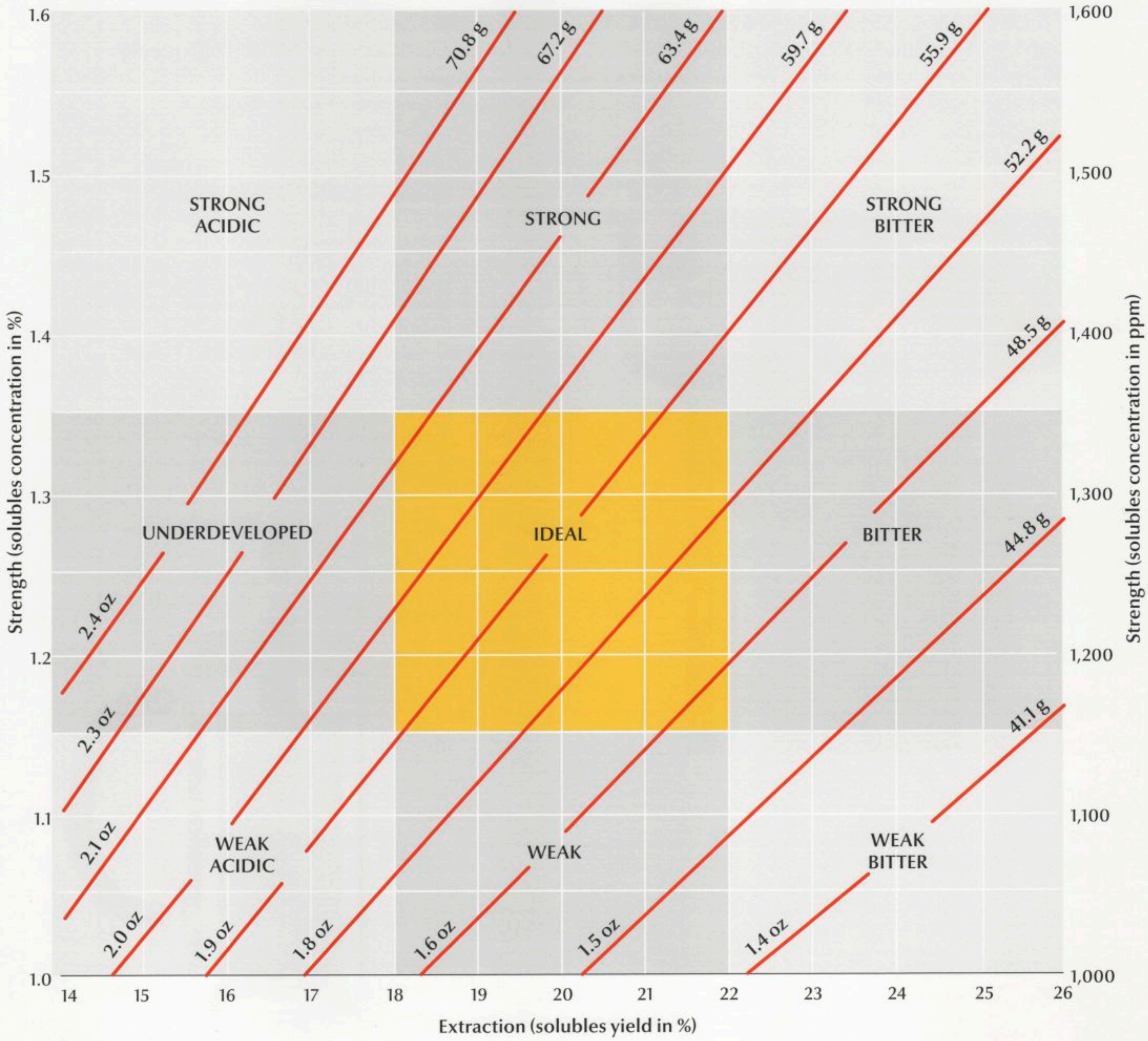


The MojoToGo is an iPhone application made by VST Incorporated that converts a refractive index reading from their digital refractometer into a measurement of solubles yield. When combined with the weight of the dose and the brewing water, the software automatically calculates where you are on the brewing control chart. More information is available at vstapps.com.

6 **Adjust dosage, grind size, or brewing time as needed.** Your goal is to move the intersection point for the brew into the ideal zone. If your coffee maker does not allow adjustments to brewing time, change the fineness of the grind and the dose of coffee. Using a finer grind will move the brew horizontally from underdeveloped toward more bitter coffee and will also increase strength somewhat. Using a coarser grind will move the brew horizontally from bitter toward sour coffee and somewhat reduced strength. The point is to adjust the grind to reach a balance between these two extremes. Increasing the dose will move the brew up vertically to greater strength, will little effect on extraction. Decreasing the dose will move the brew down vertically, toward weaker coffee. Adjust the dosage as needed for balance. Extending the brew time will move the brew up the diagonal line, toward stronger and less sour coffee. Reducing the brew time will move the brew down the diagonal line, toward weaker and less bitter coffee.

7 **Repeat steps 1–6 as needed.** Adjust only one variable at a time to prevent confusion.

The red lines in the graph below represent brewing ratios, measured in grams of coffee per liter of water or ounces of coffee per quart of water.



MAKING COFFEE

There are many methods for transferring the flavor and character of the coffee bean to the cup; they involve varying degrees of technology and produce a range of coffee styles. Each method has its devotees and its detractors. And each requires some tweaking to obtain the ideal grind, brewing time, water temperature, and ratio of water to coffee grounds.

One of the most important differences among brewing setups is the way in which the liquid is filtered from the spent grounds. Metal filters allow dissolved solids, droplets of oils, and any suspended solids finer than the holes in the filter to pass through. They tend to yield a full-flavored, full-bodied brew. Paper filters, in contrast, tend to hold back anything that isn't dissolved, so they produce a leaner (some say cleaner) extraction. Cloth filters, sometimes used with vacuum brewers, fall somewhere in the middle.

Weigh the grounds and the water before brewing to achieve consistent results—it doesn't take much variation in the dose (the ratio of these weights) to alter the brew perceptibly. A good starting point is 55 g / 1.9 oz of grounds for each 1,000 g / 35.3 oz of water, but you'll probably want to make slight adjustments (see How to Use a Brewing Control Chart, previous page). Fine-tune the brew by increasing the dose for stronger coffee and decreasing it for weaker coffee. If the coffee tastes bitter, use a coarser grind, and grind the beans more finely if it tastes sour. Once it's close to perfect, adjust the brewing time: shorter for a slightly weaker but less bitter brew, longer for a slightly stronger but less sour cup.

Experts generally agree that the brewing temperature for most styles of brewed coffee should be 91–96 °C / 196–205 °F; in most cases, our preference is 93 °C / 199 °F.

Automatic drip coffee maker

Since Mr. Coffee was introduced in 1972, this handy device has changed little and remains the most popular method for making coffee just about everywhere. Some of the programmable machines available today come with built-in grinders. Models with a glass carafe and a heated base can vaporize the most aromatic volatiles, leaving the coffee with an unbalanced harsh flavor if the coffee lingers too long or gets too hot. To avoid this problem, transfer the fresh-brewed coffee into a thermos.

The coffee should be a medium grind. If using a paper filter, prerinse it with hot water. Even more important, let the coffee "bloom" before it is fully brewed. To do this, stop the brewing as soon as the grounds are wetted through. Let them swell with water for 30–45 s, and then continue the brewing. This improves the evenness of extraction through the bed of coffee grounds.

French press

A French press brewer uses a mesh-lined plunger to push grounds to the bottom after they have steeped, leaving the coffee above ready to pour directly from the container. Many traditionalists consider French press coffee second only to the rich flavor of espresso. More recently, coffee fanatics have started to defect to other devices, such as the AeroPress. Use coarse grounds. Sifting them to remove the fine grounds will improve the clarity of the coffee and give it a less muddy mouthfeel. Add the grounds first, and then pour hot water over them, and let the mixture steep 30–45 s before stirring gently. Wait 4 min, and then depress the plunger slowly, and serve.

Pour-over, Melitta, and Chemex brewers

These three variations all work essentially the same way. A cone-shaped filter holder made of ceramic, glass, or plastic sits atop an individual cup or a serving pot to produce quick drip coffee on the spot. Simply insert the filter paper, and then pour through enough hot water to warm the holder and rinse the paper. Add the grounds, and pour just enough hot water to wet them, and then wait 30–45 s to the let coffee bloom. Pour the remaining hot water over the grounds in a spiral from the center outward to help disperse the water evenly over the grounds. When all of the water has nearly filtered through, give the grounds a gentle stir to finish the extraction, and serve.

Vacuum brewer

All the rage in the early 20th century, vacuum brewing was ultimately displaced by electric drip brewing. A recent resurgence in its popularity is under way, however, among coffee connoisseurs who claim that these brewers deliver clean, crisp, vivid results. In a vacuum brewer, steam pressure pushes hot water into the upper chamber, which holds the grounds. As the heat subsides, the higher pressure in the upper chamber combines with a partial vacuum in the lower chamber to force the coffee through a filter. Use a medium to coarse grind; take care not to compress or clump the grounds. Set a timer for 2 min as soon as the water starts to rise. Stir the grounds gently when the chamber has filled. When the timer sounds, remove from the heat, wait for the coffee to flow into the lower chamber, and serve.

Steam forming in the lower chamber raises the pressure, which forces hot water up through the siphon tube to the upper chamber

The hot water steeps with ground coffee in the upper portion

Once the heat is off, steam recondenses in the lower chamber, thus creating a partial vacuum. Now the pressure is higher in the upper chamber, so the brewed coffee is forced back down through the filter-topped spout into the lower chamber, where it is ready to drink.

AeroPress

This modern coffee maker works rather like an upside-down French press, but it has drawn the praise of coffee experts as being perhaps the best way to make a non-espresso coffee. A plunger uses air pressure to force hot water down through a bed of coffee, which sits on top of a filter. The pressure of the water is controlled by how hard you push the plunger. A very fine filter pad retains suspended particles as the brewed coffee is forced through. The manufacturer recommends using a lower water temperature of 80 °C / 176 °F to reduce the extraction of bitter compounds and produce a sweeter finish. To use the AeroPress, install the filter, and rinse the device with hot water. Add about 20 g of finely ground coffee, place over a sturdy mug, and fill to the top with hot water. Stir at moderate speed for 10–12 seconds. Slowly push the plunger to expel the coffee until the grounds are gently compacted, or until you hear a hissing sound.

The AeroPress was invented in 2005 by veteran toy inventor Alan Adler, who also invented the Aerobie flying ring. The AeroPress has become very popular with top coffee fanatics. There is even an annual world championship of AeroPress coffee making.

Cold-extraction system

High temperature is not needed to brew coffee—as long as you are willing to wait overnight. The manufacturer of the popular Toddy system for cold extraction claims that it yields a brew that is less acidic, sweeter, and mellower than coffee made by conventional methods. That is plausible, because many of the tart acidic and biting bitter compounds in coffee beans dissolve only partially in very cold water. The flavor profile of cold-extracted coffee is also unique because the ratio of grounds to water is much higher than it is in hot-brewed coffee: Toddy recommends using 225 g / 8 oz of medium-grind coffee for each 1,000 g / 35.3 oz of ice-cold water. The mixture should slowly filter for 12 h while refrigerated.

Because the aroma compounds extracted by this cold process are less volatile, the coffee concentrate keeps well for up to two weeks when refrigerated. It is diluted with three parts hot water for each one part concentrate before serving. Other mixing ratios yield denser, espresso-like drinks, and dilution with hot milk can produce café au lait. Cold extraction is ideal when the coffee is to be used as an ingredients, such as when making coffee ice cream.

THE TECHNIQUE OF

Cooking with Coffee

Water isn't the only vehicle for conveying coffee's character once it leaves the bean. You can also make coffee in alcohol or oil. Coffee made this way isn't so good for drinking, but it can have interesting culinary applications.

Coffee extracted into alcohol, for example, makes a useful ingredient for crafting cocktails. It can also be a good way to add a small amount of coffee aroma to a sauce without adding bitterness. Most of the bitter compounds aren't extracted if pure ethanol (such as Everclear) is used. The resulting concentrate is analogous to vanilla extract.

You can also make coffee using a mixture of water and alcohol to get a bit (if not the best) of both worlds: the pure, smooth character that alcohol attracts, plus the extra taste compounds that water draws from the coffee. Vodka, a pure neutral spirit diluted with water, is a great candidate for this approach.

If you use a pure fat, such as a neutral cooking oil or clarified butter, to make coffee, only the fat-soluble aroma compounds in the beans will be captured. That does include most of the aromas, but it carries none of the compounds that contribute to taste. In certain cases, that may be what you're after. But again, you can achieve more of a balance by adding some water to the mix—melted unclarified butter or heavy cream both contain plenty of water, for example. Consider the intensity of flavor you can gain by infusing freshly crushed coffee beans in cream for a batch of ice cream.

Although some cooks add espresso itself to their recipes, in our opinion this is not the best way to infuse coffee flavor. Espresso is extracted at higher pressure than coffee brewed other ways, and this makes the compounds drawn off the beans more volatile. As a result, they dissipate quickly, which is why it's so important that a shot of espresso be served immediately. Unfortunately, by the time you have integrated espresso into a dish and completed the cooking or preparation, the peak flavor of the coffee is lost.

Cold extraction (see previous page) is our favorite way to make coffee for use as an ingredient in cooking. A different approach to incorporating coffee flavor in food is to use commercial instant espresso powder. It can even be used dry, in a spice rub for a steak, for example.

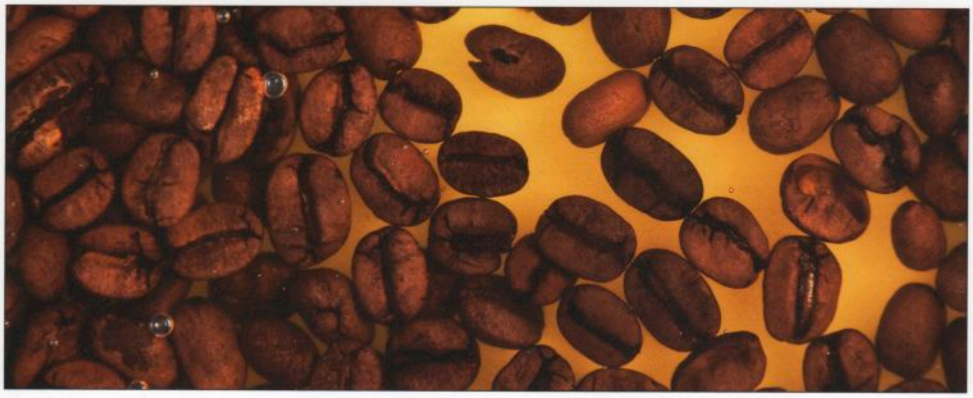
EXAMPLE RECIPE

COFFEE BUTTER

Yields 125 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Roasted coffee beans	175 g	100%	① Seal together in mason jar.
Unsalted butter	125 g	71%	② Boil for 4 h. Or, vacuum seal mixture, and cook sous vide in 90 °C / 194 °F bath for 4 h.
			③ Refrigerate.

(2010)



For more on extracting flavors using butter and other fats, see page 2·328. You might think that extraction in this coffee butter would be more effective if the coffee were ground. It would be, but unfortunately, that makes the flavor unbalanced, so we prefer whole beans here.

ESPRESSO

Hand-operated espresso machines have used the same approach for more than 100 years. Modern machines with pressure sensors and electric pumps offer much more reliable pressure and thus better shots.

The romantic ideal of espresso often evokes an image of artists, writers, and philosophers in centuries past sipping the dark, rich, exotic beverage in elegant European cafés. But the surprising truth is that espresso is an innovation of the early 20th century (see Espresso's Invention, below). In fact, espresso is one of the first examples of fast food—its very name means speed!

Of all the methods for making coffee, espresso inspires the most passion, scientific interlocution, and artistic interpretation. The scrutiny of international barista championships and the detailed, opinionated discussions in online coffee forums are just two indications of the emotion that espresso elicits.

In Italy, espresso is the national beverage (see The Special Role of Espresso in Italy, page 374), and anywhere in the world, espresso has a mystique for the average consumer. Just a few decades ago, it was nearly impossible to get decent espresso in New York City. The growth of Starbucks has brought espresso to the countries that never knew it, changing the coffee-drinking habits of millions of people. Unfortunately, the quality of coffee that you get at great restaurants is still quite poor. You can buy better espresso from street carts in Seattle than you can get at most Michelin three-star restaurants.

To make espresso, hot water is forced under pressure through a firm puck, or bed, of finely ground coffee. The water extracts, and suspends flavorful compounds as it moves through the puck. Amazingly, tiny variations in the size of the coffee particles in the grind can make an enormous difference in the quality of the espresso.

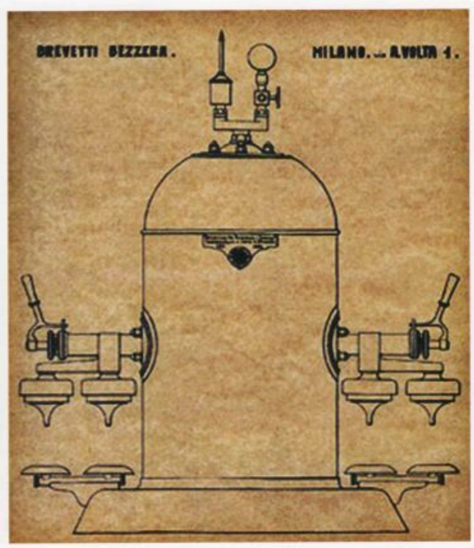
Many other subtle factors are also at work in each shot of espresso: the gauge pressure (8–10 bar / 116–145 psi), the water temperature (85–96 °C / 185–205 °F), the amount of ground coffee (7–21 g / ¼–¾ oz), the duration of extraction (18–35 s), and the volume of liquid produced (15–45 ml / ½–1½ oz). The main function of a good espresso machine is to keep the pressure and temperature absolutely consistent from shot to shot. That turns out to be harder than it sounds, and much of what makes a top-ranked machine like a Synesso worth its premium

THE HISTORY OF

Espresso's Invention

It will surprise many coffee lovers to learn that coffee made in the espresso fashion is not a centuries-old beverage that has been sipped on Italian piazzas for countless generations. Instead, it is a coffee-making method that was invented in 1901, the fast-food innovation of its time. Luigi Bezzera was a businessman who created the first known machine to force, by pressure, steam and hot water through ground coffee into an individual cup so that each customer could have the freshest possible brew in the fastest (*espresso* in Italian) possible way.

Bezzera's patent was purchased in 1905 by Desiderio Pavoni, who first made alterations to the original machine. Innovations continued over the years, refining the original Bezzera design to better control levels of pressure and temperature. By the mid-1900s, there were espresso systems in use that resemble many machines on the market today.



Bezzera's original patent illustration.

The "tiger stripe" phase of a perfect espresso pour emerges from a "crotch-less" portafilter (see page 385).

price are features aimed squarely at shot-to-shot consistency.

The same is true for much of the rest of what a barista does: the aim is to achieve consistent performance from shot to shot. There is little point in learning how to make a great shot if you can't repeat the trick over and over. Detailed procedures for grinding, grooming, and tamping have been developed to help ensure consistency.

Typically, the pressure is set to a standard value—we use a gauge pressure of 9 bar / 130 psi. The temperature, meanwhile, must be adjusted for different coffees—we generally use 95 °C / 203 °F as a starting point and then experiment to find how different temperatures affect a particular blend and roast. The effects can be quite dramatic.

The biggest variables in drawing a shot are the size of the grind and the duration of the shot. Adjusting the grind and deciding when to stop the shot have an enormous impact on quality. Learning how to do this properly is what makes a great barista.

Because the espresso procedure tends to amplify the distinct character of the beans both for good and for bad, roasters generally use a blend of beans from different sources. Further, the beans might also be roasted to different degrees, bringing out various levels of fruity, floral, spicy, earthy, or other flavors. In the manner that vintners blend wine grapes, baristas blend coffees to balance the best qualities of individual beans—aroma, taste, richness, and body—and to create a perfect flavor that is nearly impossible to achieve from a single source of beans.

For the best results, you need to optimize the temperature settings for each kind of coffee. This is especially true for decaffeinated coffees, which usually require different temperature and grind settings than conventional coffees do.

THE SOCIOLOGY OF

The Special Role of Espresso in Italy

There is no doubt that Italians have a heightened appreciation for espresso, but for them it is a simple fact of daily life. Espresso is a part of the social fabric of the country, a convivial means to the end of lingering at the table with friends. It's not considered precious, a luxury, or an upper-class indulgence. A passable cup of espresso is something that every corner café in Italy can produce.

Espresso is so fundamental in Italy that a national law regulates its cost if you consume it standing at a bar! If you sit down, you pay the unregulated price, which can be many times more.

It is a myth that espresso in Italy is always great. While espresso is omnipresent, much of it is far from excellent. In part this is cultural; many Italians view espresso in the same way that a basic cup of coffee is viewed in other parts of the world—as nothing special. Consistency is as much a challenge in Italy as in any other part of the world. Beans roasted in Milan are quite different from those roasted in Sicily, and Italian baristas vary in skill just as they do everywhere.

The most highly regarded espresso place in Italy is likely Sant'Eustachio Il Caffè in Rome. As Seattle natives, we find it interesting to compare Espresso Vivace in Seattle with Sant'Eustachio. Coffee cognoscenti rate them both excellent. At Sant'Eustachio, they've installed an aluminum screen to make it impossible to see what the barista is doing; they view it as a trade secret. At Espresso Vivace, in contrast, owner David Schomer is nothing if not generous in sharing espresso-making insights. He even posts signs in the shop that tell you exactly what pressure and temperature they are using! Both cafés have excellent espresso, but they serve it with totally different attitudes toward sharing knowledge.

The menu at Espresso Vivace in Seattle updates customers on the pressures and temperatures the baristas are using to make their espresso drinks, along with the dates on which they started using them.

THE PLEASURE OF

My First God Shot

Baristas and coffee lovers call the perfect shot of espresso a God shot. They can wax lyrical and poetic about God shots, so much so that it can seem over the top. When I (Nathan) first heard the term, I thought: Could a cup of coffee really be that good? What's wrong with these people?

I liked espresso well enough that I sought out David Schomer (see page 399) for training in the intricate art of espresso making. Still, I rolled my eyes at the florid language I heard coffee fanatics using to describe God shots. "C'mon, people, be serious," I thought.

Then one day at the Coffee Fest trade show in Seattle, a barista named Daniel Humphries of Victrola Coffee pulled me a shot of their Streamline roast in one of the earliest Synesso machines.

It was like nothing else I have ever tasted, a phenomenal and complex layering of flavors. Yes, it was coffee, but with a richness and complexity unlike those of any coffee I'd had before—unlike anything else I'd ever tasted, for that matter. That brief moment (it was only a double shot, drunk neat, so it didn't last very long) equalled or exceeded any food or drink experience I have ever had. I walked around the rest of the day haunted by that taste; it was with me for hours.

I'd had my first God shot.

Of course I now feel foolish for doubting that God shots exist. Yes, the language used by coffee lovers to describe them is over the top, but that's because the experience itself is, too.

What was it about that shot? Daniel told me he'd almost dumped it instead of serving it to me, because the pour was a little short (meaning he had stopped it earlier than he would have liked). He has made me hundreds of shots since then, and they've been good, but not like that one. I have had a couple of other God shots over the years, but—like any first love—the shot that day at Coffee Fest affected me more profoundly than any since.

It's maddening that even with the best equipment, the best coffee, and a trained barista, God shots are rare. As each small part of the puzzle comes into place, we learn a bit better how to control the coffee-making process. Achieving precise temperatures with **proportional, integral, and derivative (PID) controllers** (see page 1·271) surely helps, as do pressure-controlled tamping and the like. Pressure profiling (see page 400) is likely the next step in this quest. Someday we may have all the variables controlled, so that every shot can be a God shot. You can debate whether that will take the romance out of coffee, but it certainly will make it easier for more people to experience this wondrous phenomenon.

As with extraction temperature, the grind typically should be optimized for each different coffee, and decaffeinated coffee almost always requires a different than regular coffee beans do.

There is, however, a growing following for single-origin coffees. Although roasters certainly define their style and personality with signature blends that become standards for their regular customers, they more frequently offer special selections of coffees from one specific farm or region. As with a single varietal wine, it can be trickier to create an outstanding beverage working with one single product, particularly when making espresso, which is less forgiving than other brewing methods. But done well, it makes that product shine with an individual flavor distinct to its place of origin.

The Grind

The first step in transforming a roasted bean into a cup of coffee is the grind. In general practice, the grind is the barista's most important tool for changing the quality of the coffee. A good barista constantly adjusts the grind because the ambient temperature and humidity, the temperature of the grinder, and other factors affect it.

Grinding coffee beans for drip or French press coffee or other nonespresso brewing techniques is simple because those brewing methods allow plenty of water to contact the coffee over a long period of time (12 h for cold-brewing but 3–4 min for the other methods). Under those conditions, the size of the grind does not matter much. If you are using a French press, for example, you want the coffee to be coarse enough that it doesn't slip through the filter. If the grind is way too fine, you might get a muddy result—a too coarse grind is also problematic. But changing the grind size by a couple clicks will not make much of a difference. It helps to grind right before you brew, but the details of grinding don't affect the flavor of the resulting coffee anywhere near the way they do for espresso.

Espresso is different because the hot water is forced under pressure through the ground coffee. If the coffee is ground coarsely, lots of channels remain open for the hot water to go through, which

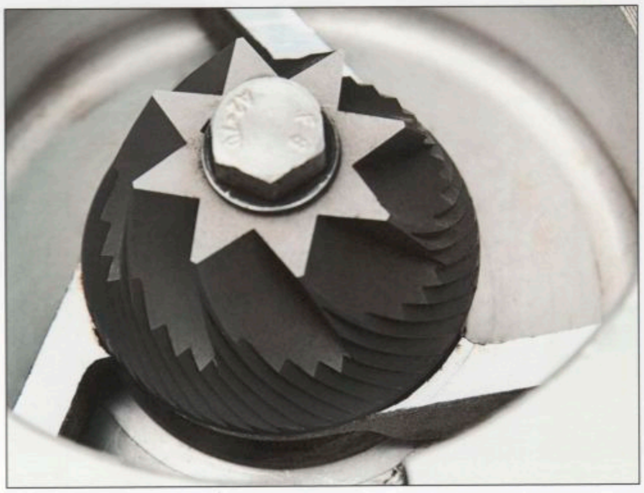
THE TECHNOLOGY OF

Burr Grinders

Blade grinders frenetically chop the living daylights out of coffee beans. Burr grinders instead shatter the beans in a more deliberate manner. An upper compartment releases whole beans into a space lined with two pieces of sturdy metal with evenly spaced shallow notches—the burrs. When one piece rotates, the burrs act as cutters, grinding the beans.

There are two types of burr grinders: conical and flat. Most coffee grinders use the conical variety. To regulate the coarseness of the grind, the spacing between the pieces of metal is increased or decreased.

The sharp notches of a burr grinder grow dull over time; the burrs should be refurbished or replaced as needed. Keeping them sharp prevents both inaccuracy in grind size and futile compression of the bean fragments, which can heat them and harm the quality of the coffee. Even the best grinder with the sharpest burrs can build up heat over time, particularly in a busy establishment. David Schomer of Espresso Vivace (see page 399) started the practice of modifying commercial grinders to use cooling fans to keep the temperature consistent during heavy use.



The burr is narrow at one end and has a wide base at the other. Whole beans first strike the burr at the narrow end, which has coarse teeth. As the burr widens, its teeth become progressively finer.

HOW TO Grind Beans for Espresso

Brewing espresso is the most technical of all coffee brewing methods. A good espresso demands proper management—all at the same time—of temperature, pressure, and water flow, none of which can happen correctly unless the coffee itself has the right consistency. Thus, it all begins with the right grind.

Beans should be ground to order for maximum flavor. Use a burr grinder, rather than a blade grinder, to keep the particle sizes as uniform as possible. Because espresso is extracted so quickly, the coffee must be ground finely.

1 **Pour the beans into the grinder.**

2 **Select a grind setting.** The grind should be chosen so that a fixed weight of grounds (the dose) will brew in an appropriate amount of time and yield the correct shot volume with balanced flavor.

3 **Verify the grind based on how the shot pulls.** You may need to adjust the grind if the shot pulls too quickly or too slowly for the chosen dose size. If the shot pulls too fast, adjust for a finer grind; if it is too slow, use a coarser grind. Make adjustments to the grind while keeping the weight of the grounds used constant. The grind must be adjusted throughout the day because differences in ambient temperature and humidity can affect the results.

4 **Set the dosing timer (optional).** Use a scale and a stopwatch to determine how long it takes to grind the correct dose weight, and then set the timer to this value.

5 **Make small adjustments to the grind setting as necessary.** This compensates for the changing conditions of the grinder and the beans throughout the day. Bigger adjustments are typically needed when switching to beans of different age or roasting level. If you are using a dosing timer, recalibrate and reset it after each adjustment.

6 **Brush the grinder clean daily.** On some grinders, the upper burr can be removed for better access to the lower burrs. Use a clean, dry brush to remove residues. Also clean the feeder channel to ensure that nothing impedes the flow of beans into the grinder. Clean the hopper periodically to remove coffee oils, which go rancid over time.

Common Problems with Grinding

Overly coarse grounds cause the coffee to be extracted too quickly, underextracting the espresso and producing a pale-colored, very sour shot.

Overly fine grounds cause the coffee to be extracted too slowly, overextracting the espresso and producing a bitter shot.

Clumping indicates the burrs are either too hot or are becoming dull and should be refurbished or replaced. Clumping can allow channels to form within the coffee bed in the portafilter, which makes for uneven extraction.

Excessively uneven particle sizes result in uneven flow and extraction rates. This is a common problem with blade-style grinders.

Dull blades or burrs yield inconsistent results and cause the machine to overheat more frequently.

Coffee grinders have a hopper in which excess ground coffee can be stored. Unfortunately, coffee goes stale very quickly after grinding, so you are better off grinding it to order for each shot.

means the water goes through fast and the effective pressure is low. If the coffee is very fine, then it is much harder for the water to find its way through. The effective water pressure is higher, and the contact time between the water and the coffee is lengthened, changing the flavor of the resulting shot enormously. For espresso, a couple of clicks on the grinding adjustment ring make all the difference in the world.

One of the main reasons that most espresso machines use a standard pressure is that the pressure regulator of the pump doesn't really determine the pressure—the grind does. Grooming and tamping also matter, but the aim with them is to pack the ground coffee consistently; it is the grind that makes the difference.

Good baristas are thus constantly adjusting the grind size. Most will make several shots in the morning to dial in the machine for the day. Further adjustments are needed depending on how the shots come out. During heavy use, the grinder will almost certainly need adjustment because heat causes the burr to expand, which changes the grind size. One of the many innovations that David Schomer brought to espresso was modifying his grinders by adding cooling fans to keep the burrs at a constant temperature. This makes a big difference in a coffee shop or restaurant but probably is not an issue for a home machine.

The ambient temperature in the room also matters. Humidity affects the coffee indirectly, mostly by changing how the ground coffee clumps together during packing. That is another reason a barista needs to keep an eye on how the shots pull and adjust the grind as needed throughout the day.

The quality of your grinder has very important consequences for the quality of your final coffee; it is a widely underappreciated factor. Blade grinders, which are the cheapest type, have poor consistency and produce a wide range of particle sizes. Burr grinders are much better (see page 376), but even they vary between the highest quality machines and cheaper versions.

Dispensing and Dosing

Dosing is the process of putting the right amount of ground coffee in the metal **portafilter** basket. As simple a task as that may seem, it can make or break the consistency with which espresso is made.

With each pull of the grinder's dosing handle, take care to distribute the grounds evenly across the basket. Even small variations in the weight of the dose can change the flow rate during extraction enough to make shots inconsistent. And uneven distribution of coffee across the portafilters causes uneven extraction and thus poor flavor. The ability to achieve both a consistent dosing weight and an even distribution of the coffee grounds is arguably the most important skill for a barista to hone.

As the ground coffee enters the basket, keep it moving constantly beneath the grinder's dispenser. Spread the coffee in an even layer, or, alternatively, build up evenly spaced mounds in the basket and rotate the filter as each pile builds up until the basket is filled with the appropriate

Consistency comes from doing the same thing every time. Achieving this begins with correctly dosing the same amount of coffee into the portafilter for every shot.

THE EVOLUTION OF

Single, Double, and Triple Shots

The Italian dosing standard for a *normale* single shot is typically 7 g / ¼ oz of ground coffee, which produces 14 g / ½ oz of espresso in the cup. The weight of espresso to the weight of the ground coffee used to make it is a ratio of 2:1. In Italy, a *ristretto,* a *lungo,* and a *caffè crema* all use the same dosage of ground coffee as a single *normale,* but the weight of the resulting coffee varies. A *ristretto* is typically half the weight of a *normale,* a *lungo* is one and a half times that weight, and a *caffè crema* is a very long pull of espresso, often two to three times the weight of a standard shot. Weight is a better measure than shot volume because the volume depends on how foamy the crema is, which can vary with many factors. Even so, many baristas use 1 oz whiskey shot glasses to judge shot size by volume.

In other places, espresso is made with a greater variety of dose and shot sizes. But many well-regarded espresso cafés now dose their standard single shots as a *double ristretto,* which means that they use a dose of 14 g / ½ oz—or even an overdose, with slightly more grounds—to brew 14 g / ½ oz of espresso. This is the dosing we prefer. It produces about the same amount of espresso in the cup as a traditional Italian *normale,* but it uses twice the weight of coffee beans to do it (see brewing ratio in chart below).

Different shot sizes are distinct products that have very different tastes. A *lungo* is much more bitter than a *normale,* which is in turn more bitter than a *ristretto* because different compounds are extracted over time and appear later in the espresso stream (see page 386). A *ristretto* is generally more brightly flavored and has more acidity because acids tend to come early in the stream.

The popularity of *ristretto*-style shots has had a ripple effect on how espresso is brewed. The larger dose of ground coffee absorbs more heat from the brewing water, causing a greater decrease in the extraction temperature when the shot is pulled; as a result, baristas have increased the brewing temperature by a few degrees to offset this effect. To get the proper shot dosing, they adjust the length of time for pulling a shot, the coarseness of the grind, and sometimes the pump water pressure.

Automatic machines have preset buttons that time or meter the amount of water put through the portafilter. The meters are very good at getting consistent shot weight, but most serious baristas do not use them because the baristas ultimately care more about shot quality than weight.

Instead, talented baristas use color and flow characteristics to judge when to stop a shot. Weighing shots and timing how long they take to pull can get you in the ballpark, but the ultimate decision should be visual.

Style	Basket size	Coffee grounds (g)	Shot volume, including crema (ml)	(oz)	Shot weight (g)	Brewing ratio (water:coffee)
ristretto	single	7	15	0.5	7	1:1
	double	14	30	1	14	
	triple	21	45	1.5	21	
normale	single	7	30	1	14	2:1
	double	14	60	2	28	
	triple	21	90	3	42	
lungo	single	7	45	1.5	21	3:1
	double	14	90	3	42	
	triple	21	135	4.5	63	
caffè crema	single	7	105	3.5	49	7:1
	double	14	210	7	98	
	triple	21	315	10	147	

dose. However you fill the basket, avoid favoring one section over another, because this will result in a more compacted region of grounds, even if you later groom them properly.

How full should the basket get? There's no single answer; it depends on the **dose standard,** which in turn depends on the size of the basket—single, double, or triple—and the style of the shot desired (see Single, Double, and Triple Shots, previous page). Whatever the target dose weight, the challenge is always to hit that target consistently. Missing it by as little as half a gram can have a sizable impact on the resulting coffee.

In practice, the best strategy for judging the proper dosing level for the basket is to use a scale, at least initially. Tare the portafilter, with its basket in place, on a scale accurate to a half-gram or better, and then slightly overfill the basket with grounds. **Groom** the surface to level the grounds (see next page), and then reweigh the filled portafilter to measure the weight of the grounds. It will almost certainly be slightly over the target weight, so groom further to reach the target weight.

Tamp the grounds and pull a shot to a specific volume or, preferably, to a target weight. As we discuss later in this chapter, you can judge from how the shot flows whether you need to adjust the grind. In general, coarsen the grind to correct for a shot that pulls too slowly and tighten it to correct for a fast-flowing shot. Repeat this process after each adjustment to the grind. Once the grinder is "dialed in," a skilled barista can judge the volume of grounds needed for the correct dose by sight, usually to within half a gram.

For even greater consistency, many baristas (and now manufacturers) have modified their grinders by adding a dosing timer, which lets the machine grind for a set amount of time and then stops it. The idea is to determine how long it takes to grind the correct dose of grounds once the grinder is adjusted and then set the timer to grind for the same length of time for every shot. The dosing timer is recalibrated using a scale and is reset after each grinder adjustment. The timer can help standardize doses from one barista to the next, particularly when the espresso bar gets busy.

Most professional coffee grinders grind the beans into a chamber that holds the ground coffee until it is dosed. Many grinders also include an automatic grinding feature so that more coffee is ground after a certain number of doses have been used, but it is a mistake to pregrind espresso. Grind only what you need for the shot you are making, and use it immediately.

It may not be standard procedure in any espresso bar (yet), but we've played around with some medical technology to help with grooming grounds. Vibration is used by dentists to eliminate bubbles in plaster castings they make of their patients' teeth. We found that when we set the dosed filter of coffee on a dental vibrator tray, the vibration quickly and efficiently settles the grounds down evenly into the filter. A few swipes of the NSEW variety (see next page), and the portafilter has especially even distribution to ensure consistent, even extraction later.

HOW TO Groom a Portafilter

An even, compact bed of coffee is crucial to good espresso, yet filling the portafilter correctly is often not given the attention it deserves. Make sure the grounds are evenly spaced and properly leveled. Don't cut corners on the grooming in the hope that good tamping will make up for it. There are no shortcuts here.

1 **Groom north.** Starting at the middle, push your finger across the coffee toward the top (north) edge, shifting the surface grounds toward the edge without pushing them over.

2 **Groom south.** Pull the mound of grounds from the north edge toward the bottom (south) edge, again without pulling them over the edge.

3 **Groom east.** Draw your finger to shift the mound to the right (east).

4 **Groom west.** Move the mound to the left (west), and then sweep any excess grounds over an edge with your finger. The surface should be smooth and level, with no gaps between the bed and the basket and no irregularities in the surface.

Whatever technique you use to groom your espresso dose, be careful not to pull the grounds away from the edges of the portafilter. This will create a gap that the high-pressure brewing water will channel through, resulting in a poor shot of espresso.

HOW TO Tamp Evenly

Several kinds of tampers work well. The traditional tamper has a milled aluminum head, which should fit tightly in the basket of the portafilter. Note that you may need a different tamper for a single, double, or triple basket. Some tampers have an absolutely flat face; others are slightly convex, and some are grooved.

As with so many other aspects of this process, there are baristas who swear by, and those who swear at, each of these. Alternatively, you can use an auto-tamp (see photograph on next page), which uses an arbor press to keep the tamping perfectly vertical. It also uses a spring to measure the precise tamping pressure.

1 **Apply even pressure to the grounds.** Creating a flat surface on the grounds is critical for good extraction. So hold the portafilter parallel to the floor with your arm bent at a right angle. Make sure that the portafilter is firmly stabilized on the counter; don't hold it out in the air.

2 **Press firmly to set the bed.**

3 **Raise the tamper (not shown).** Gently twist the portafilter to the side as you lift the tamper to prevent any coffee from sticking. Avoid rocking the tamper from side to side, as this will create dips at the edges and a mound in the center.

4 **At this stage, some baristas tap the portafilter sharply on the side before the second tamping.** They argue that this causes the coffee to settle. Others swear that you must never do this, for fear of causing a channel at the sides.

5 **Press down again with increased force (optional).** Some experts recommend ideal tamping forces ranging from 130–180 N / 14–18 kg / 30–40 lb, while other experts think that anything beyond creating a well-compacted bed of grounds is unnecessary. Consistency of pressure and a level surface matter more than the absolute amount of force used. Finish the tamp with a quarter turn (or two) of the tamper, using much less force to "polish" the top.

Grooming

You have appropriately ground and carefully dispersed your coffee, so now you're ready to pull an espresso shot, right? Not yet. First you must groom the coffee, and then tamp it. Grooming removes excess grounds to finalize the dosage. It also levels the surface of the grounds so that tamping can compact them evenly.

Several methods of grooming are commonly used. The easiest—and the best if your tamper is slightly too small for your basket—is the NSEW technique, named after the points of the compass (see How to Groom a Portafilter, page 381). The drawback to the NSEW approach is that it demands near-perfect consistency in dosing the grounds. Although the end result may look the same, a larger dose of grounds groomed this way will always create a denser bed of grounds after grooming than a smaller dose will, so it is easy to get inconsistent shots.

Stockfleth's method requires a bit more finesse, but when done right, it achieves more consistent results and is less sensitive to irregular dosing. Begin by slightly overfilling the basket relative to the desired dose. Then hold the portafilter in front of you with your elbow turned out as far as possible. Turn your other elbow out as far as possible, too, and rest the web between your thumb and forefinger on the edge of the basket. Finally, simultaneously rotate both elbows inward while keeping the portafilter and your hand level. When done right, the extra grounds rotate around the center of the basket, evenly filling it out. Repeat the motion a few times until the basket is evenly filled. Remove the small mound of remaining grounds with the gentle swoop of an outstretched finger.

To fight clumpy coffee—the telltale sign of a poor-quality grinder—you can use the **Weiss Distribution Technique** (known as WDT). It's time consuming, so not suitable for busy baristas. When dosing, add coffee to the filter through a large "funnel" (John Weiss' original recommendation is a small yogurt container with its bottom cut out), which remains in the filter. Then stir the grounds with a narrow implement, such as a bamboo skewer or long needle, which distributes them evenly and eliminates any clumps. Remove the funnel, and groom the grounds further using the NSEW or Stockfleth's technique.

A poor grooming habit for coffee is a single swipe of a finger across the top of the filter. That may produce level-looking coffee, but it's simply pushing all excess grounds toward one side of the filter and opening up gaps in the grounds at the other side. When tamped, the coffee surface will remain uneven, resulting in uneven extraction because the high-pressure water will flow through these channels of least resistance.

Tamping

With the coffee ground, dosed, and groomed, it's time to **tamp**. This step completes the creation of a compact and level bed of properly dosed and dispersed coffee grounds, through which the pressurized hot water will pass evenly at the right rate to produce a cup of espresso with ideal extraction. The most important thing to achieve is a compacted bed of coffee with an even and level surface. It takes 130–180 N / 14–18 kg / 30–40 lb of force to achieve this.

There are two reasons to care about the force used to tamp. The first is that consistency is everything, so doing the same thing every time is of primary importance. It is easier to be consistent if you know the absolute value you are trying to achieve. Tampers with built-in force gauges are excellent for teaching and for maintaining consistency.

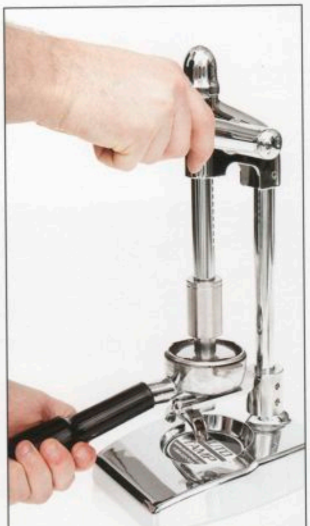
The other reason to tamp hard is that it forces the coffee into a consistent state. Static electricity and humidity both cause ground coffee grains to stick to each other and clump. Tamping with a consistent force pushes the ground coffee into more or less the same density state.

It is very important that the tamped surface be level and even, which is more important than the actual tamping force. Be sure not to tilt the tamper while using it.

It is also important that your tamper fit snugly in the basket. There is an obvious problem if it is too large, but too small is no better. If the tamper doesn't fit snugly, it won't compress the edges. Water will flow through loose channels at the periphery and will cause uneven extraction.

The problem is not with the tamper: most are precision-milled to the proper diameter (58 mm / 2¼ in for a standard single or double basket). Rather, it's that the diameters of inexpensively

A tamper with a built-in force gauge makes an audible click. This is much more accurate than judging the tamping by feel.



The auto-tamp includes a built-in gauge that clicks when the appropriate force has been applied. That feature makes it easier to apply the same pressure each time, which otherwise takes some practice. A frame also ensures that the tamping pressure is always directly vertical and never skewed.

Many baristas pull a shot into a whiskey shot glass and then pour it into the serving cup. In general, this is a bad practice: it gives you something else to clean, and it leaves some of the coffee in the shot glass. A much better method is to pull a shot directly into the serving cup.

made baskets tend to vary a lot. By some accounts, baskets of supposedly the same size can have diameters that vary by as much as 2 mm / 1⁄16 in.

The solution is simple. Buy several baskets, and find one that fits your tamper perfectly. Ideally, if the basket is held the least bit crooked, the tamper won't fit. Such a tight fit also helps keep the tamper vertical while tamping.

Pulling the Shot

Espresso shots are "pulled," a reference to old-fashioned espresso machines that required the barista to pull hard on a large lever to force hot water through the coffee. These days nearly all machines include an electric pump that supplies the pressure more evenly and consistently than any person can.

Some espresso machines even have an "automatic" brewing option that measures the volume of water flowing to the portafilter and halts the shot after a set volume is reached. Some professional baristas avoid this; others swear by it. The main problem with automatic operation is that the barista can better judge when to stop the shot by its color and rate of flow, which is a direct indication of what is happening with the coffee.

After the coffee is dosed, groomed, and tamped, it is good practice to flush some hot water through the system before putting the portafilter in place. This stabilizes the temperature of the group head and washes out any coffee debris from the last shot. Then the portafilter is locked into place, and brewing begins.

Brewing occurs in either two or three stages. On some machines, the first stage is a **preinfusion** step, in which low-pressure water flows into the basket to fill the headspace above the tamped bed of coffee, wetting the grounds. Some machines skip this step, but most experts agree that preinfusion provides greater consistency from shot to shot, with less of a chance for uneven extraction.

After this step, the pump engages, and the water pressure above the bed of coffee increases to a gauge reading of 8–9 bar / 116–131 psi, effectively compressing the coffee grounds with over 2,200 N / 225 kg / 500 lb of force. This is when the final phase of extraction begins.

The pressurized hot water washes soluble taste and insoluble aroma compounds from the fine grounds of coffee as it percolates through them. These compounds create the distinctive flavor of the espresso. The water also captures and suspends very small, but insoluble, compounds that slightly thicken the liquid and provide the body and mouthfeel of the shot.

Finally, carbon dioxide in the grounds dissolves into the high-pressure water during extraction. The CO_2 creates the crema as the gas comes back out of solution when the liquid leaves the high-pressure portafilter (see Crema on page 388). If all goes well, this entire process is completed 20–30 s after brewing begins.

The flow and appearance of the espresso changes as the shot is pulled. Paying attention to the flow gives the barista some feedback on how well he's done all of the previous steps.

Initially, a hesitant trickle of dark brown liquid

THE IMPORTANCE OF

Water Quality

A cup of coffee is more than 98% water, so it stands to reason that water quality is essential to good coffee. There are several issues to address. City water supplies typically have a small amount of chlorine and may have other dissolved gasses. These are undesirable but are easily removed with a carbon filter.

Dissolved minerals contribute calcium and magnesium ions (see page 1·335), which determine water hardness. This has several effects on the coffee. The first is that minerals in hard water tend to be deposited as a white scale on the boiler and other internal parts of the espresso machine. The harder the water, the more often you'll need to clean the scale off. Hard water can also make coffee taste bad and can affect the pH. You want a neutral pH of 7 for ideal coffee. Standard water-softening filters can help, but some feel that using such filters can lead to bad coffee.

Water that is too soft, such as distilled or deionized water, can also be undesirable. Some people find that reverse osmosis tends to remove too many minerals, so they blend a mixture of RO water with water that has only been carbon-filtered. A water-testing service or your municipal water system can tell you what is in your local water; that is the best starting point for deciding how to improve it.

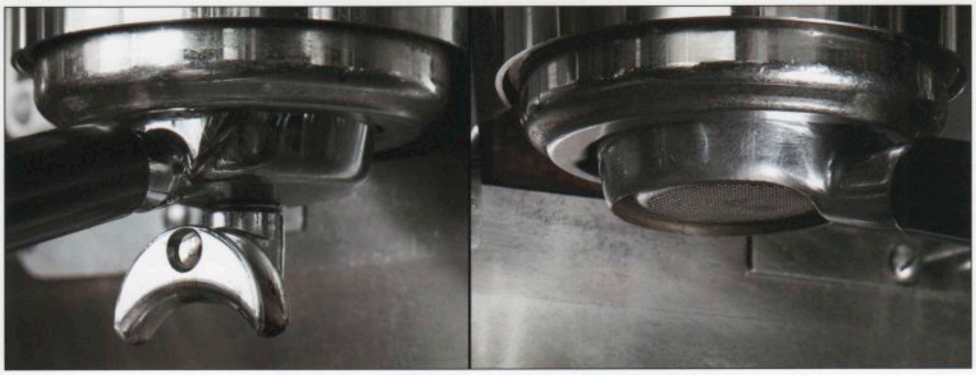
THE ADVANTAGES OF

"Crotchless" Portafilters

When espresso is brewed, the liquid passes through a portafilter. This is the basket with a sturdy handle holding the bed of ground, tamped coffee that is carefully secured onto the espresso machine. Espresso-making convention has long been to use a portafilter that has tapered metal spouts guiding the espresso either directly downward into one cup, or into two cups via ridges separating the streams.

In recent years the crotchless (also called "bottomless" or "naked") portafilter has become a tool of choice for many baristas. The two spigots, or "crotch," of the portafilter is missing. This allows the espresso to flow directly from the filter basket into the cup without passing through another channel of metal, which can affect the quality of the espresso. Baristas get a less adulterated shot, with nothing blocking the crema from its most natural formation.

More important, the barista can see qualities in the espresso and its flow that she might not otherwise notice. A spurting, off-center flow indicates trouble with the pull, groom, or tamp that she can troubleshoot with subsequent pulls. Crotchless portafilters are invaluable for learning how to make a great shot. Crotchless portafilters produce more crema because the frothy crema tends to stick to the inside of the crotch. This affects both the flavor and the appearance of the resulting coffee.



The "crotch" on the bottom of a portafilter refers to the two spouts that, in principle, allow you to make two single shots of espresso at once (at left). By cutting off the crotch, you get the "crotchless" or "naked" portafilter. Because this design lets you see the filter basket directly, it is much easier to diagnose problems.

THE SKILL OF

Choosing a Brewing Temperature

Brewing temperature is a contentious topic among espresso aficionados. To some extent, these settings are a matter of preference influenced by the beans used, the style of roast, and what a person thinks a shot should taste like. But everyone agrees these settings matter, particularly the brewing temperature. Experts also agree that too low a brewing temperature produces sour, underextracted shots, whereas too high a temperature yields overextracted shots that are bitter and acrid.

In general, the larger doses used for popular double and triple *ristrettos* necessitate using a higher brewing temperature. The greater mass of coffee cools the brewing water more during extraction; starting with hotter water offsets this effect. A higher brewing temperature also produces a more full-bodied shot of espresso that stands up to a large quantity of milk. Although these shots tend to be slightly bitter, the milk masks that taste.

Different coffee blends and roasting levels require different temperatures. Decaf coffee, which almost always needs a different temperature from the full caffeine version. When trying a new brand of coffee, it is common to try a range of different temperatures by one-degree increments to find the one that is best for that particular coffee and roast.

High-end machines that have multiple group heads often also have multiple boilers so that you can set a different temperature for each head.

HOW TO Pull an Espresso Shot

1 **Unlock the portafilter with a firm, twisting motion (not shown).** Knock out any old grounds, and wipe the basket clean and dry. Never leave the portafilter out of the group head; a cold portafilter will cool the brewing water and produce sour, underextracted shots.

2 **Grind, dose, groom, and tamp the coffee.** For detailed instructions, see pages 377, 381, and 382.

3 **Flush hot water through the system.** This stabilizes the temperature of all parts. Some machines need only a very brief flush, whereas others require more time.

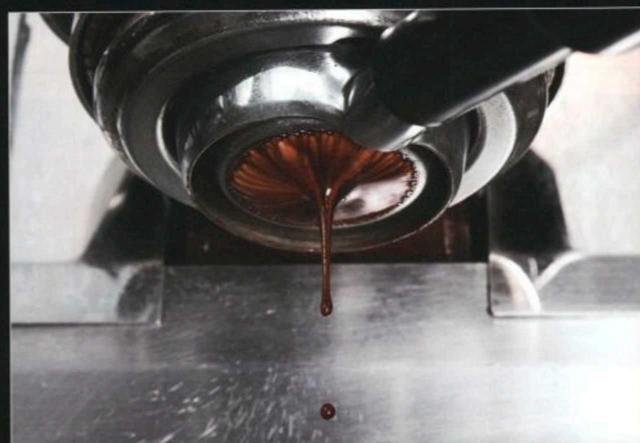
4 **Lock the portafilter in the group head (not shown).** It must be secure to contain a pressure that is eight to nine times that of the atmosphere.

5 **Preinfuse the coffee with low-pressure hot water (optional, not shown).** High-quality espresso machines offer a preinfusion option, which helps ensure even extractions.

6 **Place a warmed cup below the portafilter (not shown).** It's best to pull the shot directly into the container that will be used to serve the coffee.

7 **Engage the pump.** The first drips should appear in 3–5 s for a single basket, and a bit longer for a double basket. Triple baskets can take as long as 10 seconds.

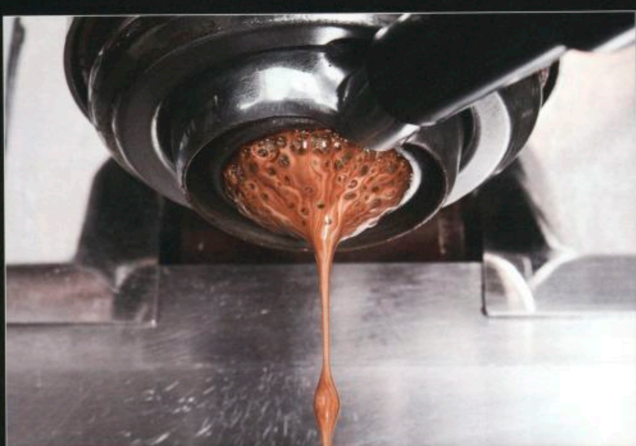
8 **Start a countdown timer as soon as the first drops appear (optional).** The timer should be preset to the appropriate shot time.



9 **Monitor the stream.** Viscosity and surface tension will cause the coffee emerging from the bottom of the portafilter to merge into a single stream that initially bows inward from surface tension (not visible above because a bottomless portafilter is shown). The color should be dark at first.

10 **As the shot progresses, the coffee lightens in color, and the flow rate increases.** A single stream forms.

11 **Lighter bands develop.** They increase in brightness, leading to the stage that baristas call the "tiger stripe" phase.



12 **The lightening continues to the "blonding" phase.** The coffee steam becomes yellow, and then almost white. A *ristretto* shot (our preference) is stopped just before the blonding phase starts; a *normale* shot goes into the blonding stage; and a *lungo* goes well into it.

13 **Stop the shot.** Ideally, a shot takes about 25 seconds from the time the first beads appear to your desired stopping point. Many variables can affect this, and most baristas consider a great shot to be anywhere in the range of 18–30 seconds. If the time is on the shorter end of the scale, make the grind finer; if on the longer end of the scale, make the grind coarser. The amount of water—the weight of the shot—will vary, but it should roughly be in accord with your desired dosing (see page 378). Adjust the grind and shot timing to get this within range.

14 **Serve immediately.** The wonderfully complex aromas and flavors in espresso begin to deteriorate the moment the shot hits the cup.

MONITORING THE STREAM

A very instructive experiment is to line up 10 cups and rapidly put them one after another under the espresso stream, catching four seconds' worth of the stream in each cup. Catch the first 40 seconds of the espresso stream, timing it from when the first drips leave the portafilter. Taste each cup. You will be amazed at the differences in sweetness, acidity, and bitterness that come from different parts of the espresso stream from a single pour. That's why we visually monitor the espresso stream.

In theory, there is a perfect grind that will deliver exactly the right weight of final coffee (see page 379) and will do so exactly 25 seconds from the time the first drops appear. In practice, we must approximate this by adjusting the grind and then cutting off the shot at certain visual indications (see previous page). It's better to stop the shot earlier or later than to have a shot that is sized correctly but tastes bad.

How can you tell whether you are in the ballpark? Monitoring the shot using a digital timer helps. But a timer alone can't make a great shot—otherwise automatic machines would be all we need. Similarly, weighing the shot helps you judge your dosing, and most baristas do this periodically. However, taste is ultimately the guide to good espresso.

should fall from the portafilter. Within a couple of seconds it should start to flow steadily. The liquid should be thick enough that a tight stream forms and arches inward rather than falling straight into the cup. After about eight seconds, the stream should loosen up, and the shot should flow more quickly and take on a striped brown and rust-red appearance called tiger striping (see previous page).

The quality of the pour is much easier to judge with a crotchless portafilter (see page 385), but you can see the color changes even when using a standard portafilter. After tiger striping, the stream becomes looser and frothy, and the color becomes progressively lighter in color until it is nearly white. Baristas describe this final phase, which is usually discarded, as the **blonding** of the shot.

The flavor of the coffee changes as much as the color does. It is very instructive to line up a set of small paper cups and use them to capture and taste different parts of the espresso stream (see Monitoring the Stream, previous page). Use 6–12 cups and move them in rapid succession, counting off four seconds, and then switching to a new cup. Taste them immediately.

You will find an incredible difference in the taste at each stage. Different compounds are extracted from the coffee as the shot progresses, depending on the temperature and pressure of the water and how it moves through the ground coffee.

The blonding phase, in particular, is bitter and, to most people, undesirable. A *ristretto* shot is cut off right before blonding starts. A *lungo*, on the other hand, goes deep into the blonding phase. In general, it should take about 18–35 s from the start of the shot (when the pressure starts) to the point where you stop the shot. Most baristas consider 25 s to be optimal. If the coffee takes too long to start, that suggests that it was overtamped or that the grind is too fine. If it starts too quickly, this suggests that channeling is occurring or that the grind is too coarse.

The barista watches the stream and cuts off the shot as soon as the stream looks right. This visual inspection is the barista's main quality control tool. The elapsed time or the amount of water produced in a shot are much less important. That is why automatic machine features that give the same volume of water aren't very helpful.

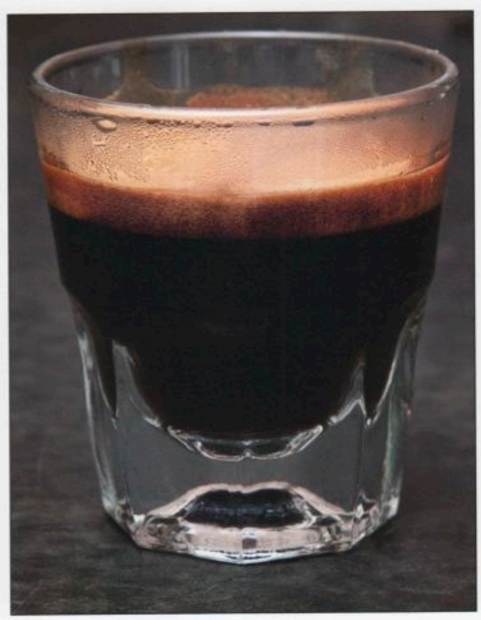
The barista's goal is thus to adjust the grind to get a good-looking stream, and then cut it off at the right time. Grooming and tamping are done the same every time (to be consistent), but the grind is varied during the day.

THE CHEMISTRY OF

Crema

Freshly ground coffee contains some carbon dioxide gas. When the coffee is packed in the filter and water passes through it under pressure, the water becomes supersaturated with dissolved carbon dioxide. But when the espresso flows out of the portafilter and returns to normal atmospheric pressure, it cannot keep all of the carbon dioxide dissolved. The gas then rapidly comes out of solution but is trapped as bubbles in the espresso by suspended solids and dissolved polymer-like molecules known as **melanoidins**. The result is the much-celebrated golden to reddish-brown foam known as crema (right).

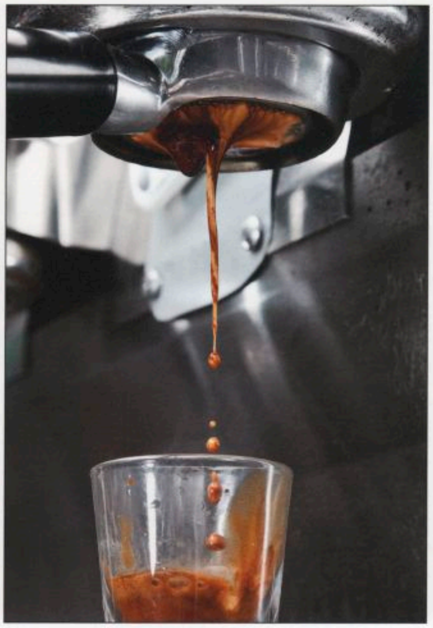
On a well-pulled shot, crema lingers on the surface for a minute or two rather than dissipating immediately. Because it blankets the surface, the crema helps trap the aromatics in the liquid below for the few moments it takes you to enjoy your first sip. Although the crema is traditionally considered an important characteristic of a well-prepared espresso shot, many leading baristas have been experimenting with skimming the crema off the shot before serving. The result is a sweeter-tasting shot.



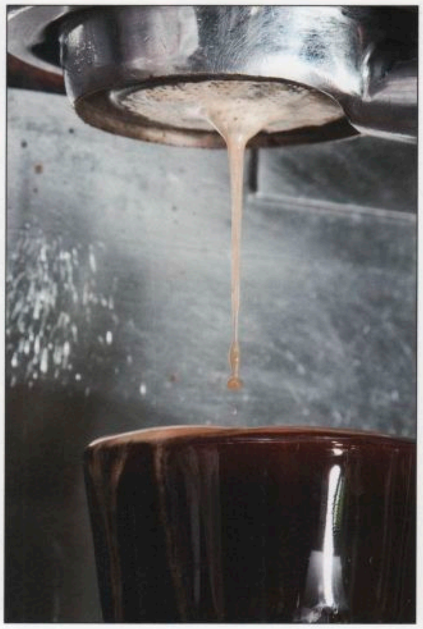
MISFIRES: COMMON PROBLEMS WITH ESPRESSO SHOTS

Problem	Possible cause	Solution
color and stream of the flow are uneven	water flowing through a gap between the coffee and the filter	Use less force when giving the filter a sideways tap to settle the grounds
flow spurts or is off-center	uneven distribution and compactness of the coffee bed	Properly dose and groom, and evenly tamp the coffee
it takes 10 s for the first drips of espresso to appear for a 7–14 g dose; more for a 21 g dose	too fine a grind	Grind the coffee a notch or two more coarsely
crema turns pale prematurely at the midpoint of the shot	too coarse a grind	Grind the coffee a notch or two more finely
crema is pale rather than reddish-brown at the end of the shot	overextraction	Reduce the time of the shot by a few seconds, while the crema still has a mahogany color


Uneven flow comes from uneven dosing, grooming, and tamping. It creates a bad shot.

A very slow extraction means that the grind is too fine.

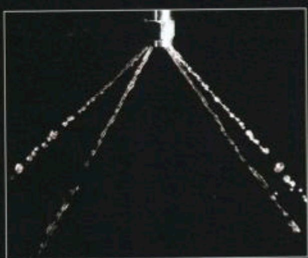


Extreme blonding turns the stream almost white, at which point the liquid has become bitter.

HOW TO Steam Milk

The delicate timing required to bring foamed milk and espresso together means that professional baristas work under different rules than amateurs do. Professionals aim to have both elements ready at the same time, as they are practiced enough to foam the milk while the espresso is brewing. Others should steam the milk first, because it is better for the milk to wait for the espresso than vice versa. Milk should only be foamed to order; do not attempt to refoam leftover milk. It won't work.

1 **Fill one-third to one-half of a chilled pitcher with cold milk.** A spouted, stainless steel pitcher with a sturdy handle is best. Always use chilled milk, and prepare only as much needed for the current drink.



2 **Run steam through the nozzle to flush out any residue or water.**

3 **Start to froth the milk and heat it, a process called stretching.** Start with the nozzle just below the milk's surface near the center of the pitcher and tilted about 30 degrees from vertical. Engage the steam wand to full pressure. You should hear a slight slurping noise. You can vary the stretching time depending on the amount of aeration desired, but halt before the milk exceeds 38 °C / 100 °F. This is when the pitcher begins to feel warm to the touch.

4 **Increase the depth of the nozzle to continue to heat the milk.** The milk should swirl within the container to form a dense microfoam. The sound will change with depth to a deep rumbling noise. Keeping your hand on the bottom of the metal pitcher will help you monitor the temperature.

4

5

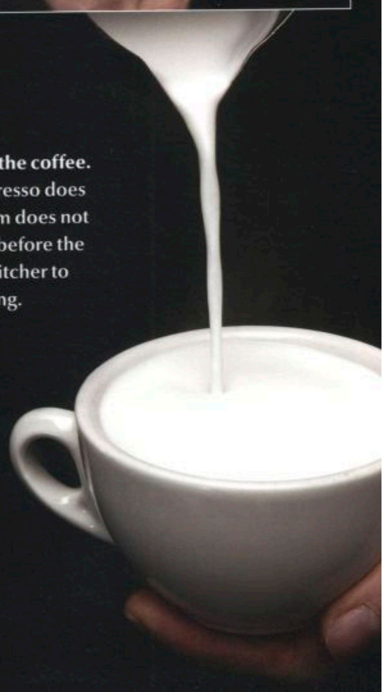
5 **Continue until the milk reaches 60 °C / 140 °F.** Do not let the milk get above 68 °C / 155 °F, or it will scald and smell cooked. If the foam is too dry and frothy, heat it less next time.

6 **Finish.** Turn off the steam, remove the pitcher, and wipe the nozzle clean (not shown).

7 **Tap the pitcher of milk firmly to burst any large bubbles on the surface (not shown).**

8 **Swirl the pitcher, and observe the consistency of the milk (not shown).** Underaerated milk looks thin and tends to splash around. Perfectly aerated milk seems slightly sluggish as it swirls because the bubbles make the foam viscous. Overaerated milk appears to have a thick layer of froth that floats on top of liquid swirling beneath it. If the milk is overaerated, skim some of the lightest froth off the top with a spoon, and then swirl the pitcher again. Keep removing froth until the foam has an even, consistent texture when swirled.

9 **Pour the textured milk over the coffee.** Work quickly so that the espresso does not go stale and the milk foam does not separate. If the milk is ready before the shot, periodically swirl the pitcher to keep the foam from separating.



THE ART OF MILK AND COFFEE

A perfectly brewed shot of espresso with carefully steamed milk foam is a thing of beauty in and of itself. An even more elaborate presentation of the caffé latte has become an art form all its own.

It's hard to pinpoint the moment at which latte art—intricate designs created in the foam— was born. It may have evolved organically, with no particular moment of invention. After all, the contrast of snowy milk foam on mahogany-colored espresso is an inspiring medium. Whatever the origin, top espresso shops have in recent years made quality latte art a point of professional pride. Although it can be an aesthetic addition, the milk foam on an espresso drink is not just for style points. A top-quality espresso drink is distinguished by the texture and body of the foam. The ultimate goal is microfoam: a thick, moist, lustrous foam of imperceptibly small bubbles, rather than a coarse, frothy foam with large, clearly visible bubbles.

Although many espresso drinkers choose their milk type based on dietary preferences, you should know that the milk selection has an impact on the quality and style of the foam, which is formed by heated milk proteins surrounding bubbles of air. Interestingly, skim milk produces foam of the greatest volume and stability. The larger amount of fat in whole milk tends to destabilize bubbles and makes for less aerated foam. Whole milk does, however, produce a richer mouthfeel than skin milk does, thanks to the extra fat in it. Many espresso drinkers choose milk with 2% fat as a reasonable compromise.

Whichever type of milk is used, the goal of creating a microfoam is the same. Milk steaming, also known as texturing, should create foam with a glassy surface that contains no large bubbles. The milk should always start cold, and the steam wand should be held just beneath the surface so that the initial blast of steam draws air into the milk and forms miniscule nucleation bubbles. This initial phase is called **stretching** the milk.

When done just right, stretching produces an audible slurping sound as air is sucked beneath the surface. Once the milk becomes slightly warm to the touch, stretching is over. Plunge the steam wand far below the surface to heat the milk to a temperature of 60 °C / 140 °F. The jet of steam will cause the milk to swirl around the pitcher, which makes the temperature more uniform and allows the nucleated bubbles to swell as they fill with steam.

The correct degree of aeration depends on which beverage you are preparing. A latte, for example, needs dense, wet foam with moderate aeration, whereas a cappuccino needs greater aeration for dry, light foam. The more the milk is stretched—and the hotter the steam makes it—the drier and lighter the foam.

Steaming milk to the perfect texture once is tricky, but doing so over and over consistently is quite a challenge. If the milk is underaerated, nothing can be done except to start again—there is no point in trying to resteam milk. On the other hand, if milk is slightly overaerated, you can groom it to remove the frothiest foam before pouring—see How to Steam Milk on the previous page.

Part of the art of steaming milk is timing the process just right so that it is ready to be poured as soon as the shot is done. Or you can add foam stabilizers, as described on the next page that make milk foam last 30 minutes or more. Standard foam separates and coarsens in steamed milk as it lingers, and an espresso shot will go stale if it sits for too long waiting for the milk to be poured. Before you know it, the magical texture of a perfect latte or superb cappuccino is lost.

If you don't have a steam-driven frother for your milk, you can instead use an aerating wand. The battery-powered device has a specially designed head that produces foam as it gyrates just under the surface of the milk. In a pinch, you can even use a wire whisk to froth milk in a saucepan as it heats on the stove. Neither alternative will produce superior microfoam, but both work passably well.

The Perfect Pour

Once the shot is pulled and the steamed milk is ready, pour the drink. Most baristas use a free-pouring technique for lattes. They pour the textured milk slowly but steadily into the cup containing the espresso, taking care to avoid breaking up the crema. Spouted pitchers make it easier to control the pour, and they also make it possible to create latte art while pouring (see How to Make Latte Art, page 394).

Large, coarse foam bubbles like these indicate poor foaming technique. Fine foam with a uniform bubble size is the goal.

Higher-fat milks don't foam as well—or create foams that are as sturdy—as low-fat milks do because fat naturally destabilizes milk foams. As milk ages, spontaneously occurring chemical reactions cause some of the fat to break down into fatty acids and glycerol. It's glycerol that wreaks havoc, impeding the development of foam by weighing down the air bubbles and causing them to burst. So for best results with high fat milks, use them fresh and keep them away from heat and light.

Lambda carrageenan can be substituted for the sucrose esters in the recipe below. Use 0.05% lambda carrageenan (so 0.2 g for every 400 g skim milk).

The most common form in latte art is surely the rosetta, the fern- or leaf-like pattern that baristas often first perfect as they study the art. Other forms include the heart, tulip, apple, wreath, and elaborate combinations of multiple designs. The possibilities are nearly limitless.

Some baristas also apply an "etching" technique, using a toothpick to draw lines through the foam, or adding drizzles of chocolate sauce for detailed accents. These extra embellishments can be pretty and intriguing, but the time it takes to make them keeps the customer from enjoying the coffee at its best.

Most baristas do not free-pour cappuccinos. The very aerated milk makes it difficult to consistently pour the correct ratio of one third espresso, one third steamed milk, and one third foam. Instead, they use a spoon to hold back the foam in the pitcher while they pour out the correct amount of nonaerated hot milk. They then finish the pour by using the spoon to push out an equal portion of foam that caps the beverage. When done correctly, a thin ring of dark, espresso-stained foam rings the cup, and a glossy sea of white foam fills the center. Actually pulling this off, however, is just as difficult as creating perfect latte art.

EXAMPLE RECIPE

STABLE LATTE FOAM

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Skim milk	400 g	100%	① Dry blend powders, and disperse in cold milk.
Whey protein isolate	4 g	1%	② Blend until fully dissolved.
Sucrose esters (Sucro, Texturas brand)	4.8 g	1.2%	③ Steam with steam wand, or whip with an Aerolatte wand until stiff head of foam forms, 2–3 min.
			④ Stir to moisten with milk.
			⑤ Foam remains stable for up to 30 min.

(2010)

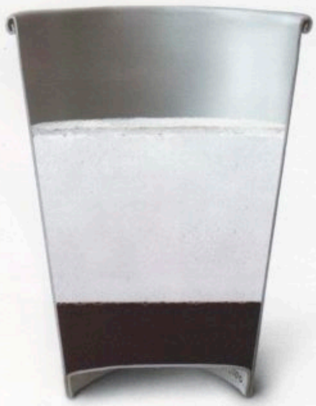
A TAXONOMY OF ESPRESSO BEVERAGES

Espresso
one shot of espresso

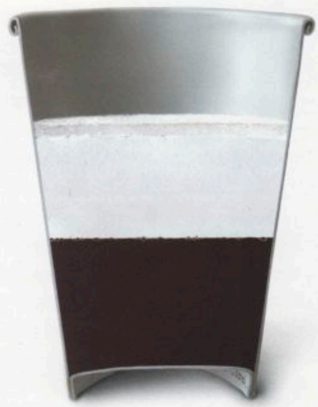
Macchiato
one shot of espresso topped with a dollop of milk foam

Espresso con panna
espresso topped with a dollop of whipped cream

Caffè latte
one or two shots of espresso; cup filled with steamed milk

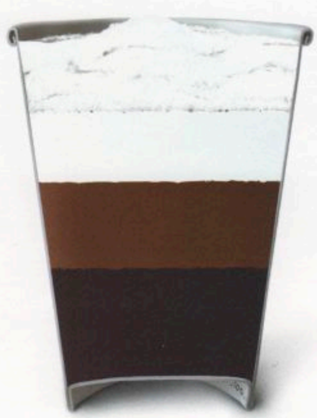


Caffè breve
latte or cappuccino made using half-and-half rather than milk



Café au lait
equal parts strong brewed coffee and steamed milk or hot milk

Cappuccino
one part each of espresso, steamed milk, and milk foam



Caffè mocha
one part each of espresso, hot chocolate, and steamed milk, topped with whipped cream

Americano
one or two shots espresso, cup filled with hot water

HOW TO Make Latte Art

Many professional baristas today present their caffè lattes and cappuccinos with some touch of artistic panache in the form of poured patterns of steamed milk. The effect may seem intricate and complex, but with a little practice it becomes as natural to the well-trained barista as dosing and tamping are. Below are instructions for make the free-poured rosetta pattern, one of the most popular.

1 **Prepare an espresso drink and steamed milk (not too hard and dry), tilt the cup slightly, and pour milk slowly into the center of the crema.** Lift the back of the cup to tilt it slightly toward you as you pour steadily, but not so fast that the crema breaks up. Keep the lip of the pitcher close to the surface of the coffee to avoid undue turbulence.

2 **Rock the pitcher to expand the pattern.** When a pale cloud of milk breaks the surface, begin rocking the pitcher back and forth to form zigzags of foam against the espresso background. At the same time, draw the pitcher toward the near side of the cup. Do not raise the pitcher higher as the cup fills.

3 **Complete the design.** As you add the last of the foam, raise the pitcher slightly and pour a thin stream back across the surface through the center and to the far side of the cup. This action forms the central stem of the rosetta.

Heart

Tulip

Rosetta

The heart, tulip, and rosetta are a few of the many beautiful examples of latte art created by experienced baristas. They should be enjoyed promptly. Within moments, coarse bubbles become visible, indicating that the foam is dying, and, with it, the wonderful texture dies, too.

ACHIEVING CONSISTENCY

Who makes the best espresso in the world? That is a deeply controversial topic among coffee lovers. There are no Michelin stars or Zagat Ratings to consult, as there are with restaurants. Starbucks is everywhere. But even cities that are famous for their food often have very little to offer in the way of top-quality artisanal espresso.

We haven't had coffee everywhere, but to our taste the top five cafés in the world are (in no particular order), Sant'Eustachio Il Caffè in Rome, Victrola Coffee and Espresso Vivace, both in Seattle, Vovito Caffè in Bellevue, Washington, and Square Mile Coffee in London. We hear great things about Tim Wendelboe in Oslo, but as of this writing have not yet been there.

You've done it once; can you do it again? Good baristas make phenomenal coffee now and then by circumstance and good fortune. The mark of an exceptional professional is when that great espresso becomes the rule rather than the exception.

Reliably high quality can come only from consistency applied to every step of the process discussed thus far, from the grinding technique through finishing a shot. Consistency, in fact, is a major theme throughout this book. To employ techniques as well as a professional does, you need to shoot for mastery, not just one-time results.

Consistency drives people like David Schomer (see page 399) to obsess about subtleties such as the heat produced by coffee grinders. He knows that uncontrolled changes in the grinder temperature can have a negative impact on the bean that carries through to the flavor in the cup. The search for consistency sends world-class baristas, like James Hoffman, and serious coffee amateurs, like coffeegeek.com contributor Andy Schecter, on research binges. They test brewing ratios, dosages, and shot weights as part of their quest to achieve outstanding results that they know they can repeat.

Consistency should be brought to bear on every part of the espresso-making process. Look at all the synonyms of the word "consistent" used in the steps: accurate dosing, uniform dispersing and grooming, even tamping, stable temperature, steady water pressure. These elements are quantifiable.

On the other hand, there is no handy reference chart or standard values that are applied universally when making espresso. That's taking consistency rather too far. Instead, the term "consistency" expresses the expectation that in a specific scenario—working on a particular machine, on a particular day, with a specific batch of beans, and so on—the first pull will be as good as the fifth pull and the fiftieth.

The elements of the consistency puzzle that can't be quantified come from individual baristas: their talent, experience, and inherent adeptness at the craft of making espresso. Early in their training, baristas monitor temperature with thermometers; they use digital scales to measure their dosing and shot weights; they might even tamp the portafilter on a bathroom scale to learn the feeling associated with applying an optimal 13.5 kg / 30 lbs of pressure to a bed of grounds. When it comes to perfecting the human touch, there is no alternative to practice, practice, practice.

Keeping Clean

Just as with any tool used in the kitchen, proper cleaning and general upkeep of your brewer and coffee grinder. Upkeep ensures that they work at their maximum capacity and produce the most delicious product. Oily residues on parts can turn rancid, build-up of grounds can give off bitter-sour flavors, and calcium deposits compromise the efficiency of the boiler and other parts. How often you clean your machines depends directly on the volume and frequency of brewing and grinding that you do. The instructions for your machines surely included recommended cleaning processes, but for a quick overview, see the next page.

Further Reading for Coffee

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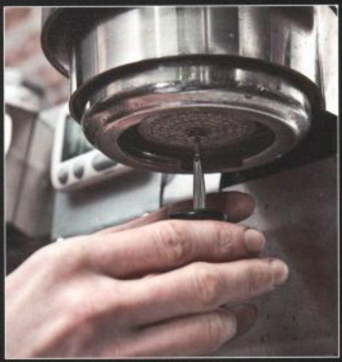
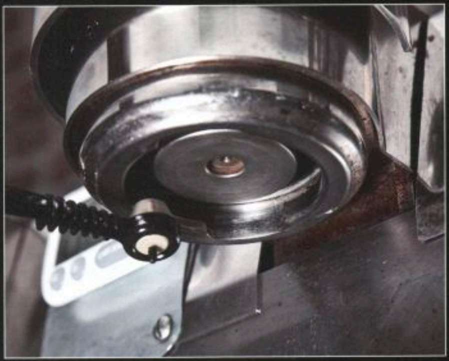
Mark Prince's web site, CoffeeGeek.com

Andy Schecter's blog, Portafilter.net

Home-Barista.com

HOW TO Clean an Espresso Machine





1 **Remove coffee baskets from portafilters, and scrub them at least daily.** Baskets should be cleaned frequently, as often as every hour at very busy cafés. Flush empty portafilters with hot water to remove any residue.

2 **Clean group head at least daily.** After every shot, remove the portafilter and release a little water from the machine. Wipe down the group head gasket with a damp cloth at least once a day, more often for high-volume production. Remove the screen from the group head, rinse, and wipe; rinse its screw as well before reattaching the screen.

3 **Backflush the machine.** Insert a blind filter basket (one without any holes in the bottom) and run the pump for a few moments. Water will meet the blind filter and flush back up into the group head, further cleaning the machine. For maximum cleaning, use espresso machine cleaning solution for the backflush, following the manufacturer's recommendations. Then backflush the machine several times with plain water to ensure that all cleaning solution is rinsed from the machine before use.

4 **Purge the steaming wand with hot water, and wipe it down well after each use.** As needed, remove the tip and soak for further cleaning.

5 **Remove and clean the machine's drip tray (not shown).**

6 **Brush the burrs in the grinder clean (not shown).** The upper burr may be removable for better access to lower burrs. Use a clean, dry brush to remove the residue of grindings. Finally, clean the feeder channel to ensure that buildup isn't impeding the good flow of beans into the grinder.

THE HISTORY OF

The Coffee Capital of the World

Although espresso is an Italian invention, the world capital for all things coffee is Seattle. It's not clear exactly how this happened. Among the many theories is that Seattle's famously overcast winters drive people to caffeine.

What is clear is that an espresso coffee culture developed in Seattle in the 1970s and 1980s, driven mostly by small operators. One of them, a little operation called Starbucks, grew from a simple storefront shop in the city's Pike Place Market into a multibillion-dollar corporation that revolutionized the way the world drinks coffee.

The first Starbucks store opened in 1971. Initially, the company focused on sourcing beans and roasting them for retail and wholesale customers. The drive to put a contemporary coffee shop on every street corner bloomed in the 1980s after eventual-chairman Howard Schultz spent time in Milan, where he noticed how the city's cafés act as social hubs.

Schultz saw the potential to provide that same kind of community gathering place for his Seattle customers, so he added a menu of coffee drinks and casual seating to the Starbucks retail stores. The rest, as they say, is history. Now Starbucks has more than 16,000 locations around the world.

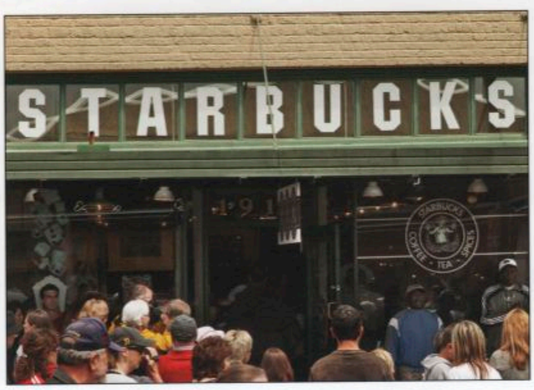
While Starbucks led the way, Seattle went on to produce two other international coffee chains. Stewart Brothers Coffee was another early player in the quality roasted coffee scene in Seattle, having grown from a small, popular coffee shop called the Wet Whisker. The company later changed its name to Seattle's Best Coffee (conveniently retaining their logo) and ultimately was acquired by Starbucks. Tully's was a later addition, opening its first coffee shop in Seattle in 1992, but it has quickly grown to be one of the largest specialty coffee retail companies in the country, with stores in the western United States and Asia.

Large as they are, those three major players do not dominate Seattle coffee. Hundreds of local espresso stands and shops fill the streets, and almost every Seattleite has a favorite. Starbucks may have brought the joy of espresso drinks to millions of people, but hard-core coffee lovers prefer smaller local establishments, many of which roast their own beans to control style and quality. Coffee shops such as Espresso Vivace and Victrola Coffee rank high among Seattle coffee hounds. Even grocery stores in the city display fresh, locally roasted whole beans for purchase by the pound, in stark contrast to the usual supermarket fare of prepackaged beans that have been in storage for who knows how long.

Seattle is a town that doesn't take coffee for granted. Its denizens are always stretching, researching, exploring, and seeking out an even better cup of coffee than the one they had yesterday. As a result, almost all of the latest innovations in espresso come from Seattle.

David Schomer (of Espresso Vivace) singlehandedly invented many of the elements of modern espresso practice, including PID controllers, fan-cooled grinders, and pressure-controlled tamping. Most baristas agree that the crotchless portafilter was invented at Seattle's Zoka café. The breakthrough Synesso and Slayer espresso machines, and the Clover coffee machine, are also Seattle products. Even La Marzocco, the leading Italian maker of espresso machines, is co-owned by its CEO Kent Bakke, who lives in Seattle.

The Internet age has now broadened the innovation circle. Coffee lovers unite, inspire, and share ideas in online forums such as home-barista.com and coffeegeek.com, which allow people to pass tips and techniques around the globe. Seattle isn't the only place where great new ideas are applied to coffee, but it is, for now, the coffee capital of the world.



Even in London one can find cafés that advertise Seattle-style coffee drinks (top). And when in the major cities of the world, you are rarely far from an outlet of Seattle-based Starbucks (bottom).

PROFILE

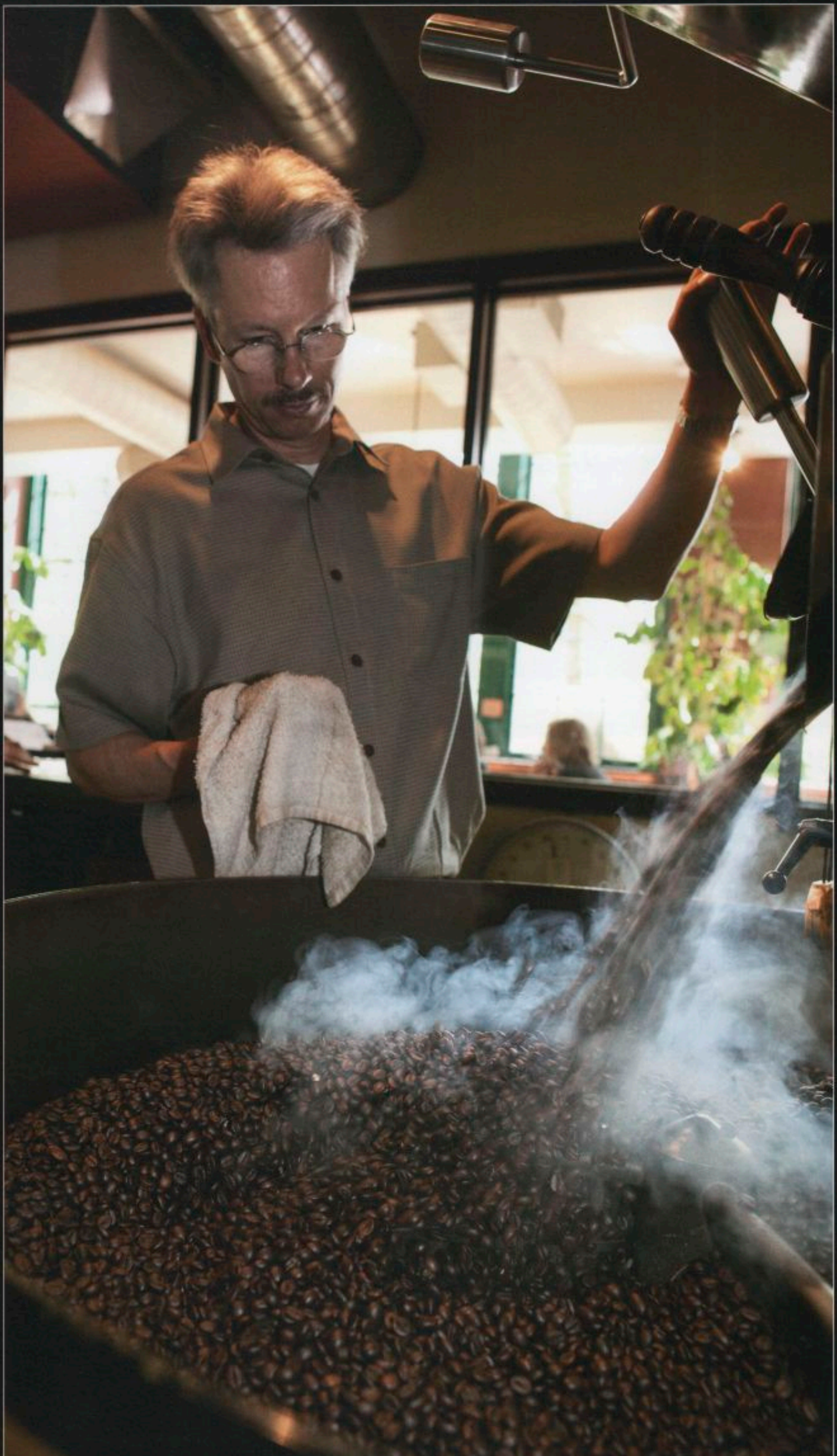
David Schomer

Many have chronicled the science and art of espresso, but David Schomer wrote the book on the subject—literally. His book, *Espresso Coffee: Professional Techniques,* first released in 1996, has become something of a bible for baristas near and far.

Schomer began his career in coffee with an espresso cart on a Seattle street in 1988. In 1992, he and his partner Geneva Sullivan moved the business indoors, and the Espresso Vivace company has since helped define the pinnacle to which modern espresso crafters aspire.

The company's web site (espresso-vivace.com) alone is enough to inspire even the most nascent coffee fanaticism with a wealth of information, photos of beautiful latte art, and blog entries by Schomer that offer equipment reviews and musings on quality customer service. Schomer is an advocate of caffé espresso as a culinary art, and Vivace's coffee shops, retail coffee blends, professional training videos reflect his daily celebration of coffee and the pursuit of perfect—and perfectly consistent—espresso.

Schomer's blend of engineering aptitude and artistry reflects his former work as a metrologist (one who studies the science of measurement) and his study of classical flute performance. His intent interest in the finest details of the espresso-making process have led him to refine his espresso machines so that they can maintain temperature to within a single degree—and even to work out exactly when and how to clean the portafilters.



THE TECHNOLOGY OF

Pods and Capsules

Capsule and pod systems greatly simplify and standardize the brewing process. Because they contain premeasured portions of preground coffee, capsules and pods eliminate the need for grinding, dosing, tamping, and otherwise preparing coffee for brewing.

Two kinds of pods dominate the market: paper pods and capsules. Paper pods securely contain a firm puck of coffee in a paper filter. With a pod adapter on a regular portafilter, these can be used in many of today's consumer-level espresso machines. Other paper pods are made with drip coffee in mind. They contain more loosely packed ground coffee that simply replicates coffee in a filter, but with no loose grounds to clean up at the end.

Capsules contain doses of ground coffee measured into small, hermetically sealed, coated aluminum containers, which are dropped into a customized slot in a specially made machine. The capsule is perforated and water extracts a shot of espresso or brewed coffee, depending on the machine. Some are of a proprietary design so that only capsules of the same brand can be used. Nespresso is the most prominent player in this market. Other machines, such as the Keurig line, can be used with a range of branded coffee capsules created in a compatible form.

Both types of systems can make decent—sometimes even good—brews. The standardization makes it unlikely that you will ever have to endure a terrible cup of coffee. But you'll never get a God shot from one of these either.

THE TECHNOLOGY OF

Pressure Profiling

Perfecting the espresso-making process is a never ending pursuit for the more passionate coffee professionals out there. So-called PID systems that accurately control the temperature of the water in the boiler to within a few tenths of a degree have gone far in helping to ensure consistent extraction results.

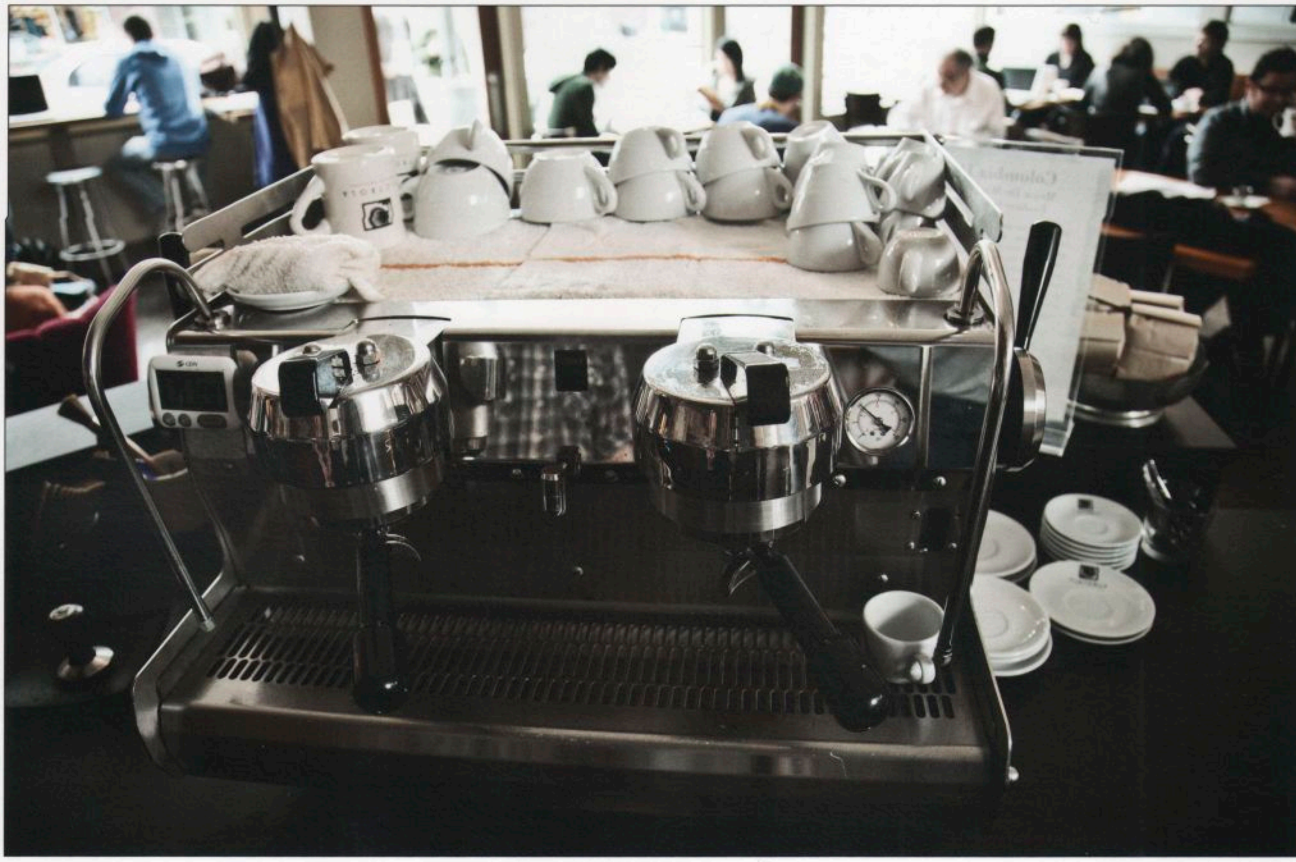
Following temperature, pressure is the next element on the minds of espresso problem-solvers. Many machines operate at a single pressure, often a gauge pressure in the vicinity of 9 bar / 131 psi. The pressure pump is either on or off, and it doesn't allow for regulated stages of pressure increase or decrease or for customized settings.

Pressure profiling allows a barista to control the pressure in a way that makes the most of the "heart" of the espresso pull, by ramping up the pressure at the beginning and down at the end, when the compounds being extracted from the grind might not be optimal. For example, the first 5–8 s of the pull might see the pressure rise from 0–3.4 bar / 0–49 psi, with an increase to 8.25 bar / 120 psi for another 10 s, and then a decline to 6.2 bar / 90 psi through the end of the shot.

Once you have determined a desired sequence of pressure levels, the goal is to make that part of a consistent regimen. If your machine has both analog and digital pressure gauges, you can tweak the pressure and then save the sequence to run perfectly again and again.

Pressure-profiling machines recently have been introduced by La Marzocco, Synesso, and Slayer; more manufacturers likely will follow suit. These first-generation machines allow baristas to control the pressure at various points during the brewing cycle, either manually with a paddle or by programming a digital controller. The effects of pressure profiling are dramatic, but the initial reactions by top baristas is mixed.

Tim Wendleboe of Norway, who won the world barista championship in 2004, has posted enthusiastically about his initial experience with pressure profiling. "We have only seen the beginning of what this new style of brewing can do," he says. "I am quite sure that once we get more experience we will see a of lot of interesting results in the cup. It is just another tool to get a better cup of coffee." Others, like 2007 world champion barista James Hoffman, are more reserved about the benefits, in part because of the difficulty of determining which profiles give the best results.

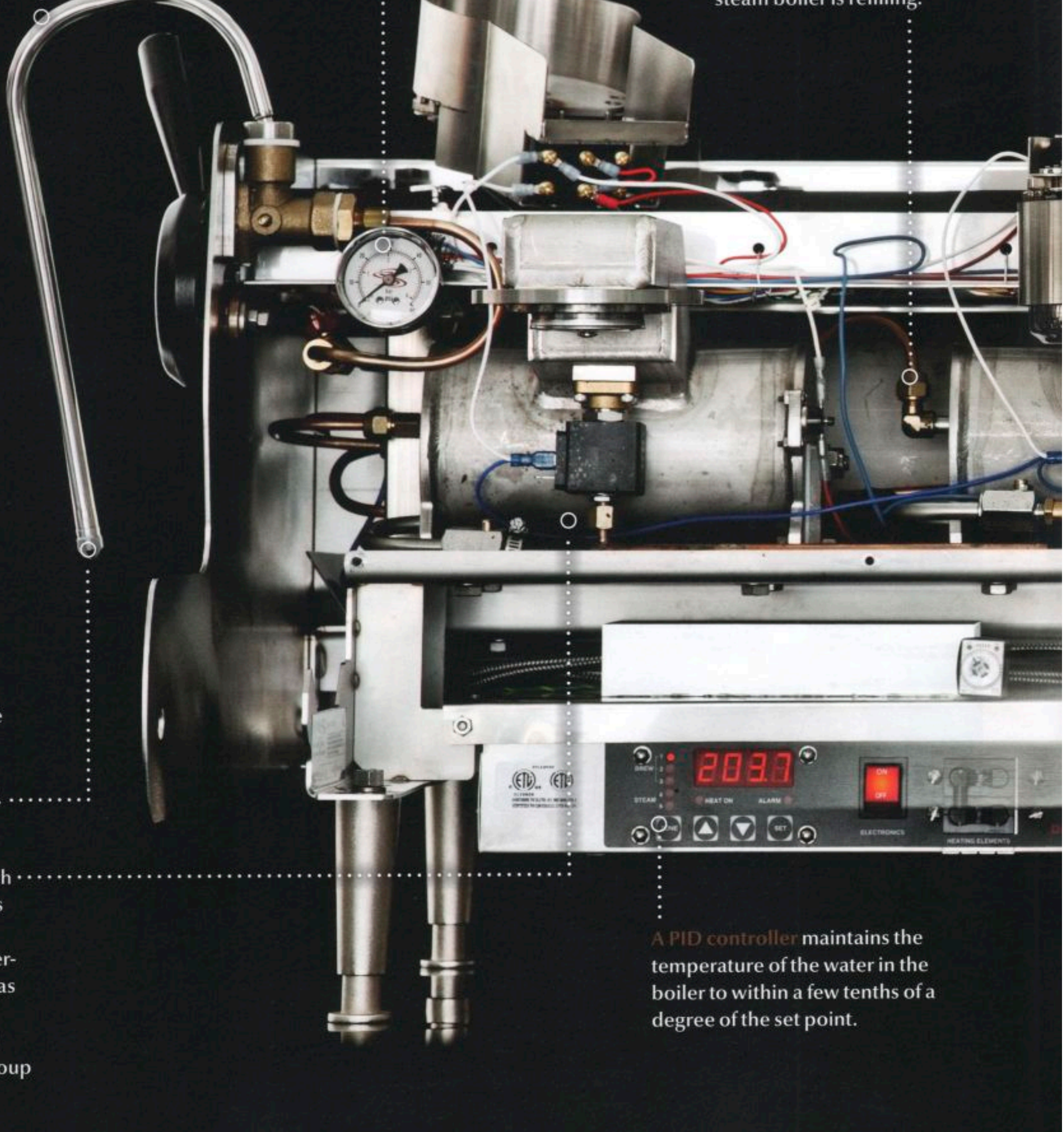


High-quality espresso machines are essential to making quality coffee. The Synesso Cyncra, shown above at Victrola Coffee in Seattle, was created by a startup company in Seattle in 2004. The Slayer machine, shown below at Vovito Caffè in Bellevue, Washington, near Seattle, is a new entrant developed by a more recent Seattle-area startup.

A BARISTA'S DREAM MACHINE

The task of an espresso machine is to force hot water through a packed bed of coffee grounds in a short period of time. A high-quality espresso machine should be able to brew consistently by producing the same water temperature and pressure profiles in shot after shot.

Although managing this job is the responsibility of the barista, even the best barista in the world will struggle unless the espresso machine has been engineered to produce consistent performance. Top-rated commercial espresso machines, such as those by La Marzocco, Synesso, and Slayer, include many or all of the features below. Less expensive, "prosumer" machines include only some of these options but can still perform well. Inexpensive domestic machines, however, share only a passing resemblance to serious, well-made equipment.



The steam wand is used for foaming milk. The best steam wands carry the steam through a small diameter inner tube that is mounted within in a larger outer tube. The air gap between the two tubes provides insulation so that you don't burn yourself—or scald the milk—with the tube.

Group heads, exposed and independently heated, isolate the temperature of the group head from the temperature of the machine itself.

Separate water inlets for the steam boiler and the brewing boilers avoids any drop in water pressure while a shot is being pulled, even if the steam boiler is refilling.

A steam nozzle that has several small holes in the tip, rather than a single large hole, creates higher velocity steam that makes it easier to properly texture the milk, particularly when preparing milk for one beverage at a time. A tip with one or more larger holes can be useful for quickly heating a large amount of cold milk. Some machines have dual wands, in which case tips of both kinds can be used.

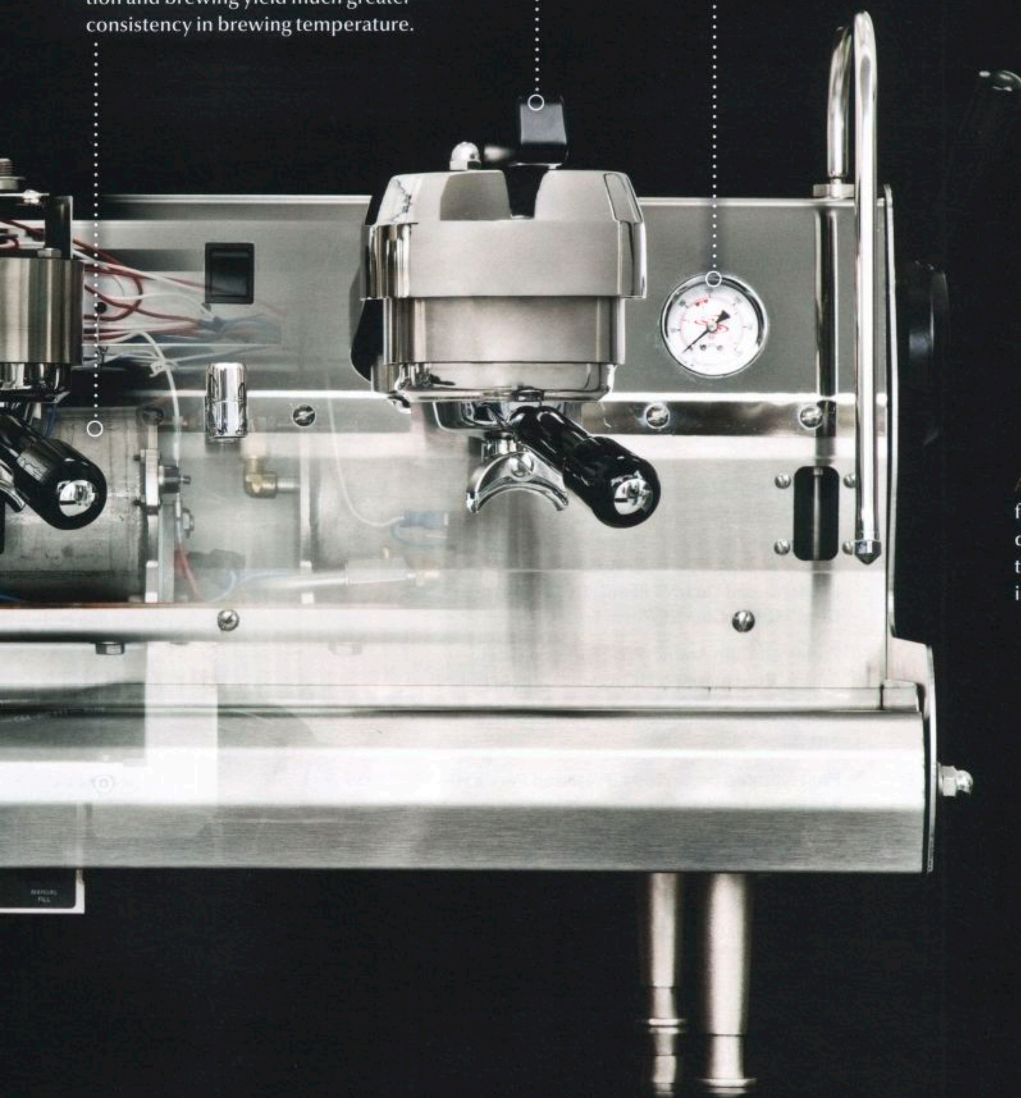
A dedicated brewing boiler for each group head and steam wand allows the barista to tailor the brewing temperature to accommodate different styles of espresso shots as well as variations among roasts. Multiple boilers also prevent fluctuations in brewing pressure when another group is being purged.

A PID controller maintains the temperature of the water in the boiler to within a few tenths of a degree of the set point.

A preinfusion feature uses low-pressure water to swell the bed of coffee evenly before full brewing pressure is applied. Most baristas agree that preinfusion creates a more uniform extraction and reduces instances in which high-pressure water forces its way through weak spots in the grounds, which yields uneven extraction and poor-tasting shots. You control preinfusion by moving the group head lever.

The pressure gauge indicates the hydrostatic pressure of the brewing water in the boiler. The pressure is generated by a powerful electric pump, which may be mounted externally.

Separate boilers for steam production and brewing yield much greater consistency in brewing temperature.



Alloys of steel or brass are used for crucial parts to increase both durability and thermal mass, thus dampening fluctuations in temperature.

REFERENCE TABLES

Hydrocolloid Product Guide

Throughout the book, wherever space permits we have listed the specific product and brand we used in developing our recipes. Many other brands are available, however, and for any given application similar products may work equally well or even better than the product we used. The table below lists comparable hydrocolloid products of several manufacturers

Main ingredient	Manufacturer				
	CP Kelco	**Tic Gums**	**Texturas**	**texturePro**	**Sosa**
agar		Pretested Agar Agar 100 FCC, Pretested Agar Agar 100-44 HG, Pretested Agar Agar 150 FCC, Pretested Agar Agar RS-100, TICorganic Agar Agar 150-C FCC/NF	Agar	Agazoon	Agar Agar
calcium chloride			Calcic		Clorur
calcium gluconate			Gluco		Glucono-Lactat
calcium lactate				Calazoon	
kappa carrageenan	Genu texturizer, Genugel CHP-2, Genutine 310-C, Genugel WR-78	Ticaloid 710 H-96, Ticalod 750, Ticaloid 825, Ticaloid 795, Ticaloid 1252, Ticaloid 881 M, Ticaloid PM 9399	Kappa		
lambda carrageenan	Genuvisco CSM-2, CSW-2, Genulacta		Lambda		
iota carrageenan	Genugel LC 5 (iota), Genuvisco J		Iota	Iotazoon	
gelatin		TICAgel 795			InstanGEL, Gelatina Vegetal
high-acyl gellan	Kelcogel LT 100				Goma Gellan
low-acyl gellan	Kelcogel, Kelcogel F		Gellan	Gellazoon low	
glucono delta-lactone					
guar gum		Pretested Gum Guar 8/24, Pretested Gum Guar 8/22, Pretested Gum Guar 8/22 A, Pretested Gum Guar TICOLV FCC Powder, GuarNT 3500 F, TIC Pre-Hydrated Guar Gum 8/24, TIC Pre-Hydrated GuarNT Bland, TICorganic Guar Gum 3500 F, GuarNT Flavor Free 4000		Guarzoon	
gum arabic		Pretested Gum Arabic, Pre-Hydrated Gum Arabic, Pre-Hydrated TICorganic Gum Arabic SF			Goma Arábiga
gum tragacanth		Ticaloid 310 S Stabilizer, Pre-Hydrated Ticaloid 210 "S"			
HM pectin	Genu Pectin Type D Slow Set-Z	Pre-Hydrated Pectin 1694, Pretested Pectin HM Rapid Set, Pretested Pectin HM Slow Set			Pectina de Manzana
LM pectin	Genu Pectin Type 101 AS, Genu Pectin Type 104 AS	Pretested Pectin LM 32, Pretested Pectin LM 35			GelGras
konjac gum		Ticagel Konjac High Viscosity			
lecithin, soy			Lecite	Emulzoon	Lecitina de Soja
locust bean gum	Genu Gum RL-200	Pretested Locust Bean Gum POR/A, Pretested Locust Bean Gum POR/A2, Caragum 200, Caragum 200 FF, Caragum 300 2473, Pretested Stabilizer 424		Locuzoon	

according to their principal ingredient. Products within each category can vary substantially in performance, so you may need to contact an applications specialist at the manufacturer for guidance if problems arise when making a substitution.

Manufacturer					
FMC BioPolymer	Cargill	Dow	Aqualon	ISP	Others
					Arnaud SA brand, Purac
Gelcarin GP812 NF, Gelcarin GP911 NF	Satiagel, Satiagum, Aubygel			Textureze MT700	
Viscarin GP-109NF, Viscarin GP-209NF					
Gelcarin GP-379 NF					
	Vitex Blends				
					Jungbunzlauer
	Viscogum		Supercol Guar Gum		Polypro, Procol U, Procol G2
	Unipectin				
	Lecisoy				
	Viscogum				

Hydrocolloid Product Guide

Main ingredient	Manufacturer				
	CP Kelco	Tic Gums	Texturas	texturePro	Sosa
methylcellulose (MC)		Ticacel LV (low viscosity), Ticacel HV (high viscosity)	Metil	Celluzoon	Metilgel
hydroxypropyl methylcellulose (HPMC)		Ticacel 100 Cellulose			
carboxyl methylcellulose (CMC)	Cekol LV-D	Pre-Hydrated Ticalose CMC 15, Pre-Hydrated Ticalose CMC 2500, Pre-Hydrated Ticalose CMC 6000, Ticalose 400 SF, Ticalose 602, Ticalose CMC 15, Ticalose CMC 15000, Ticalose CMC 2500, Ticalose CMC 6000			
microcrystalline cellulose (MCC)		Ticacel MCC FG-100			
propylene glycol alginate		Saladizer MAX, TIC Pretested Freedom Gum X-PGA/LV			
sodium alginate		TICA-algin 400, TICA-algin HG 600 F	Algin	Algizoon	Gelesfera A, Alginat
sodium citrate			Citras		
sodium hexametaphosphate					
sodium pyrophosphate					
xanthan gum	Keltrol T-630	Pre-Hydrated Ticaxan Xanthan, Ticaxan Xanthan 200, Ticaxan Xanthan, Ticaxan Xanthan Smooth	Xantana	Xanthazoon	GelEspesa (Xantana)

Gelatin Gels with Alcohol

Alcohol in dish	Suggested amount of gelatin
(scaling)*	(scaling)*
0	1.0%
5	1.8%
10	2.0%
15	2.2%
20	2.4%
30	2.8%

*(*set weight of food to 100%*)

Content for the tables Gelatin Gels with Alcohol, Gelatin and Bloom Strength, Overview of Texture-Hydrocolloid Combinations, Common Kitchen Chemicals, and Calcium Content of Selected Foods adapted with permission from Lersch, M. (ed.) "Texture—A hydrocolloid recipe collection" (v. 2.3, 2010). Available online at blog.khymos.org/recipe-collection/

Manufacturer					
FMC BioPolymer	**Cargill**	**Dow**	**Aqualon**	**ISP**	**Others**
		Methocel Cellulose Ethers, Walocel M	Benecel MC		
		Methocel Cellulose Ethers, Walocel HM	Benecel HPMC		
		Walocel C, Walocel CRT	Aqualon CMC EZ, Aqualon/Blanose Cellulose Gum, Aquasorb Sodium CMC, Aqualon CMC7HOF Cellulose Gum		
Avicel CG, Avicel-plus, Avicel CE-15, Novagel					
Protanal Ester BV				Textureze PC 64	
Protanal	Algogel, Cecalgum, Satialgine			Textureze MT625, Textureze BF 250, Textureze MT 670, Manugel DMB	
	Trisodium Citrate Dihydrate				
					ICL Performance Products
					ICL Performance Products
	Satiaxane		Supercol XG Xanthan Gum		

Low-acyl Gellan Gum Concentrations for Fluid Gels

When using low-acyl gellan to make a fluid gel, you must adjust the amount of gellan used to account for the ionic concentration of the food. Deionized water and foods that are low in calcium and high in sodium require a bit more gellan than do foods that contain little salt or calcium.

Ionic concentration	Gellan gum concentration
low calcium (<50 ppm)	0.1%–0.3%
low sodium (<0.25%)	0.1%–0.3%
typical savory salt levels (0.5%–2%)	up to 0.05%
optimum calcium for gel strength (100–600 ppm)	up to 0.05%
high calcium (>50 ppm)	0.05%–0.2%
high sodium (4%–10%)	0.05%–0.2%
milk and cream	0.05%–0.2%

Gelatin and Bloom Strength

Name	Bloom strength	Grams per sheet
bronze	125–155	3.3
silver	160	2.5
gold	190–220	2.0
platinum	235–265	1.7

Converting Bloom Strengths

If you know both the mass M_A and the Bloom strength B_A of gelatin A, you can calculate the equivalent mass M_B of gelatin B having a Bloom strength of B_B by using the formula $M_B = M_A \times B_A \div B_B$

Overview of Texture-Hydrocolloid Combinations

Type of use	Agar	Carrageenan	Cornstarch	Gelatin	Gellan	Guar gum	Gum arabic	Konjac	Lecithin
emulsion	✓			✓	✓				✓
film	✓			✓	✓				
fluid gel	*	✓*			✓			*	
foam	✓*	✓*	✓	✓*				*	✓
frozen	*	*	✓	✓	✓	✓*		✓	✓
gel	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓
liquid	✓	✓*	✓	✓	✓	✓			✓
noodle	✓*				✓*			✓	
other use	✓			✓		*	✓		✓
solid			✓		✓			✓	
solid foam	✓*		*	✓*		*	✓		
spherification	✓*	✓		✓	✓				

✓ appropriate for this use by itself; *appropriate for this use when combined with other hydrocolloids—see Hydrocolloid Interactions, page 42.

Common Kitchen Chemicals

Popular name	Synonyms	Formula	Chemical Abstracts Service registry number	E-number
calcium chloride	calcium(II) chloride, calcium dichloride, anhydrous calcium chloride	$CaCl_2$	[10043-52-4]	E509
calcium gluconate	calcium *(2R,3S,4R,5R)*-2,3,4,5,6-pentahydroxyhexanoate	$C_{12}H_{22}CaO_{14}$	[299-28-5]	E578
calcium lactate	calcium 2-hydroxypropanoate	$C_6H_{10}CaO_6$	[814-80-2]	E327
calcium lactate gluconate	Glocal	$C_9H_{16}CaO_{10}$	[11116-97-5]	E327, E578
carbon dioxide		CO_2	[124-38-9]	E290
citric acid	2-hydroxypropane-1,2,3-tricarboxylic acid	$C_6H_8O_7$	[77-92-9]	E330
cream of tartar	potassium bitartrate, potassium hydrogen tartrate	$KC_4H_5O_6$	[868-14-4]	E336
glycerol	glycerine, glycerin, propane-1,2,3-triol	$C_3H_8O_3$	[56-81-5]	E422
isomalt		$C_{12}H_{24}O_{11}$	[64519-82-0]	E953
lime	pickling lime, calcium hydroxide	$Ca(OH)_2$	[1305-62-0]	E526
nitrous oxide	dinitrogen oxide	N_2O	[10024-97-2]	E942
potassium citrate	tripotassium citrate	$C_6H_5K_3O_7$	[866-84-2]	E332
potassium phosphate	potassium dihydrogen phosphate	KH_2PO_4	[7778-77-0]	E340
sodium citrate	trisodium citrate, trisodium 2-hydroxypropane-1,2,3-tricarboxylate	$Na_3C_6H_5O_7$	[68-04-2]	E331
sorbitol	*(2R,3S,4S,5S)*-hexane,1,2,3,4,5,6-hexol	$C_6H_{14}O_6$	[50-70-4]	E420

Locust bean gum	Maltodextrin	Methylcellulose	Pectin	Sodium alginate	Tara	Xanthan
		✓				✓
		✓	✓	✓		
						*
	✓	✓*	✓			✓*
✓*						✓*
*	*	✓*	✓*	✓	✓	✓*
✓	✓	*	✓			✓*
*		✓				*
		✓	✓			✓*
	✓		✓			
		✓	✓*			✓*
*				✓		

Calcium Content of Selected Foods

In nutrition tables, the calcium content of foods is typically reported in mg/100 g. A content of 100 mg/100 g corresponds to a calcium concentration of 0.025M. Some typical calcium concentrations are given in the table below. Note that the calcium is not necessarily present in a form that makes it available for gelling purposes.

Food product	Calcium content (mg/100 g)	Calcium molar concentration (M)
milk	100	0.025
yogurt	128	0.031
brie	510	0.127
mozzarella	720	0.179
semisoft or hard cheese	800	0.199
ice cream (heavy cream or milk-based)	120	0.029
soy flour	210	0.052
sesame seeds	980	0.244
dried figs	250	0.062
almonds	240	0.059
frozen spinach	280	0.069
black currant	65	0.016
rhubarb	140	0.035

Rheologic Descriptions of Food Gels, Liquids, and Foams

State	Term	Description	Examples
solid	elastic	recovers its original shape after pressure has been applied	gummy bear, marshmallow
	plastic	permanently deforms after pressure is applied; deformable without rupturing	starch custard, panna cotta
	brittle	hard gel that tends to easily fracture or crack	hard-boiled egg white, tofu, agar gel
	soft	has low resistance to deformation when pressure is applied; gel or solid is composed of fine-grained particles	crème brûlée, soft-boiled egg
	firm	has high resistance to deformation when pressure is applied	Gruyère
	chewy (gummy)	has high resistance to breakdown upon chewing	pâté de fruit, gummy bear, mozzarella curd
	short	tends to fracture easily despite being perceived as plastic; has low resistance to breakdown upon chewing	brie
	long	fails to fracture until deformation becomes relatively large; stringy	string cheese
	crumbly	tends to break down easily into small, irregularly shaped particles	feta cheese, hard-boiled egg yolk
fluid	gelatinous	has high viscosity and adherence; tends to coat surfaces at a slow flow rate	demiglace
	stringy	forms cohesive strands that adhere to each other when agitated or masticated	starch-thickened sauce; mature, runny cheese
	creamy, smooth	causes no resistance on palate; continuous and even (homogenous) fluid with very fine suspended particles	custard, mayonnaise, oil
	grainy	causes resistance on palate; loose or rough fluid with coarse suspended particles	grits, porridge, coarse nut butter
	sticky, syrupy	tends to resist separation from another material it comes in contact with	honey, sugar syrup
	thixotropic	viscosity decreases as duration of force applied increases	honey
	shear thickening	viscosity increases as amount of force applied increases	thick cornstarch slurry, cream cheese
	shear thinning	viscosity decreases as amount of force applied increases	ketchup, whipped cream
foam	coarse	tends to fracture easily when force is applied; has a large bubble size and low to medium foam stability	milk shake, sponge cake
	fine	tends to fracture easily when force is applied; has a small bubble size and medium to high foam stability	beer foam, marshmallow
	dry	has a low moisture-retention capacity	sponge cake, baked meringue, lecithin foam
	wet	has a high moisture-retention capacity	whipped cream, sabayon

Coffee beans

Mung beans