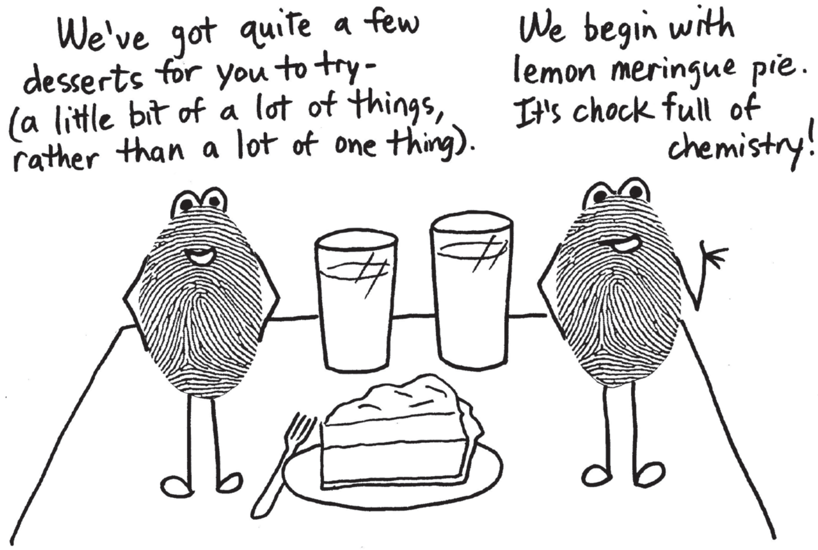
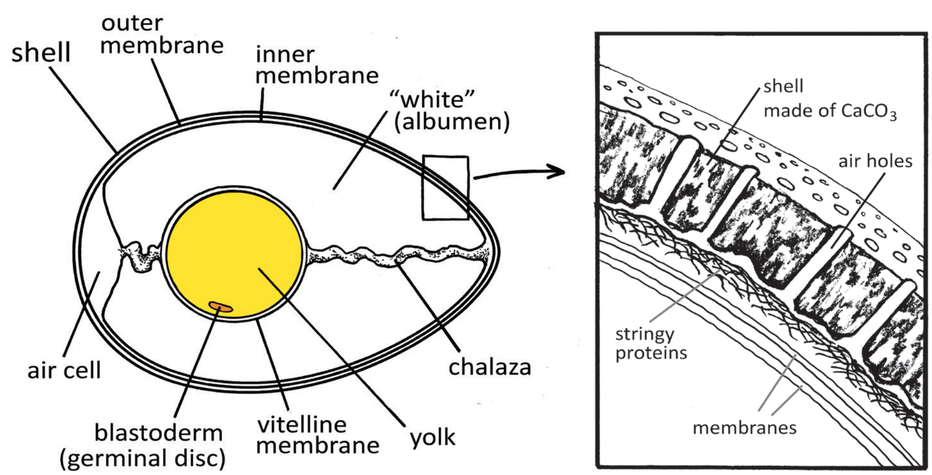
6: Dessert



Lemon meringue *(mer-RANG)* pie gives us three things to study: the yellow filling, the fluffy, white meringue, and the pie crust. The filling and the meringue are both made from eggs, but one uses the yolks and the other uses the whites. Before we get into the chemistry of each, let's look at the inside of an egg.



The ***shell*** is made of the same stuff as limestone rock—***calcium carbonate***, $CaCO_3$. There are two thin ***membranes*** just inside the shell; they serve as a barrier to bacteria, and they keep the eggs from drying out. The outer membrane sticks to the shell and the inner membrane sticks to the albumen.

Egg white, also called ***albumen*** (from the Latin "albus" meaning "white"), is 90% water and 10% protein. The protein in egg white is a mixture of proteins, not just one type, but for our purposes we don't need to know all the names of these proteins. The role of the egg white is to insulate and protect the yolk, and also to provide proteins for the developing bird embryo if the egg happens to be fertilized (with sperm by the male before the egg develops) and is kept warm by an adult bird, or inside an incubator device at a hatchery.

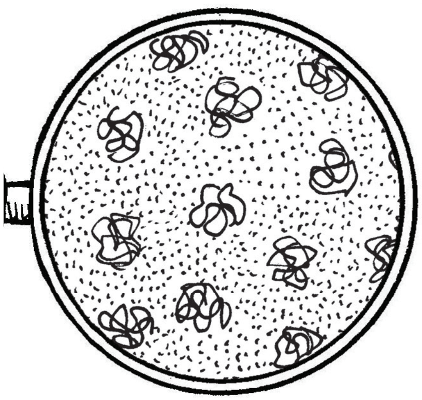
Egg yolk is full of all kinds of things—vitamins, minerals, proteins, fats, beta-carotene (which provides the yellow color), and ***lecithin***, a type of emulsifier. (Remember how we used eggs as an emulsifier for making mayonnaise?) The reason that the yolk is so rich in nutrients is because it is the primary source of nutrition for a growing bird embryo. The part labeled ***blastoderm*** is where an embryo will start to grow in a fertilized egg. (Please note, however, that eggs you buy in a store can't ever grow into a baby bird. Hens will lay eggs regardless of whether there is a rooster around to fertilize the eggs. If an egg is not fertilized, it has only half the amount of DNA it needs and therefore can't grow an embryo. Even if you get your eggs from a farm that keeps roosters, the eggs will have been kept at a temperature that prevents the growth of an embryo.)

The ***chalaza*** is the anchor that keeps the yolk in the middle of the egg. The ***air cell*** is always at the large end of the egg and provides a good place for gas exchange, allowing oxygen to come in and carbon dioxide to flow out. Gas exchange can occur in other parts of the egg, also, because the shell has over 10,000 microscopic holes.

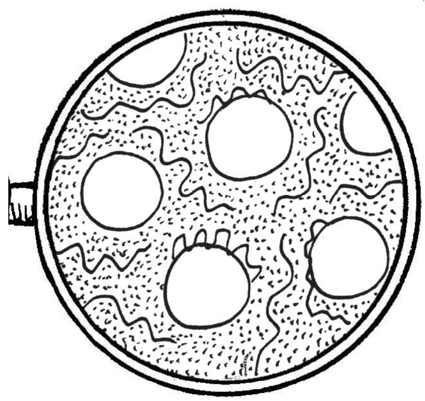
The process of making a lemon meringue pie starts with separating the eggs. You crack an egg and then very carefully tip the halves back and forth, allowing the white to slop out into a very clean bowl. You have to be careful not to let even the tiniest bit of yolk get into the whites because the chemistry of the fluffy meringue depends on it.

The proteins in egg white come in little clumps. This is their "natural" state. When egg whites are whipped, the little balls are disrupted and they come apart. After the proteins unfold, we say that they have been ***denatured*** (taken out of their natural state).

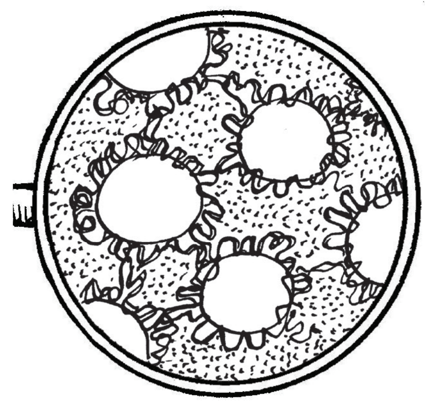
Whipping the egg whites also introduces lots of tiny air bubbles. (Cooks have discovered that the whites will whip better at room temperature than at refrigerator temperature. Cold proteins apparently don't unfold as well as warm ones.) The denatured proteins are attracted to the air bubbles and begin to stick around the edges. Soon the air bubbles have been completely coated with a thin layer of proteins. We might imagine these bubbles as tiny balloons made of proteins instead of latex rubber. The end result is a massive network of microscopic protein balloons all stuck together. These little balloons can be made more stable by cooking the meringue. This toughens the proteins and helps the balloons not to pop.



1) Egg white before whipping, with clumps of proteins.



2) Egg white during whipping. Proteins unfold and air bubbles appear.

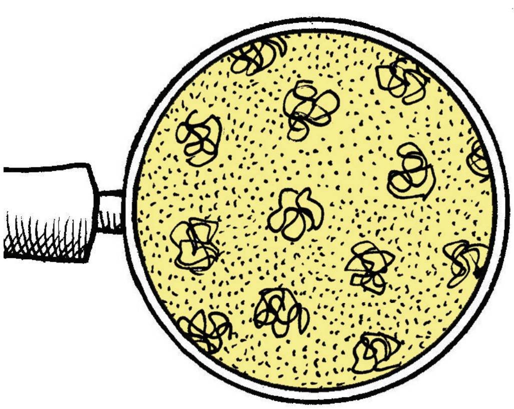


3) Proteins stick to the edges of the air bubbles and stabilize them.

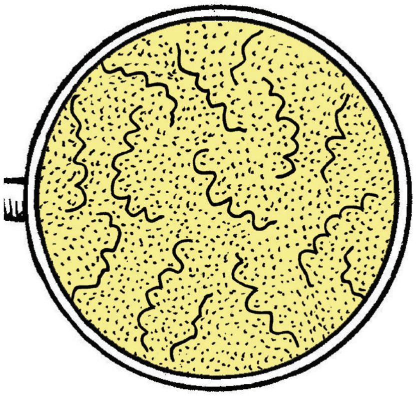
Another trick that cooks use to stabilize the meringue "sponge" is to add some cream of tartar and some sugar during the process of whipping the egg whites. However, these substances slow down the denaturing of the proteins, so you can't add the sugar and/or tartar too fast. You add a little at a time while doing the whipping. The key is to be patient and allow the meringue to develop slowly. When the meringue starts making tall peaks with pointed tops, you know it is time to turn off the beater.

Before modern times, when cooks did not have access to all the conveniences we have today, such as baking powder and gelatins, eggs were the primary ingredient used to thicken liquids and to help baked goods attain a lighter texture. The chemistry behind these uses for eggs is essentially the same as the process we just saw in the meringue. Heat can also cause the egg proteins to denature and then rearrange themselves.

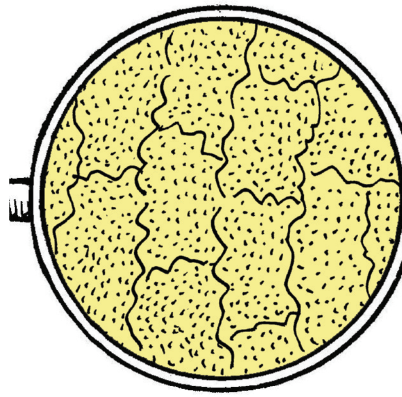
The egg yolks in our filling start out looking a lot like the whites, but with yellow beta-carotene.



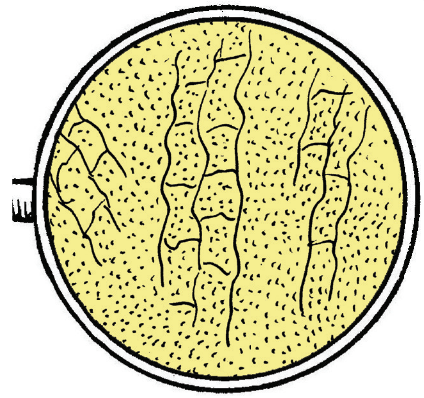
All the fats, lipoproteins and emulsifiers in egg yolks slow down the processes of denaturing and coagulation (reforming into new structures). This is the reason that egg custards take so long to bake in the oven. Adding milk or water can slow down the process even more, but the result is an enjoyable, smooth, mildly firm texture.



1) Heat causes the clumped proteins to unfold and become "denatured." Water flows freely around them.



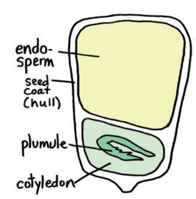
2) The proteins begin to coagulate and form new structures. Water is trapped in pockets and cannot flow.

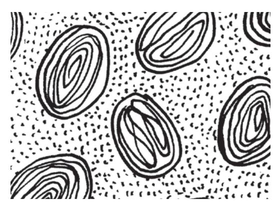


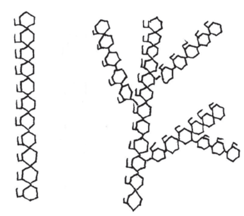
3) This is what happens when egg proteins are over-cooked. The structures shrink and water is released.

What would the textures of the above pictures be like? In the first picture we have water and proteins floating around freely, so the mixture would be watery in our pan. In the second picture, protein structures have created "pockets" trapping water molecules inside so that water can't flow freely. This texture would be a soft solid, harder than pudding but softer than jello. In the third picture, we left the egg custard in the oven a little too long and the protein structures shrank and became tighter. If we took at bite of this, we'd find it to be very runny, with rubbery strings or clumps of protein. We should have set a timer!

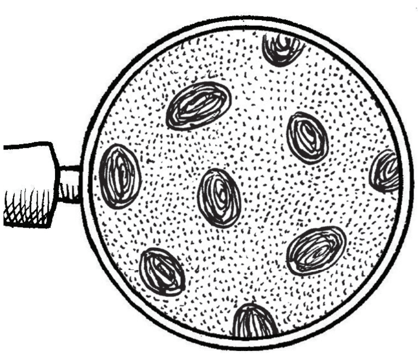
The recipe the chef used for the lemon filling also called for some cornstarch, to add additional thickening. (If we had used whole eggs, we'd have had extra thickening help from the whites.) We saw starch granules in the last chapter. They are inside amyloplasts and are made of long strings of glucose molecules, either in straight lines or in branched shapes. In corn, the starch granules are found in the endosperm part of the seed.



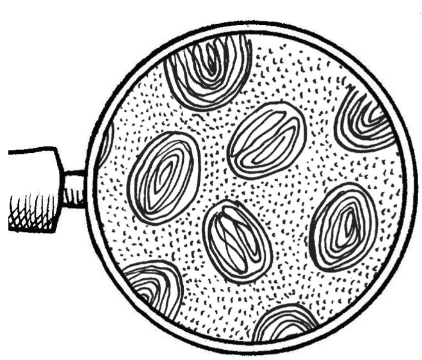




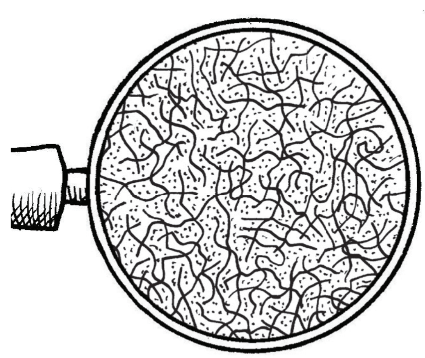
The cornstarch is combined with some water and sugar and then put on medium heat and stirred constantly so the starch won't stick to the bottom or sides of the pan. As the solution warms up, the starch granules start to absorb water. (Imagine balloons slowly filling with water.) As the granules swell, the solution starts to get a little thick. Then, suddenly, many of the granules burst and the amylose chains spill out. The chains get all tangled up and hold water in little pockets so it can't flow freely (as we saw with the eggs).



1) Starch granules floating in water. The granules contain amylose chains.



2) Starch granules swell up with water as the water becomes very warm.



1) Starch granules explode and release amylose. Water can't flow very well.

Since this is not a cookbook, we won't go into all the details about exactly how to make lemon meringue pie. We just need to make sure we've looked at the molecules. We just learned about eggs and cornstarch, and in past chapters we've discussed sugar, salt, water, cream of tartar, butter and vanilla. The remaining essential ingredient—lemon juice—has chemicals that belong to categories we've already discussed: vitamin C, B vitamins, flavonoids, natural oils, acids, and amino acids. So let's move on to looking at that pie crust.

Some people make pie crust with just butter, but many people use a combination of butter and shortening. We decided to put shortening into our crust so that we could yak on at you about the chemistry of hydrogenated oils. You don't have to eat the crust, but you do have to learn about its molecules. (If you can't remember a thing about butter, you might want to take a few minutes to go back and review those pages at the beginning of chapter 3. We're going to dive right into shortening chemistry.)

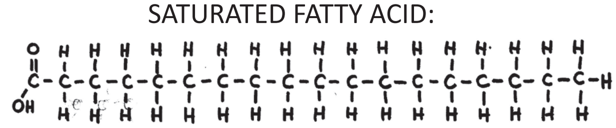
Shortening is usually made from soybean oil. We saw "oil bodies" in bean seeds on page 83. (If you would like to see the process of oil extraction, there are a few videos posted on the youtube channel.) All vegetable oils are made of those 3-legged triglyceride molecules. The "legs" are made of chains of carbon atoms that are usually about 16 to 18 carbons long. Most of these carbon chains have at least one double bond, and many of the chains will have several double bonds. A double bond means that there are two hydrogen atoms "missing" and the carbon atoms at that place are having to improvise by "holding hands" with each other instead of with hydrogens.


soybean pods

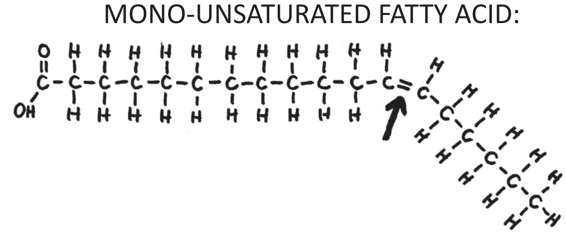

harvested beans

Carbon atoms make four bonds. We can imagine these bonds as "arms" that are holding on to other atoms. In our illustration, the lines are the "arms." Notice that each C has four lines going out from it, though the lines are often shared. In the saturated fatty acids, the carbons are holding on to the maximum number of hydrogens that they can possible have. In the mono-unsaturated fatty acid, we see one place ("mono" means "one") where two H's are missing. The carbon atoms do a double handshake to compensate. Unsaturated means "not completely full."

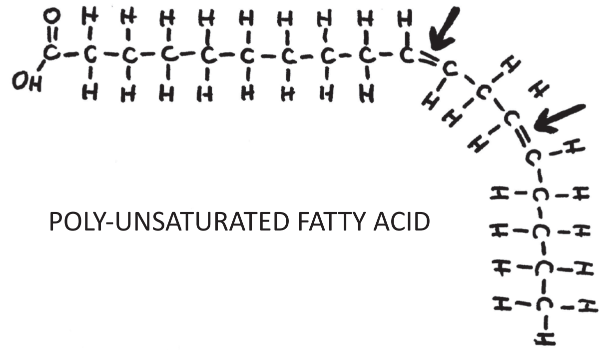
SATURATED FATTY ACID:



MONO-UNSATURATED FATTY ACID:

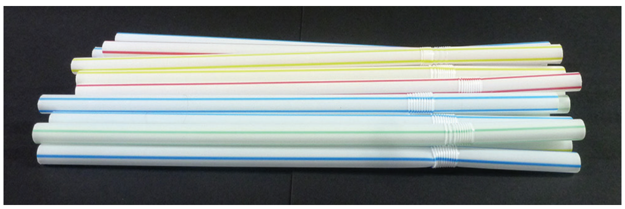


Some of the fatty acids we find in soybean oil are poly-unsaturated, meaning that there are multiple places with a double bond due to "missing" hydrogen atoms. In a previous chapter we commented that when hydrogens are missing, the molecule will bend, due to the fact that the hydrogen atoms really don't like to be next to each other, so when a gap opens up they will shift their positions a bit. In the last chapter we learned that when the first double bond occurs at the third carbon from the end of the string, we call it an "omega-3" fatty acid. This unsaturated molecule is an omega-5, not an omega-3.



POLY-UNSATURATED FATTY ACID

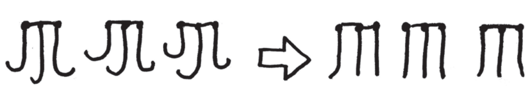
Let's imagine our fatty acids to be plastic straws. Saturated fats would be straight straws, and unsaturated fats would be curved straws. Which type of straw would take up more space?



The straight straws line up very nicely into a compact bundle. The curved straws have an awkward shape and therefore can't be compact. We are told that saturated fatty acids, being a straight line, are like the straight straws and form a compact solid, like the white fat we find on red meat. Unsaturated fats are like the curved straws and are more loosely held together and therefore tend to be liquids, like olive oil or corn oil. Some natural oils, like coconut oil, are a mix of saturated and unsaturated, so they have properties of both. On cold days, your jar of coconut oil will be a white solid. On very hot summer days, your coconut oil will turn into a thick liquid.

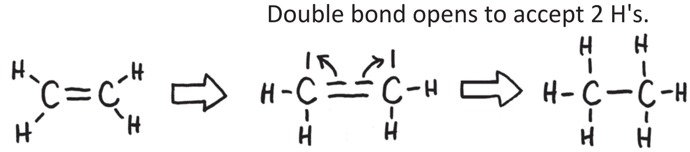
The triglycerides in soybean oil are made of (mostly) unsaturated fatty acids. When the soybeans are pressed, the oil comes out as a liquid. If we can force these unsaturated molecules to accept hydrogen atoms, they will be turned into saturated molecules and therefore take on a more solid texture. This process is called ***hydrogenation***. The oils are exposed to hydrogen gas in the presence of a catalyst, usually a metal such as nickel or platinum. The only role the catalyst plays is to provide an environment that encourages the carbon chains to open up and accept more hydrogens.

HYDROGENATION TURNS CURVED, UNSATURATED FATS INTO STRAIGHT, SATURATED FATS



WHAT HAPPENS DURING HYDROGENATION:

Double bond opens to accept 2 H's.



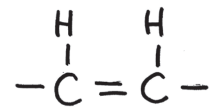
The process isn't perfect and some chains just can't be convinced that it is a good idea to open up their double bonds. When only some of the molecules have been changed, we saw that the oil has been ***partially hydrogenated***. If you start reading labels on boxes of crackers and cookies you will often see "partially hydrogenated soybean oil" listed as an ingredient. Partially hydrogenated oils have an ideal texture for making baked goods.

Hydrogenation offers an additional benefit. Baked goods made with partially hydrogenated oils are more "shelf stable," meaning the product won't go stale as quickly. This is a huge advantage for large manufacturers who don't know how long their products might sit on a shelf at a small country store. They don't want unhappy customers complaining about boxes of stale biscuits.

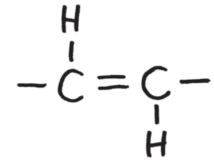
(Whoa, that's one unhappy customer!)

Hydrogenated oils seemed almost too good to be true. Modern science had made it possible to take inexpensive soybeans and turn them into a solid fat that had a perfect texture for baking AND had a long shelf life. All was well in the industrial baking world until someone discovered a seemingly minor issue that was having seemingly major effects on people's health.

There are two ways that these double bonds can be configured. One option is that the H's are on the same side of the bond. We call this the "***cis***" *(sis)* format. The other option is that they are on opposite sides. We call this the "***trans***" format. You've probably heard about "trans fat." In the past few decades there has been a considerable amount of research on these types of fat, and evidence has been growing to support the idea that cis fats are better for you than trans fats. It seems strange that such a small difference in a molecule can be so important.



CIS FAT



TRANS FAT

What's so bad about trans fats? Scientists speculate that the trans shape tends to get stuck in bad places, such as along the insides of our blood vessels. A build-up of fat in small blood vessels will narrow their diameter and make it hard for blood to get through. Yeah, not good.

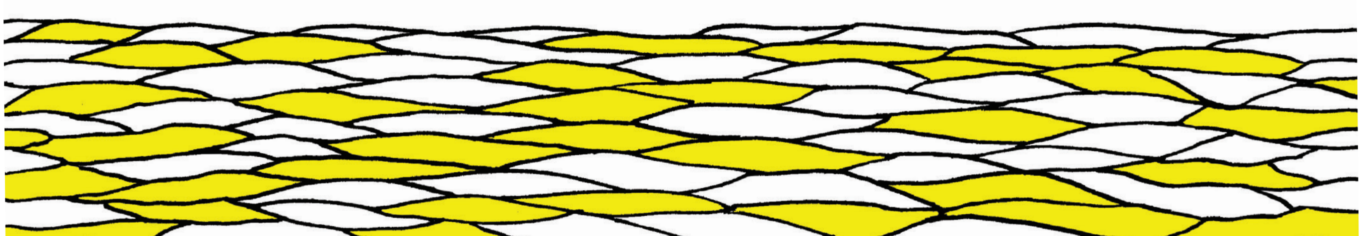
When researchers examined the partially hydrogenated oils that food companies were using, they found a considerable number of fatty acids with double bonds in the "trans" configuration. When this news reached the general public, many people went into a panic and some got very angry at large manufacturing companies. Governments began to ban all products that contained trans fats. Companies that processed vegetable oil had to quickly figure out a way to reduce the number of "trans" molecules in their hydrogenated oils. They seem to have succeeded, and we now see "NO TRANS FAT" proudly printed on the labels of many food products.

Here is the list of ingredients in our shortening: **Soybean oil, fully hydrogenated palm oil, palm oil, mono and diglycerides, TBHQ and citric acid.** Notice that "partially hydrogenated oil" is not in the list. Palm oil contains a mix of saturated and unsaturated fatty acids, but, because it is a natural product, is unlikely to have many trans fats. The last two ingredients, TBHQ and citric acid are preservatives that keep the oil from going rancid. (TBHQ stands for "tertiary butylhydroquinone.") We briefly discussed preservatives in chapter 2 and explained why food companies use them. If a company produces products that go bad easily, they don't stay in business long. People can say they don't want "chemicals" in their food, but they would be even more unhappy if their food was stale, rancid, or had bacteria growing in it.

Although this book is not about cooking, let's take a minute to discuss how pie crusts are made because they can show us how the ***physical properties*** of a substance can be manipulated. As a general rule, we don't have any chemical reactions going on here. All the ingredients keep their chemical identity.

The chef who made your pie crust had a tricky job. The flour and the fats had to be combined in a way that would make the crust both flaky and tender. The goal is to have thin layers of fat and flour that are not completely mixed together. Pie crust is the opposite of bread—you don't want to knead it. The less you touch it, the better. You roll it just enough to flatten it, and then stop.

A close-up cross section of pie crust would look like flat pieces of fat interspersed with flat bits of flour.



YELLOW IS FAT, WHITE IS FLOUR

The gluten in the flour is both friend and foe. Too little gluten and the dough will be impossible to roll. Over-developed gluten will make the crust tough. For this reason, "pastry flour" is lower in gluten than bread flour. When water is added to the dough (last step), the gluten problem will increase. Often, ice water is used because very cold water will be even less inclined to react chemically with either the flour or the fat. Other ingredients are often kept cold, as well. Some recipes recommend putting the dough into the refrigerator for a few hours before starting to roll it out.

Fortunately, the chemistry in this dessert will seem very familiar, because both the gelatin and the whipped cream involve thickening—a topic we've already been learning about.

The history of gelatin goes back to the 10th century (the 900s). In an Arabic cookbook that dates to this time period, we find a recipe for fish "aspic." ***Aspics*** are savory (not sweet) gelatins that contain pieces of meat, fish, vegetables or egg. The Arabic recipe called for boiling several fish heads with vinegar, parsley, onions, black pepper, and various other spices. Saffron was then added to give it a radiant red color. The fish heads were eventually removed but the eyes and lips were returned to the broth which was left to cool until it hardened.


Pork jelly is an aspic that is very popular today in Eastern European countries.

By the 1300s, aspic technology had moved into Europe and French cooks found additional methods of gelling meat broths. In the 1400s, people in Britain discovered how to extract gelatin from boiled cow hooves.

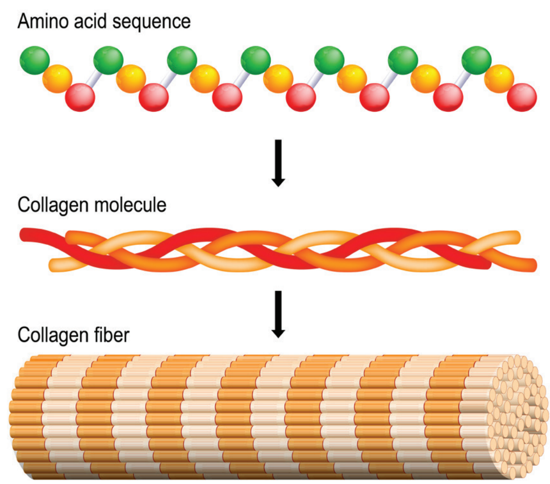
In the 1700s, a French chef received a patent for a process that used cow bones to make gelatin. Soon after, it was discovered that the gelatin could be poured out into sheets and allowed to cool, making a product that could be stored and used at a later time. Gelatin continued to be sold in sheets until the mid 1800s when Americans discovered how to dry the gelatin and crush it into a powder. The brand name Jell-O® began in 1897 in New York. Jell-O® wasn't an overnight success. It took a decade of marketing and advertising before Jell-O® achieved the popularity we associate with it today. One advertisement from 1910 read like this:

"Who likes Jell-O? The children. Do you remember the dreadful disappointment it used to be in the old days at home when mother brought on for dessert some baked apples or pie-plant pie, or something else that was "common," and you wanted shortcake or pudding? Now, the little folks want Jell-O. Every child loves Jell-O which is so delicious and refreshing, so full of nutriment, so pure and wholesome, so economical and so easily prepared, that there is no reason why the little tots, or anybody else, should be disappointed in dessert. The whole family like it just as well as the littlest members. A Jell-O dessert costs ten cents and can be made in a minute. It sounds almost too good to be true, but it isn't."

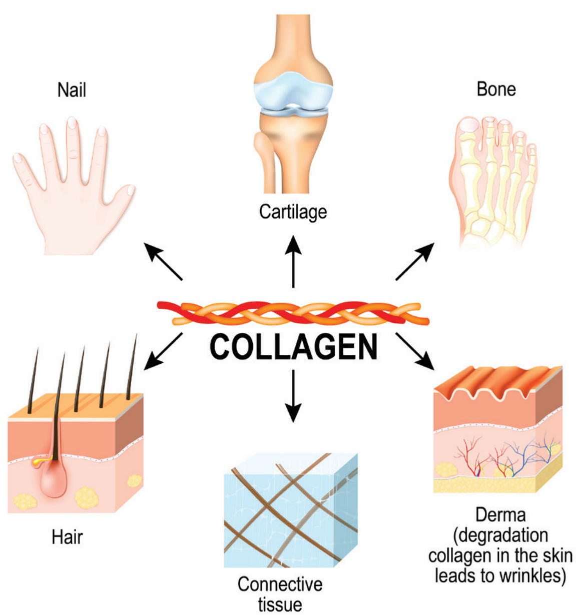
Jell-O was not immediately successful. It took years of advertising to make it into a heavily consumed product. The company gave away free cookbooks that had recipes for gelatin-based desserts.

Now for the chemistry of gelatin. We learned from our history lesson that this mysterious gelling agent could be extracted from fish heads, cow hooves, or cow bones. During the 1800s, the most popular source was pig skins, which the butchers would otherwise throw out. It wasn't until the 1900s that scientists really figured out what gelatin was made of.

The main ingredient is a protein called ***collagen***. Like all proteins, collagen is made of strings of amino acids. The amino acid glycine is very prevalent in collagen because it is so small. It allows the strands to wind tightly together. Three strings wind together to create a single strand of collagen. Multiple strands of collagen wind together to form a bundle called a fiber. Collagen fibers are found throughout your body, and there are over 20 different types of collagen. Some collagens form a scaffold in your bones into which hard minerals can be deposited. Your skin is loaded with collagen types 1, 3 and 4, which make the skin both strong and stretchy. Collagen is the fabric that holds all your blood vessels and organs together. It's also found in the connective tissues in your joints.

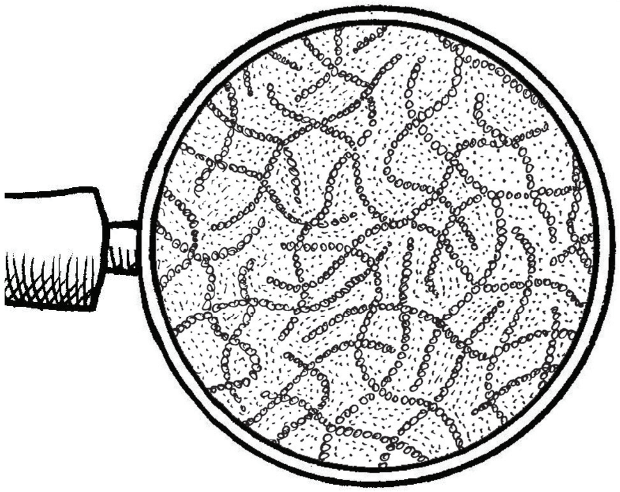


y



The diagram on the left explains why chefs have been able to extract gelatin from so many different animal body parts. Skin has the highest concentration of collagen, which is why pork skins took over the gelatin industry for many decades. Recently, there have been more options for consumers, such as kosher and halal gelatins made from fish or cow bones, or plant-based gelatins for vegans which are made from seaweed.

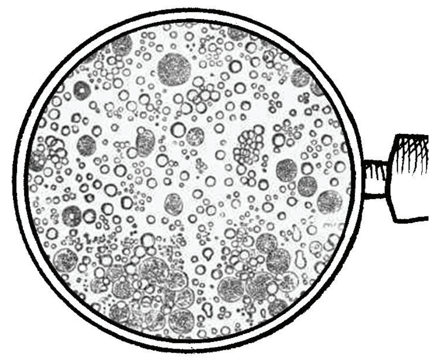
Extracted collagen has many other uses, besides making desserts. Many medicines come in clear capsules made of gelatin. Doctors use collagen products to heal wounds, and for reconstructive and cosmetic surgery. As long as a patient is not allergic to it, collagen from cows can be used in all these medical applications.



Now let's take a look at our gelatin dessert through our magnifier. We find a structure that is surprisingly similar to the lemon pudding that was thickened with eggs. We see long strands of protein (in this case collagen proteins) all tangled up so that the water can't flow around very well.

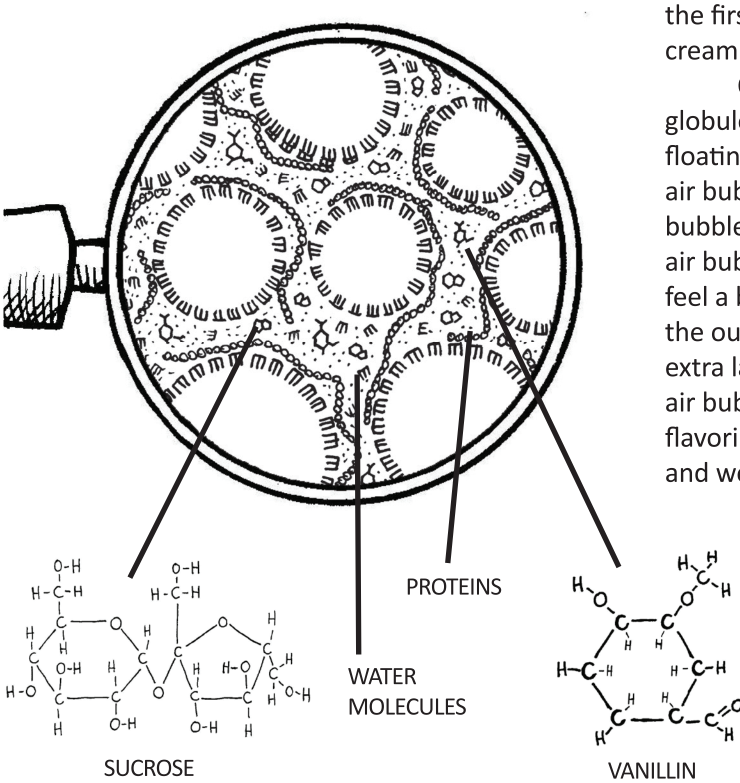
Water is the smallest molecule we see, but there are a few others almost as small, such as flavor molecules and pigment molecules. Our chef decided to use natural flavors and colors, so they would all be classified in one of those categories on page 67. Most instant jello mixes contain artificial dyes made from hydrocarbons that originally came from petroleum. We saw the Yellow #5 molecule back in chapter 2.

"Thickening" is a major theme in the world of desserts. In the whipped cream on top of the gelatin we see yet another example of something that was prepared by a thickening process. We were introduced to cream back in chapters 2 and 3, when we learned about milk and butter. Cream is made of water, a small amount of protein, and a lot of fat. The fat in cream is made of triglycerides that are inside globules surrounded by membranes. The cream is taken out of the milk and is used to make butter, or is sold as heavy or light cream, depending on the fat content. Only cream with at least 35% fat content will make whipped cream. Light cream has about 20% fat, so don't ever bother trying to whip it. Heavy cream has 38% cream, so it will make the best whipped cream. (Just for comparison, whole milk is 3-4% fat, and half-and-half is about 12%.)



globules of fat in fresh "raw" milk

Whipped cream reminds us of meringue, except that here we have tryglcerides stabilizing the air bubbles, instead of proteins.



During the whipping process, the globules are broken apart and the triglycerides are release. If you think this sounds familiar, you are right. This is also the first step in making butter. In fact, if you whip your cream too long, you'll end up with butter.

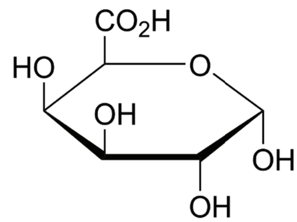
Once the triglycerides are no longer inside their globules, they begin freaking out because they are floating in water. Fats hate water! They see a nearby air bubble and turn their tails towards the inside of the bubble. More and more triglycerides do this, until the air bubble is covered with them. The small proteins also feel a bit lost in the mess and will tend to associate with the outside of these fat-covered bubbles, adding an extra layer of stability. Floating between these stabilized air bubbles are molecules of water, sugar and vanilla flavoring. We saw the sucrose molecule in chapter 1, and we looked at vanillin in chapter 2.

Instant whipped cream is cream that has been dissolved into compressed nitrous oxide gas. N_2O. As the gas is released this process happens very quickly.

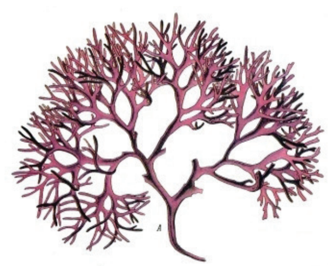
Before we leave the topic of thickening, we should mention a few other substances that can do this.

AGAR: Made from red seaweed that has been boiled so that cellulose and other polysaccharides are released. The reasons agar might be used instead of another thickener are: 1) it is 100% vegetarian, and 2) it remains a gel at room temperature, unlike gelatin which must be kept refrigerated. Agar is more commonly used in Asian cuisine, and it is also used in biology labs as a "growth medium" for bacteria cultures. Nutrients required by the bacteria are mixed into the agar. The petri dishes can sit at room temperature or even be kept warm and the agar will remain firm.

PECTIN: This is a natural substance found in fruit. The long molecular chains found in pectin are made of individual units called galacturonic acid (shown here). This is a galactose molecule with a COOH (acid) as the "flag" at the top of the molecule. Pectin is used to make jam and jellies. Jams that contain the whole fruit might have enough pectin in them to be able to "gel," but more often, extra pectin is added. Pectin is sold as a white powder, with the most well-known brand being Sure-Jell®.

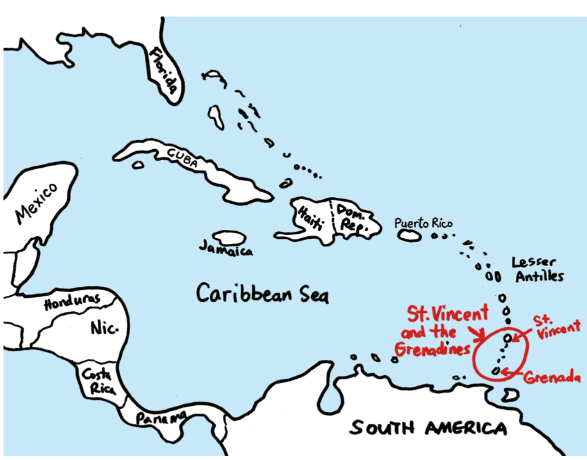


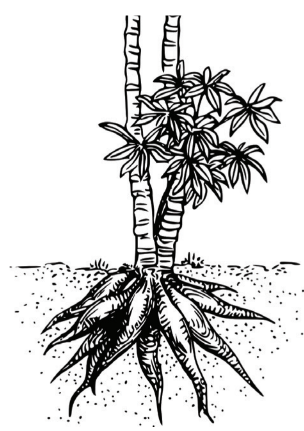
CARRAGEENAN: (called "E407" in Europe) This is another seaweed product. The word "carrageenan" comes from the Irish word "carraigin" which means "little rock." The red seaweed plant can be found growing on rocks along the coast of Ireland (where it is called **Irish moss**), as well along many of the rocky shorelines in northern Europe and North America. Seaweed isn't a plant, it is a type of algae. The carrageenan molecules that are extracted are "sulfated polysaccharides," which means "long chains of sugar molecules that have sulfur groups like SO_3 attached." The addition of sulfur groups tends to make the molecule more hydrophilic (water loving). Their hydrophilic nature makes them compatible with many milk and meat products, so carrageenans are used extensively in the manufacturing of ice cream, yogurt and other dairy desserts. It is natural product and can be included in products that are advertised as having "no artificial ingredients." Carrageenans are used in many non-food applications such as toothpaste, fire-fighting foams in fire extinguishers, shampoo, shoe polish, gel capsules for medicines, and in biotech they are used to hold cells and enzymes in place.



WHEAT STARCH: White wheat flour is the most popular choice of home cooks to thicken meat gravies. We know what starch is (very long chains of glucose molecules) so we don't need to say a lot more about it.

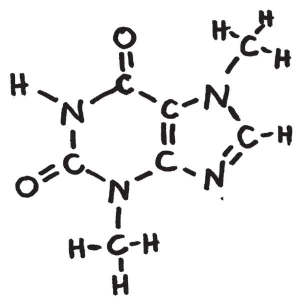
ROOT STARCHES: Another place we can find starch molecule is in certain types of roots. Tapioca starch and arrowroot starch are the best examples. These starches are soft, white powders and are especially good options for people who are allergic to corn and wheat. Tapioca starch comes from the roots of the cassava (manioc) plant. The word "tapioca" comes from the Tupi natives who lived in Brazil when the Portuguese explorers arrived in the 1500s. The word means "coagulated." No surprise there. Arrowroot plants grow in the tropics and the main producers today are the islands of St. Vincent and the Grenadines.





CASSAVA ROOTS

Yes, there is a chocolate molecule! Well... sort of. The molecule that gives us the distinct chocolate flavor is ***theobromine***. ("Theo" comes from the Greek word for "gods," and "bromine" comes from the Greek word for "food." Thus, we have "food of the gods," though the gods in this case weren't Greek, they were the Mayans of ancient Mexico.)



The plant that produces this chemical has the scientific name *Theobroma cacao*. The word ***cacao*** *(kah-cow)* is a very old Mayan word. We know how this word was written in the Mayan language. They used simple pictures, not letters, to represent syllables, so this word won't look like a word to you. Each part of the symbol stands for a syllable: "ka-ka-wa."

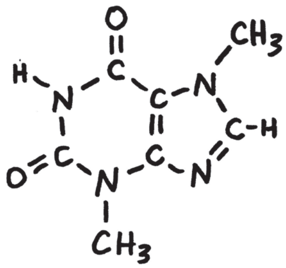
In the foreground we see an opened seed pod containing the raw seeds. In the background you can see the seed pods growing on the trunk of the tree.

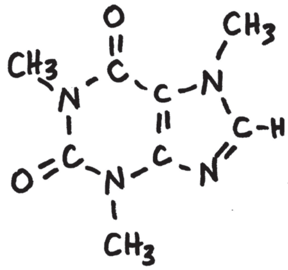
The cacao tree grows seed pods on the sides of its trunk. When you cut open a pod, it looks nothing like chocolate. You see a bunch of white, slimy seeds. It's hard to believe that these seeds will become dark brown cocoa powder. The beans will be put into large wooden boxes where they ferment for almost a week. (You'll remember that we learned about fermentation in chapter 3.) The fermentation of cocoa beans is accomplished by friendly bacteria. After this, the beans are dried for several weeks. Once dry, the beans can either be shipped to other parts of the world, or they can be used locally to make chocolate products.

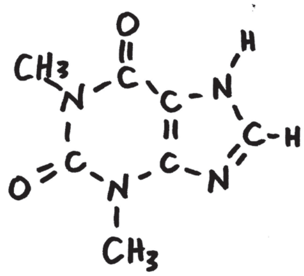
The next step is to roast the beans. Roasting changes the flavor and it also dries and loosens the thin hull surrounding the seed so that it can be removed easily. The roasted, hulled bean is then chopped into small pieces, called "nibs." The nibs are then ready to be ground into a fine powder. The powder is bitter and will need to be combined with a sweetener.

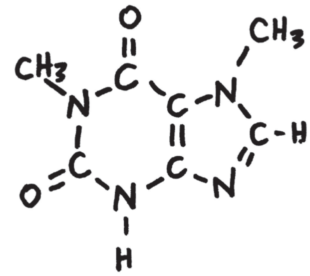
Half of the weight of cacao beans (or you can call them cocoa beans) is fat. If this fat is extracted we call it cocoa butter. It is a highly saturated fat and therefore has a long shelf life. Because it is so stable, it is used in beauty products, such as skin creams, that won't ever be refrigerated. 10 to 15 percent of the weight of the cacao bean is protein and the remaining 35 percent is carbohydrates, minerals such as potassium and magnesium, and a selection of chemicals related to theobromine.

Let's play "Spot the Difference" and look at four molecules found in cacao beans. Compare each one to caffeine (which we saw in chapter 2) and find what is different.


CAFFEINE


THEOBROMINE


THEOPHYLLINE


PARAXANTHINE

Caffeine seems to be the "parent" molecule from which the others are made. One evidence of this comes from physiology labs, where scientists have been able to track what happens to caffeine molecules after someone eats them. They discovered that when you consume caffeine, your liver will turn it into one of those other molecules as a first step in the digestion process. Interestingly, theophylline *(thee-OFF-ill-in)* is a molecule that is used as a medicine; it is given to people with asthma or similar breathing problems, as it causes the muscles in the airways to relax and open. Paraxanthine *(para-ZAN-theen)* has similar properties to caffeine, but isn't as potent; it is used in research but has no uses beyond that.

In addition to these chemicals, cacao contains many phytochemicals (flavonoids and phenols) that are antioxidants, helping to protect our cells from damage. This is why chocolate is often refereed to as a "superfood." However, it's not a superfood for our pets. Theobromine is manufactured by the cacao plant as a poison to kill bugs, and it can also have a toxic effect on dogs and cats. (Though the author's border collie once ate five pounds of marshmallow-filled chocolate candies and suffered no ill effects.) The biggest downside for humans of eating chocolate isn't the chocolate itself—it's the sugar that it is mixed with.

The other ingredients in your chocolate cake are things we've already discussed: flour (starch and gluten), sugar (sucrose), baking powder (baking soda plus a powdered acid), eggs, milk, and vegetable oil. Now let's look at what is on top of your cake. There's a dusting of powdered sugar, a drizzle of caramel sauce, and an edible flower.

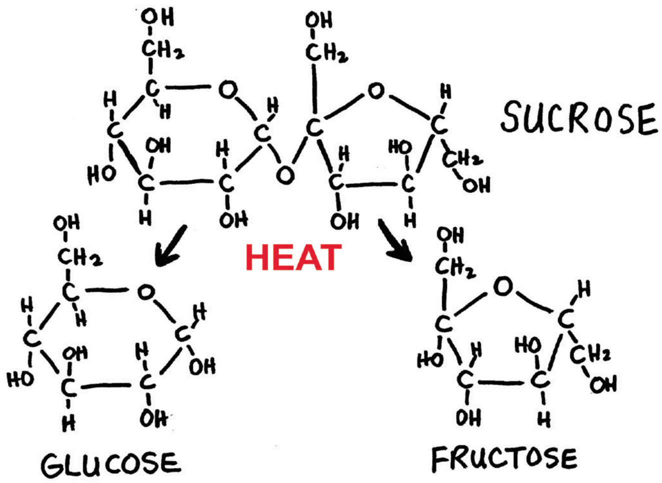
Powdered sugar, also called confectioners' sugar, is table sugar (sucrose) that has been ground with an industrial blender until it is a super-fine powder. Usually, a little bit of cornstarch, potato starch, or tricalcium phosphate is added as an "anti-caking agent." These additives absorb moisture and keep the powder dry and fluffy. Two other types of powdered sugar that professional bakers use are "caster sugar," which is not as fine as regular powdered sugar and does not have any starches added, and "snow powder," a mix of glucose and starch that is resistant to dissolving and can be used on damp products like fruit tarts or even ice cream.

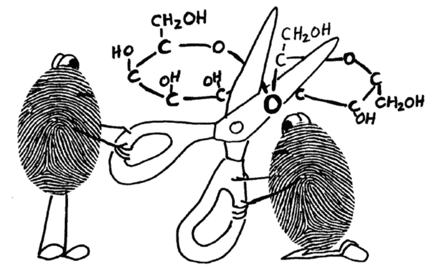

caramel apples

Caramel is plain old sugar (sucrose) that has undergone a chemical change. You'll remember that we saw some very odd chemistry happening in those ***Maillard*** reactions (chapter 3). Heat caused the breakdown of proteins, sugars and fats, and those broken molecules began sticking to each other to create "nonsense" molecules. We likened these "mutant" Maillard molecules to useless items created by merging appliances, tools, and toys. Those silly hodge-podge items certainly were strange. The reactions that happen in ***caramelization*** are similar to the Maillard reactions, but here we have only sugars, no proteins or fats, so our funny picture analogy won't work.

You can make caramel simply by heating sucrose, but usually a little water is added to slow down the process. Too much heat too fast will cause too much chemical activity and will result in molecules that taste bitter. Watching the temperature of the solution is a key to success, so cooks often use a "candy thermometer" when making caramel. The temperature of the solution must be kept under 375º F (190º C). You stir at first, but then, unlike many other recipes, you stop stirring and let the liquid boil undisturbed. Gradually, the liquid turns brown and you start to smell the new chemicals that are being formed.

In previous chapters, we saw sucrose and fructose separated by an enzyme. In carmelization, heat does the separation.

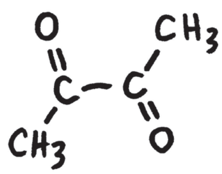




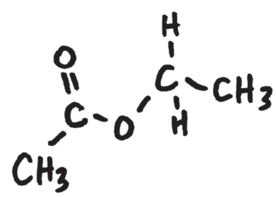
Remember this picture from chapter 1?

SIDE NOTE: A sugar syrup that is made of glucose and fructose molecules is called ***invert syrup***.

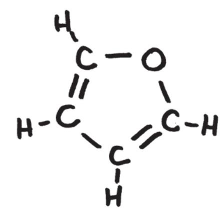
After fructose and glucose are formed, the heat continues its work and breaks them apart, too. Broken pieces of fructose and sucrose begin bumping into each other and forming new molecules. Some of the new molecules will be small enough that they will go up into the air and eventually into your nose where you will smell them. Taken all together, they will smell like caramel, but here is how people describe the individual smells:



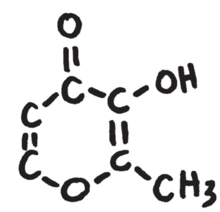
Diacetyl: "buttery"



Ethyl acetate: "fruity"



Furan: "nutty"



Maltol: "toasty"

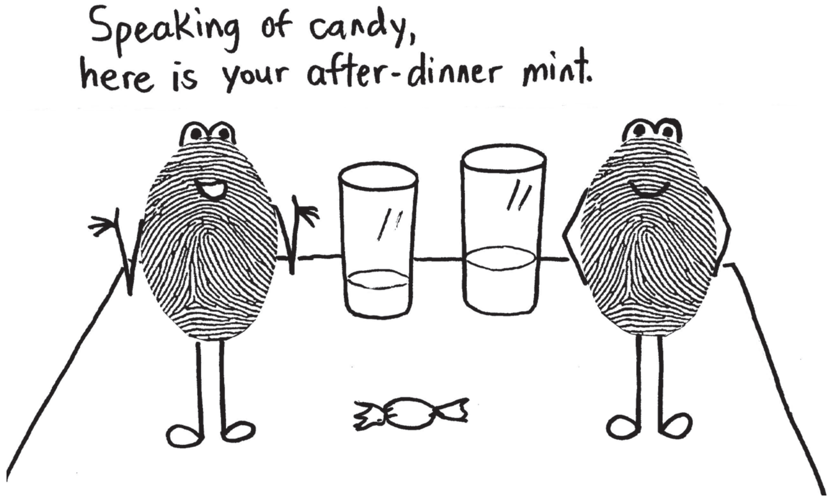
Can you see where these molecules might have come from? (Furan and maltol are the most obvious.)

Some really large molecule are formed, too. You can't find pictures of these molecules; they are known by their formulas and their names: Caramelan: $C_{12}H_{12}O_9$ Caramelen: $C_{24}H_{26}O_{13}$ Caramelin: $C_{36}H_{18}O_{24}$
They are what makes caramel thicken.

The edible flower on top of your cake is made of ***fondant***, a flexible blend of gelatin and sugar that can be rolled, cut, and molded into just about any shape. Fondant allows bakers to be artists. All the figures on this cake are made of fondant. You can eat the elephant!

Fondant can be molded into any shape.

Time and temperature plays a huge role in sugar chemistry. As we mentioned during the caramel discussion, the texture, color, and taste of sugar can change as it is heated. Candy thermometers are marked with words like these: soft ball, hard ball, soft crack, hard crack. These words describe what the mixture in your pot would be like if you took it out as soon as that temperature was reached.

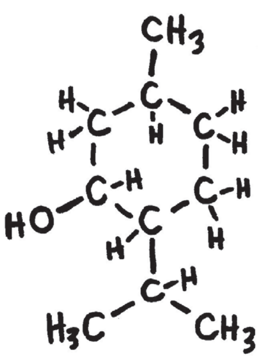


In hard candy that goes "crunch" when you bite it, the sugar has been cooked to the highest temperature on a candy thermometer, the "hard crack" (or "hard tack") level. It is a thick liquid when it is removed from the stove but quickly becomes hard as it cools.

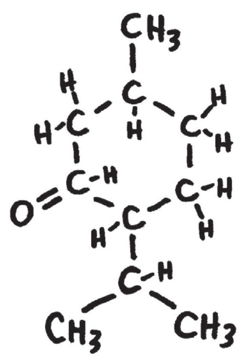
Besides the sugar in your peppermint, there are quite a few flavor molecules. Peppermint plants produce over a dozen flavor-related molecules, but we're going to look at just a few. The molecule that makes peppermint feel cool in your mouth is ***menthol***. Menthol works the same way capsaicin does—by interacting with a portal found in your nerve cells. You have both hot and cold sensors. Capsaicin stimulates the hot sensor and menthol stimulates the cold one. You also have these sensors in your skin, which is why some skin creams include menthol. A chemical that looks almost identical to menthol is menthone. We're going to ask you to spot the difference between menthol and menthoe, but we'll make it easier by showing you a more simplified way to draw these chemicals.

Here are the molecules with every atom shown.

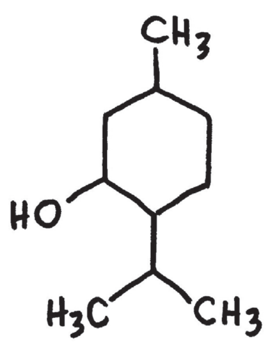
Here they are with some of the C's and H's taken out.



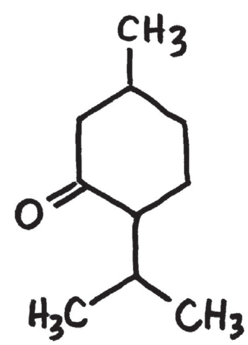
MENTHOL



MENTHONE



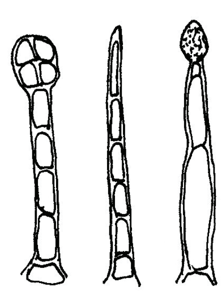
MENTHOL



MENTHONE

If you look at the simplified drawings, it is easy to see the difference. The simplified drawings are missing seven C's, plus the H's attached to the C's. Sometimes, chemists will even omit (leave out) the CH_3's. They will just leave a "stick" hanging off, and trust that you know there must be a carbon atom at the end, plus its three hydrogens. The simplified drawings are a little hard to read at first, but you can see why they are used.

The phytochemicals produced by the peppermint plant are intended to be insecticides that deter bugs from biting the leaves. These chemicals are found in cells that form tiny hair-like structures on the leaves and stems. These cells produce over a dozen phytochemicals as well as oils. When these hair-like structures touch something, they burst open, releasing their chemicals.

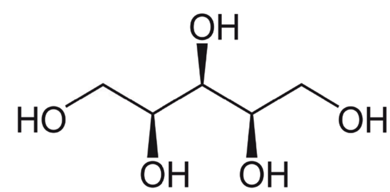


Any type of sweetener, be it sugar or a sugar substitute, does the same thing in your mouth. Not only do you have hot and cold sensors, you also have sweet sensors. Any molecule that is able to stimulate the sweet sensors in the nerve cells on your tongue will cause those nerve cells to send an electrical signal to your brain. Your brain will interpret this signal as "tastes sweet."

The most popular all-natural sweetener is ***stevia***. It comes from a plant called stevia. The name of the plant comes from the name of a Spanish botanist, Petrus Stevus. The molecule that triggers your sweet sensors is very large and complicated, so we're not going to bother you with it. Basically, it has a glucose molecule bonded to a larger molecule that you can't digest. So the sugar triggers the sensor but then passes through your intestines as fiber.

The native peoples of Brazil and Paraguay have been using stevia as a sweetener for at least 1,500 years.

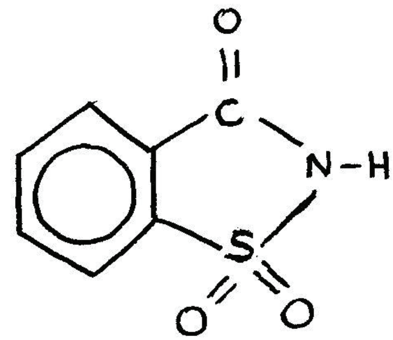
Another all-natural, no-calorie sweetener that is rising in popularity is ***monk fruit***. Monk fruit is estimated to be well over 100 times as sweet as sucrose, so just a pinch will sweeten your drink. As with stevia, the monk fruit has molecules that have sugars attached to them, but the sugars stay on the molecule and are not able to be digested by our bodies. So they tingle out sweet sensors, then pass through our systems undigested. Monk fruits have been grown in southern China for centuries and were known as Luo Han Guo. The name "monk fruit" comes from the fact that the monks of Luo Han used this plant for herbal medicine.



A natural, but processed, sweetener is ***xylitol***. "Xylo" is from the Greek word for "wood." The "-ol" on the end tells you that part of the molecule is classified as an "alcohol," meaning that is has an "-OH" bonded to each carbon atom. Xylitol occurs naturally in some fruits and vegetables but in very small quantities. Large scale production of xylitol was first proposed during World War II when sugar was in short supply. Xylitol can be made from almost any type of vegetation, including a lot of the waste (corn husks, rice hulls, bark, etc.) left over from other processes. The key molecule is xylan, which is found between the cells of almost all plants. The xylan undergoes several chemical processes to turn it into xylitol. Though not often used in kitchens, xylitol is widely used in sugar-free gum and candy.

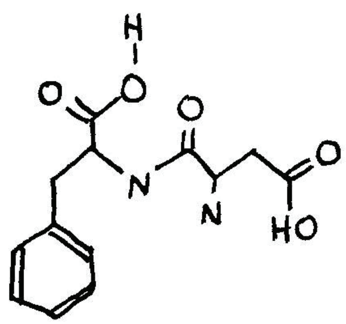
If you want to learn about some artificial sweeteners, you can read the following page. Oddly enough, all four of these sweeteners were discovered by accident!

"Oops! I discovered a sweetener…"



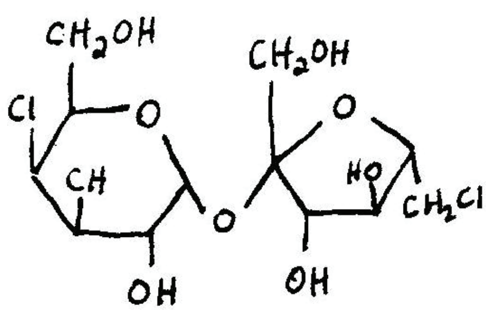
***Saccharin** (SACK-a-rin)* was discovered by accident in 1879 by a chemist named Fahlberg. He spilled an unknown chemical on his hand and didn't bother to wash up before dinner (not a recommended lab procedure). He noticed the bread he was eating was unusually sweet and by tasting residues on his clothes and hands (also not a recommended lab procedure), figured out that the sweetness had come from the chemical. He later named this chemical saccharin. By 1907, saccharin began to be used as a sugar substitute. In the 1960s it began to be used by the soft drink industry for diet sodas. Two sweeteners that contain saccharin are "Sweet 'N Low®" and "Sugar Twin®."

Despite the controversy over whether saccharin is safe for human consumption, not enough evidence has piled up to have it taken off the "generally recongnized as safe" list. This does not mean it is the right choice for everyone. Some people seem to have negative responses after eating saccharin.



Aspartame was discovered by accident in 1965 by a chemist named Schlatter. He was working on a project aimed at discovering new treatments for stomach ulcers. One of the steps in the process was to make something called "aspartyl-phenylalanine methyl ester." He accidentally spilled some on his hand and later licked his finger as he reached for a piece of paper (not a recommended lab procedure). He noticed a sweet taste and decided to test the chemical to see if it would sweeten his coffee. It did, and the rest, as they say, is history.

Cyclamate was discovered at the University of Illinois in 1937. A chemistry graduate student named Michael Sveda was working on developing a new fever-reducing medicine. Back then, it was considered normal to smoke cigarettes while working, so Michael was smoking as he was working with his chemicals. He laid his cigarette on the lab bench in order to use both hands to move some equipment. When he put the cigarette back into his mouth, he noticed a sweet taste and realized he had gotten cyclamate on it. The lab went on to patent cyclomate as an artificial sweetener and it was very popular in the U.S. until the FDA banned it in 1970. A rat study from 1969 had shown that 8 out of 240 rats came down with bladder cancer when forced to consume the amount of cyclomate you'd get if you drank 550 cans of diet soda every day. Some countries still use cyclomate.



Sucralose was discovered by accident in England. A British sugar company was doing research on sucrose. They were adding chlorine atoms to the sucrose molecules. They sent samples of this chlorinated sugar to one of their employees for testing. This particular employee was not a native English speaker and he misunderstood what they wanted. He thought they wanted it "tasted" instead of "tested." Well, he tasted it... and found out that this substance is about a hundred times sweeter than sugar.

NOTE: None of this information is intended to endorse any product.

NOTE: Don't forget to check the YouTube playlist one last time!

* *

Comprehension self-check

1) What is the primary role of the yolk and the white in a developing egg?

2) What is the role of the blastoderm spot on the yolk?

3) What is the name of the emulsifier found in eggs? a) albumen b) lecithin c) collagen d) carrageenan

4) Name two things that will cause egg proteins to unfold:

5) In meringue, the egg white proteins gather around ______ ______________.

6) When a protein unfolds and straightens, we say it has been: d__________________.

7) What plant is most often used to make vegetable shortening?

8) Which is curved, a saturated fatty acid or an unsaturated fatty acid?

9) Which contains double bonds, saturated fatty acids or unsaturated fatty acids?

10) Which will be a solid at room temperature, saturated fatty acids or unsaturated fatty acids?

11) When vegetable oils are hydrogenated, do they become more solid or less solid?

12) "Trans" means "across." In trans fats, ________________ atoms are across from each other.

13) Will you find trans fats in many products today?

14) Is a gelatin aspic sweet? What do people put into aspics?

15) Name three animal sources of collagen used for gelatin:

16) Cream is made of three-legged fat molecules called:

17) In whipped cream, the fat molecules collect around the outside of _____ ______________.

18) Name two thickeners made from seaweed:

19) What thickener is found in fruit?

20) TRUE or FALSE? Jell-O® was an instant success.

21) Name two plants that are used to make root starch thickeners:

22) Does theobromine taste sweet?

23) How much of a cacao bean is fat? a) 5% b) 15% c) 50% d) 95%

24) Which of these is NOT designed to be toxic to pests? a) caffeine b) theobromine c) pectin d) menthol

25) Cacao is considered a superfood because it contains:

26) Sucrose can be separated into glucose and fructose by ________________ or ________________.

27) Sugar syrup that has had its sucrose turned into glucose and fructose is called ___________ syrup. (pg. 111)

28) When broken sugar and protein molecules form nonsense molecules this is called the _____________ reaction.

29) Which of these is mixed with sugar to make fondant? a) gelatin b) starch c) fat d) vegetable oil

30) Which of these was not discovered by accident? a) aspartame b) stevia c) saccharin d) sucralose

ACTIVITY 6.1 And now for the bad news...

Sugar is so sweet and so much fun to eat, but sadly, the truth is that it's really not very good for us. Scientific studies have shown that eating more than a certain amount of added sugars per day can significantly affect your health, even if you are young. So how much is too much? Many health agencies recommend no more than about 36 grams (9 teaspoons) for an adult male and no more than 25 grams (6 teaspoons) for an adult female.

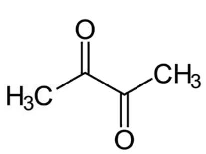
Food products that come in boxes and bags are required to tell you how many grams of sugar have been added. Some products have a surprising amount of sugar. For example, a can of soda ("pop") has about 40 grams (10 teaspoons) of sugar. Can you imagine eating 10 spoons of sugar? Yet when you drink a can of sweetened soda, that's how much sugar you are taking in.

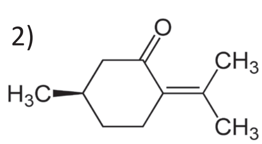
Find out how many grams of added sugar you eat in a day. Keep track of at least three days because, as we all know, some days you eat more or less of various foods. (The days don't have to be all in a row.) Under each day, list the name of the food and how many grams of sugar. (Don't count natural sugars, like apples.)

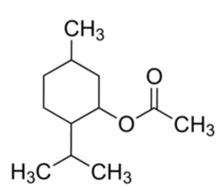
DAY 1	DAY 2	DAY 3
TOTAL:	TOTAL:	TOTAL:

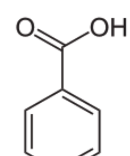
ACTIVITY 6.2 How many carbon atoms?

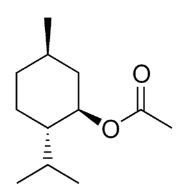
At the very end of this chapter we learned how chemists draw carbon-based molecules. They assume everyone knows that at every vertex (corner or intersection), or at the end of every empty stick, there is a carbon atom and enough hydrogen atoms to give the carbon the four bonds it wants. Figure out how many carbons are in each of these molecules. (Your answer will include any carbons that are shown as "C".)

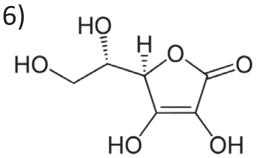
1) 

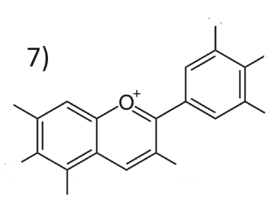
2) 

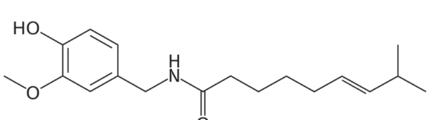
3) 

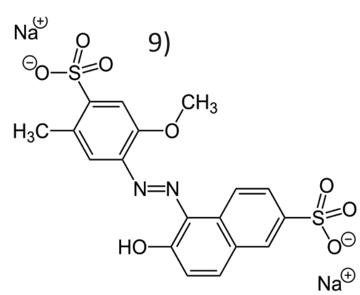
4) 

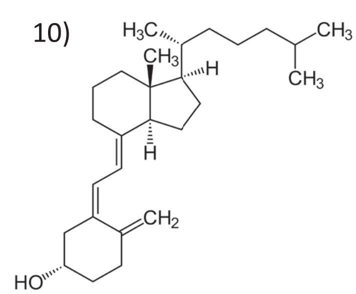
5) 

6) 

7) 

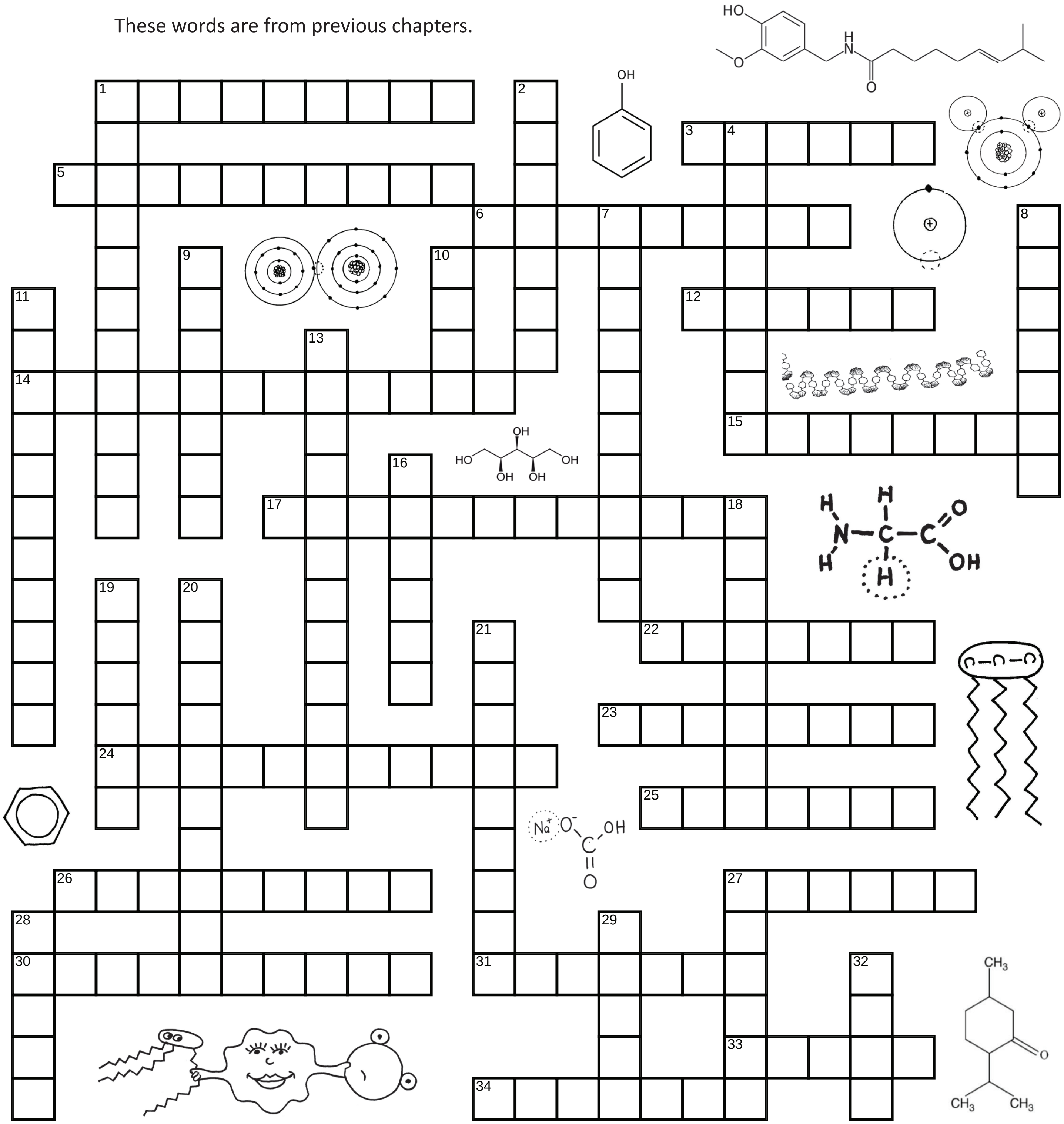
8) 

9) 

10) 

ACTIVITY 6.3 REVIEW CROSSWORD PUZZLE

These words are from previous chapters.



ACROSS
1) (OH-) is called the _______________ ion.
3) A polyphenol found in tea.
5) The structure in a plant cell where starch molecules are stored.
6) The molecule found in peppers that triggers the hot sensors in our tongue.
12) A "hydrogen ion" is the same thing as a ________.
14) A glycerol molecule with three fatty acids attached to it.
15) Liquids that have particles evenly dispersed through them. (Milk is an example.)

ACROSS (continued)
17) If you cut this molecule in half you get two retinol molecules.
22) A microscopic ball of protein found in milk.
23) The "amine" group contains two hydrogen atoms and a ________ atom.
24) The molecule that makes leaves green.
25) Six carbon atoms and six hydrogen atoms will form a _______ ring.
26) Most of a corn seed is made of ____________, which stores starch plus some other nutrients.
27) This element (type of atom) allows molecular bridges between long chains, such as glutenin and gliadin.
30) A substance that can hold on to both fat molecules and to water molecules.
31) Carbon dioxide and _______ are waste products created by yeast during the bread making process.
33) A potato is classified as this plant part.
34) The enzyme that can cut apart a molecule made of glucose and fructose.

DOWN
1) When milk fat globules are put through a screen that makes them all the same size they have been _________.
2) This type of nutrient is essential to life and was discovered by studying deficiency diseases.
4) Another name for vitamin C is _______ acid.
7) These are the things that enzymes put together or tear apart. (Bet you've forgotten what they are called!)
8) The enzyme that can take apart the sugar molecule found in milk.
9) The enzyme that can disassemble the long chains of glucose molecules that form starch.
10) These are usually blue or green and are put into certain cheeses to create distinctive flavors.
11) This pigment molecule produces both red and blue colors, depending on the surrounding pH.
13) When bacteria turn pyruvate molecules into lactic acid this process is called ___________.
16) The milk protein used for paint and glue.
18) A tiny particle with a negative charge.
19) A long chain of glucose molecules that we can digest.
20) Most of a bean seed is made of the "seed leaves" which are also called the _________.
21) A long chain of glucose molecule that we CAN'T digest.
27) In a salt water solution, the salt is the _______.
28) A one-celled fungus that is used to make bread rise.
29) What is known as the universal solvent?
32) Casein is the main protein in milk. All the other smaller proteins are known collectively as _______.

ACTIVITY 6.4 Questions, questions, questions...

Imagine you are shopping with a 5-year old, and as you walk through the aisles they do what all kids do—ask a zillion questions. Here are a few of them. Can you answer them? (They aren't one word answers!)

1) Why is goat butter white?
2) Is corn a vegetable?
3) Why don't oil and water mix?
4) Why do people say carrots are good for your eyes?
5) How to beverage companies get so much fizz into their cans of carbonated drinks?
6) How can cows live on nothing but grass?
7) Why is brown rice better for you than white rice?
8) What's so bad about gluten?
9) Why does crispy brown bread crust smell and taste so good?
10) What's wrong with trans fats?
11) Is margarine better than butter?
12) Can any vegetable be purple?

ACTIVITY 6.5 Final installment of "Chew It Over," a group game to be played during a meal

Here is another round of questions for you to use at a mealtime that you share with family or friends. These questions relate to the topics we learned about in this chapter. Again, you can use these questions in a varity of ways. You can be the quiz master and determine who gets which questions, or you can cut the questions out of the book and put them into a bag or bowl and let people choose a question randomly. The answers on are the back of this page.

CHAPTER 6: DESSERT

1) Guess the weight of the world's largest chocolate bar (as recorded by Guinness):

a) 500 lbs (225 kg) b) 2,300 lbs (1,043 kg)
c) 12,770 lbs (5790 kg) d) 47,500 lbs (21,500 kg)

CHAPTER 6: DESSERT

2) We get our word for chocolate from the Aztec word "xocolatl." Guess what it means.

a) sweet food b) dark medicine
c) bitter water d) edible gold

CHAPTER 6: DESSERT

3) Guess the melting point of chocolate:

a) 80º F (26.6 ºC) b) 93º F (33.9º C)
c) 100º F (37.7º C) d) 120º F (48.8º C)

CHAPTER 6: DESSERT

4) Try to guess each person's favorite kind of pie. (For those who don't like pie, you can guess another favorite food.)

CHAPTER 6: DESSERT

5) Can you guess which country consumes more chocolate per person that any other country?

a) United States b) France
c) Italy d) Switzerland

CHAPTER 6: DESSERT

6) WHICH STATEMENT IS FALSE?
1) Grape juice is much lower in sugar than soda.
2) Cats cannot taste sugar.
3) Sugar can be used as a preservative.
4) Most sugar comes from beets, not sugar cane.

CHAPTER 6: DESSERT

7) WHICH STATEMENT IS FALSE?
1) Benjamin Franklin sold chocolate in his print shop.
2) George Washington told his wife never to serve chocolate.
3) Soldiers during the American Revolutionary War were sometimes paid with chocolate.

CHAPTER 6: DESSERT

8) WHICH STATEMENT IS FALSE?
1) An egg can have two yolks.
2) The color of a hen's earlobes predict what color eggs they will lay.
3) Brown eggs are more nutritious than white eggs.

CHAPTER 6: DESSERT

9) How many ways can you think of to cook an egg?

CHAPTER 6: DESSERT

10) WHICH STATEMENT IS FALSE?
1) Older hens will lay eggs with thinner shells.
2) "Free range" hens always live outdoors.
3) Fresh eggs will sink in a glass of water.
4) Some chickens lay blue eggs.

CHAPTER 6: DESSERT

11) INTERESTING FACT:
Did you know that the less sugar you eat, the more sensitive you will be to its taste? Once your brain adjusts, a lower amount of sugar will taste just as sweet.

CHAPTER 6: DESSERT

12) INTERESTING FACT:
White chocolate doesn't contain any theobromine. The only part of the cocoa bean that is used is the fat (the "cocoa butter").

1) c 2) c 3) b

5) d 6) #1 Grape juice is very high in sugar.

7) #2

8) #3 Brown and white eggs are identical on the inside, with no nutritional differences.