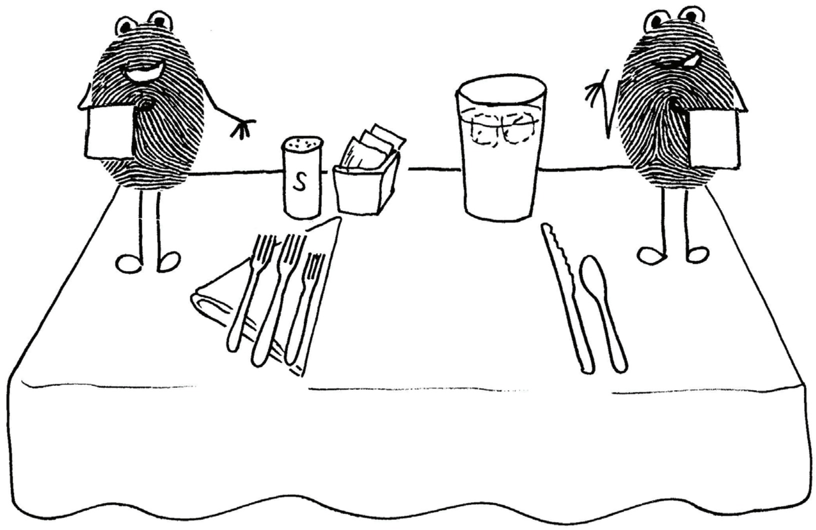
1: Before Dinner Begins

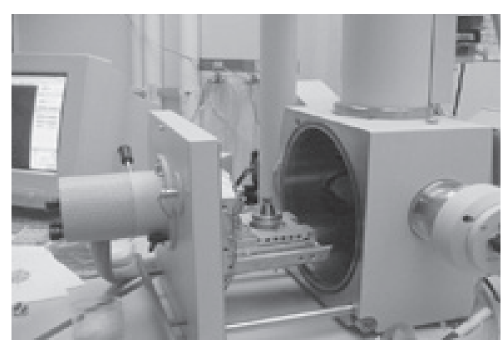
Good evening, and welcome to our restaurant! We offer a unique dining experience—not only do we serve the finest cuisine, we also assist you in dissecting your dinner all the way down to the molecular level! We just hired these waiters last week, so we might need to be patient as they learn their new job.



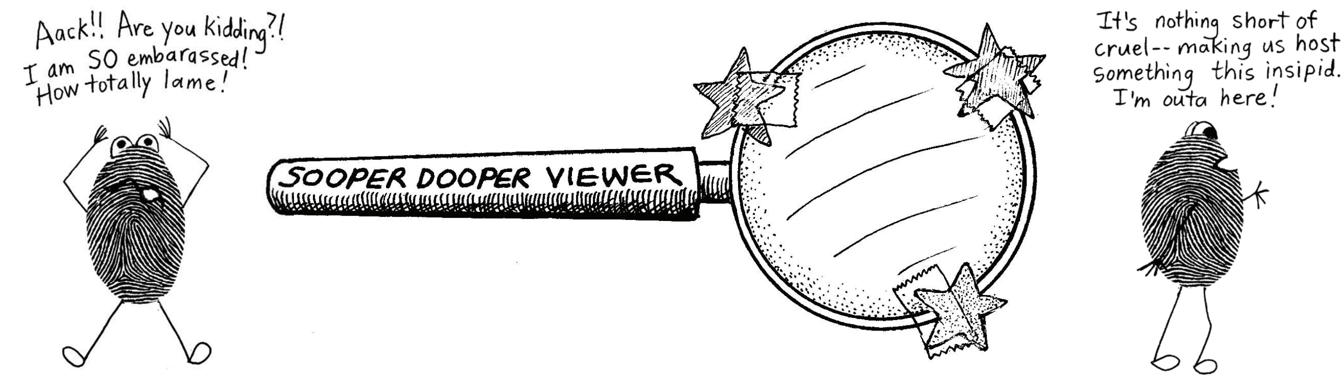
We will begin the dissection of your dinner even before the appetizers arrive. There are three edible things on your table already: water, salt and sugar. Let's start with your glass of water.

Yes, to dissect things down to the molecular level, we'll need some special equipment. Your ordinary scalpel and forceps won't be adequate. We'll need an amazing magnifying machine that will let us zoom in at ridiculously high levels of magnification, making things look up to one million times larger. In real life, we'd have to go to a lab that has an electron microscope worth tens of thousands of dollars. And even this machine might not even be good enough. We might have to use a machine that uses X-rays and needs super smart physicists to figure out what the pictures mean.

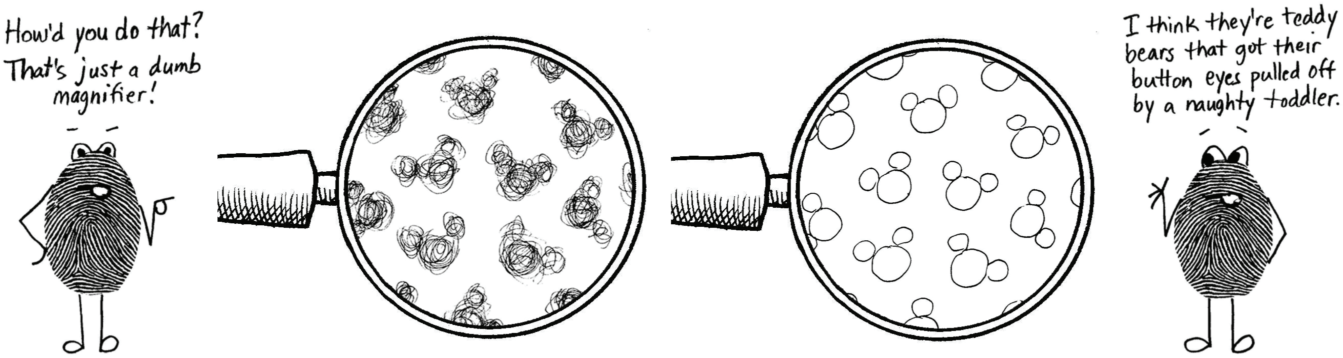
However, here on paper we can go cheap and just draw pictures. We can imagine that we have a super duper magnifier...



An expensive magnifier we can't afford



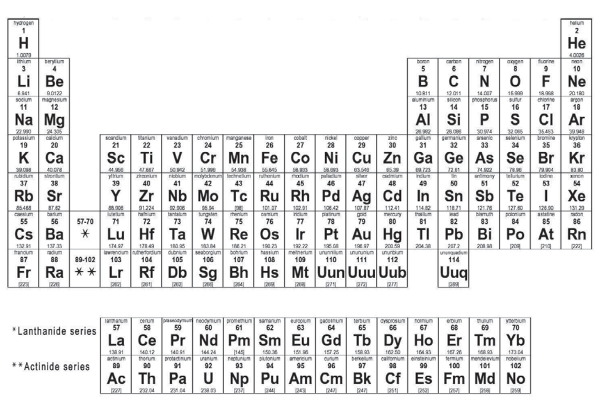
Hey—you haven't seen this little beauty in action yet! Please reserve your judgment for a moment. Let's use our magnifier to take a look at water. When seen with just our eyes, water doesn't appear to be made of anything. It's only when we magnify it several million times that we can actually see what it is.

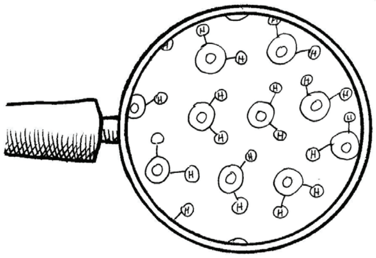


All those fuzzy blobby things are water molecules. As you can tell, water molecules are made of three parts—one large one and two little ones. The fuzzy view shows you that in reality, molecules are constant motion so it's impossible to get them in focus. The view on the right has an artificial focus imposed upon it. (And you thought our magnifier was wimpy. It's got artificial focus!) Those Mickey Mouse shapes (yes, we knew you were thinking that) are made of three atoms: one oxygen and two hydrogens.

Atoms are the most basic particles that exist. They're a little bit like building bricks ("Legos®"). Building bricks come in many different sizes and colors and can be used to make large structures. Structures can be taken apart and the pieces can be recycled. Atoms are like the individual bricks. When we speak of a type of atom in general, we call it an ***element***. Oxygen atoms can be referred to as "the element oxygen." In our building brick example, an element would be one type of brick, such as red 2x2 bricks, or white 2x6 bricks.

There are 118 different types of elements. Most of them are very useful, but some of the largest ones (numbers over 100) are very strange and only exist for a few seconds and are therefore practically useless. These 118 elements are usually written down not as a continuous list, but in a nice, neat rectangular chart called the Periodic Table of the Elements. The word "Periodic" means that there is a pattern to the way the elements are arranged, and "periodically" the pattern repeats itself. Some of these 118 elements are substances you've heard of, such as oxygen, nitrogen, hydrogen, helium, neon, carbon, calcium, magnesium, gold, silver, nickel, copper, iron and lead. Others are not so familiar and have names that look hard to pronounce. Fortunately, most of the atoms you meet in food chemistry are the easy and familiar ones, such as oxygen, hydrogen, carbon, nitrogen, sodium, and magnesium.

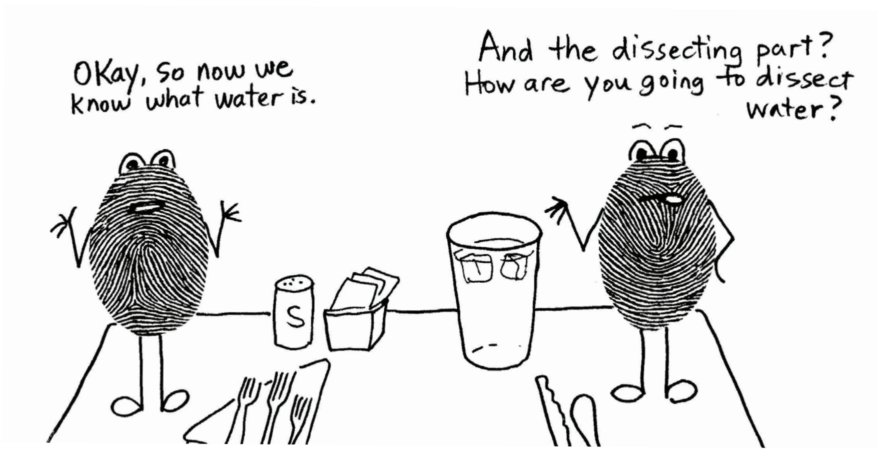




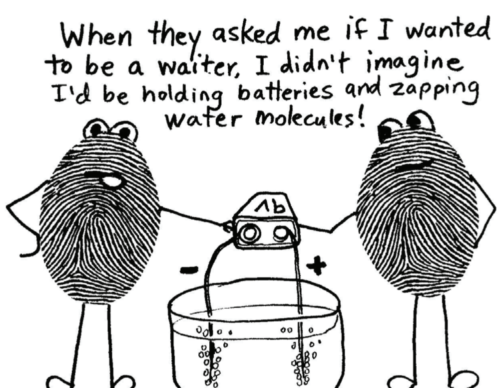
In this view, the molecules are shown as little balls stuck together with sticks. The balls are atoms. O stands for "oxygen" and H stands for "hydrogen." The sticks represent the bond that keeps the atoms together (in this case. by sharing electrons).

As you can see in our magnifier, atoms can stick together to make clumps. We call these clumps ***molecules***. Here we see clumps (molecules) that are made of two hydrogen atoms and one oxygen atom. Every molecule is exactly the same. The atoms stay together because the tiny hydrogen atoms are sharing their only electron with the oxygen atom.

Just like an ***atom*** is a single particle of an ***element***, a ***molecule*** is a single unit of a ***compound***. ***A compound is a large amount of similar molecules, with each molecule being made of at least two different elements.*** Is water a compound? Yes, because all the molecules look the same, and each molecule is made of two different elements—oxygen and hydrogen. Would chicken soup be considered a compound? No, because there are so many different types of ingredients. Would pure oxygen be considered a compound? No, because even though the molecules are all the same, each molecule is made of just one element—oxygen.

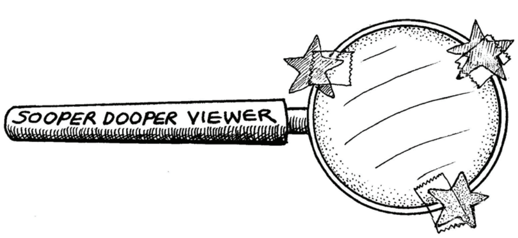


So, how <u>do</u> you dissect, or tear apart, a water molecule? With a microscopic knife? Nope. Water molecules are so incredibly small that a knife would be useless. A knife blade is made of molecules that are much larger than the water molecules. It just wouldn't work. But there is a way to tear water molecules apart. We need... an electrical ZAPPER!

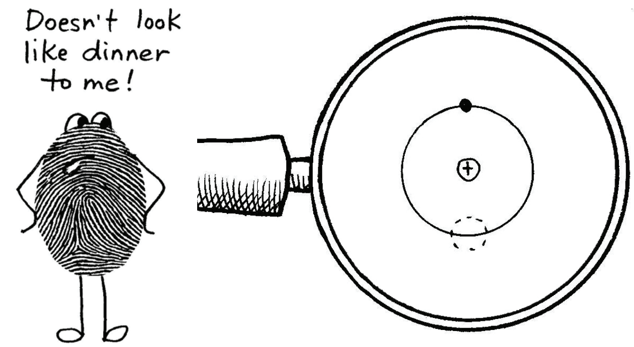


If we put electrodes from a battery into a glass of water and add a tiny pinch of salt or some other substance that conducts electricity, we will see bubbles forming on the electrodes. Bubbles of pure hydrogen gas will form on the negative electrode and bubbles of pure oxygen gas will form on the positive electrode. We have successfully dissected water molecules!

Does it work in reverse? If you put hydrogen and oxygen gases together would they form water molecules? Yes, they would. This is how a fuel cell works. Water molecules are split, then the gases are allowed to mix and form water again. Energy is released as the gas molecules form water molecules. The problem is that it takes energy to split the molecules in the first place, so a fuel cell can't actually create energy.



Now we're going to show you the full capabilites of our Sooper Dooper Viewer. We can zoom in using an even higher magnification and look at a single atom! Let's start with the smallest of all atoms—the hydrogen atom.

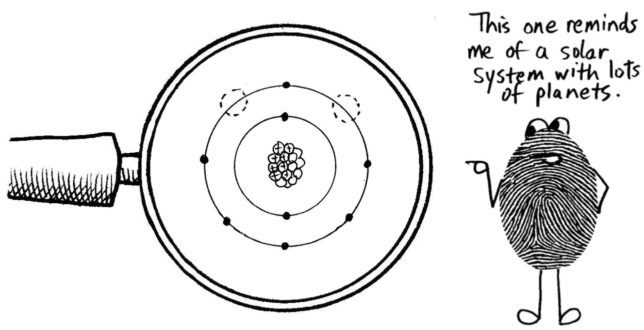


Here is a hydrogen atom. In reality, you can't actually see an atom. Atoms are just too small to see. Scientists figured out the structure of atoms using math and logic more than anything else. We draw diagrams like this one to represent atoms, but real atoms don't look like circles and dots. The dot in the center with the plus sign on it represents a ***proton***. What is a proton? It's a particle with a ***positive*** charge (thus the plus sign). What kind of particle? That's a question for a particle physicist, not a food scientist. If we understand that a proton is a particle with a positive charge, that's enough.

The dot represents an ***electron***. An electron is a particle with a ***negative*** charge. The circle around the proton represents an over-simplified "orbit" in which the electron travels. The electron actually whizzes around the proton in a three-dimensional way, being everywhere and nowhere all at once, looking more like a cloud than a circle. However, a circle will serve us much better as we try to understand how and why atoms stick together.

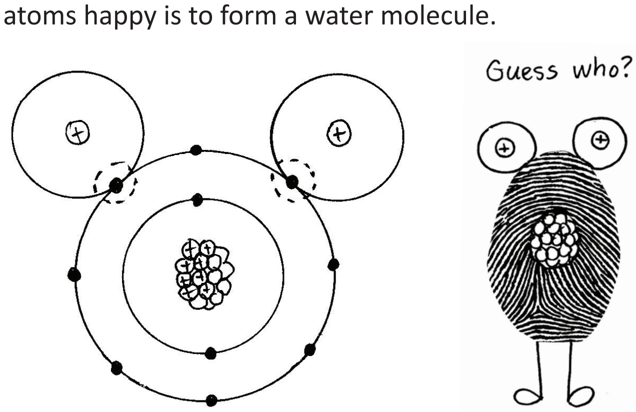
The small circle made dashes (opposite the dot) represents an empty place that another electron could fill. Electrons love to be paired up, and hydrogen's lonely electron would love to have a partner to fill that empty space. However, if the atom takes on another electron, it will create a new problem: the atom will no longer be electrically balanced. As it is right now, the atom has one positively charged proton and one negatively charged electron. With one of each, it's balanced. If it takes on a second electron, the score will be: protons: 1, electrons: 2. The atom will have an extra negative charge, giving it an overall charge of (-1).

What should hydrogen do? It has three options it doesn't like: 1) have a lonely electron, 2) be electrically unbalanced, or 3) give its electron away to another atom. It's a no-win situation for hydrogen. Yes. such a travesty. Let's find out what hydrogen does when an oxygen atom comes along.

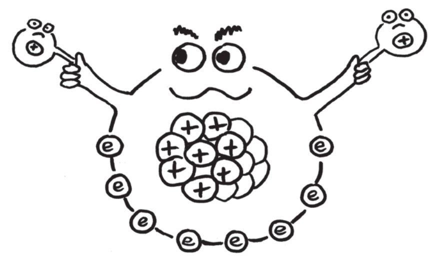


In this magnifier view, you see a representation of an oxygen atom. It's a bit more complicated than a hydrogen atom, but it's still similar. In the center, the oxygen has more than one proton; it has a whole clump of particles. There are 8 protons and also 8 ***neutrons***. Neutrons are electrically ***neutral***, neither positive nor negative. They just sit there. This little clump of protons and neutrons is called the ***nucleus*** of the atom. You'll notice that there are two rings around the nucleus, not just one. The inner ring has 2 electrons and the outer ring has 6. Those two electrons in the inner ring are very happy. They are paired up and their small ring is full with just the two of them. The outer ring is larger can hold up to 8 electrons. (Think of it as an 8-seat minivan.) Those two dotted circles are empty "seats" that the oxygen atom would really like to fill with electrons. However, just like the hydrogen atom, the oxygen atom is faced with the problem of being electrically unbalanced if it takes on more electrons. Right now it has 8 electrons and 8 protons. If it fills those circles with extra electrons, the score will then be 10 negative electrons to 8 positive protons. What will the oxygen do?

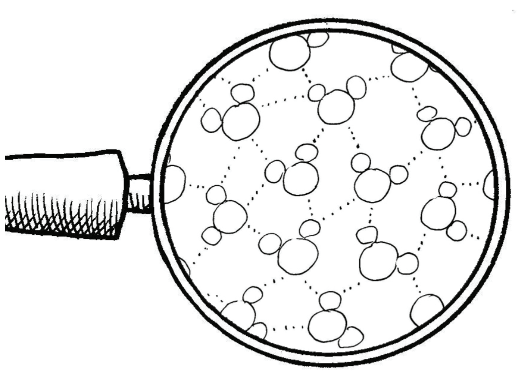
One solution that makes both hydrogen and oxygen atoms happy is to form a water molecule. When one oxygen and two hydrogens get together they have a total of 8 electrons in their outer rings. 6+1+1 Although in this picture it looks like the oxygen has gotten all of the electrons, this is not so. The electrons can move at lightning speed (literally) and are able to circle around the hydrogens often enough to make them reasonably happy. All three atoms get the electrons circling around them just often enough to convince them that this was a pretty good solution to their problem.



However, even though all three atoms are basically happy, this doesn't mean they are equal. The



harsh reality for hydrogen is that it is puny in comparison to oxygen (or to any other atom, for that matter, since hydrogen is the smallest atom in the universe!). Hydrogen's one little proton is no match for oxygen's clump of 8 protons. Oxygen becomes a bully and begins "hogging" the electrons. This means that the electrons end up spending more time circling around the oxygen atom than they do around the hydrogen atoms. This unequal time-share of the electrons creates an imbalance in the molecule. Because the negatively charged electrons spend more time around the oxygen atom, that side of the molecule becomes slightly more negative. The side where the hydrogen atoms are stuck on becomes slightly positive because of the two protons sitting there unguarded by any electrons. Molecules like this, with a slightly negative side and a slightly positive side, are called ***polar molecules***. This use of the word "polar" doesn't have anything to do with snow or bears. It simply means "having two opposite sides." The earth's poles are north and south, and function a bit like opposite ends of a magnet.

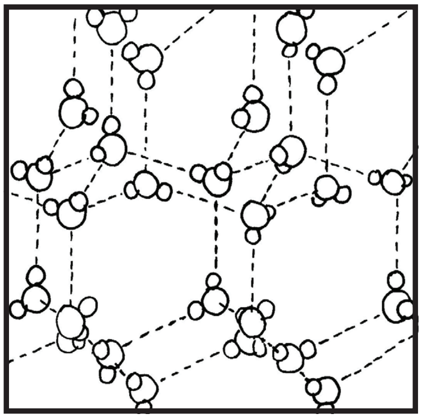


Being electrically lopsided, with a more positive side and a more negative side might seem like a bad thing, but actually it's a very good thing, and it's the reason you can take a bath or drink a glass of water. It's also the reason that plants can take up water through their roots. The negative side of one water molecule is attracted to the positive side of another water molecule. The end result is that water molecules stick together—in your bathtub, in your glass, in a raindrop, and inside plants.

This attraction between the water molecules is called ***hydrogen bonding***. (At least the poor hydrogens got the bond named after them. It's compensation for getting the short end of the deal when it comes to electrons!) Hydrogen bonds are much weaker than the bonds between the oxygen and hydrogen atoms, but they are strong enough that you can see them at work. Try putting a few drops of water on a penny. Then keep adding drops until the water finally spills over onto the table. You'll be amazed at how those water molecules stick together and form a really large droplet on top of the penny! That's hydrogen bonding at work.

Some "waiters" you turned out to be! You're not very good at waiting. Be patient. The rest of this dinner won't make sense if our guests don't understand their glass of water.

There's one more very important fact about water. You'll notice that there is ice floating in your glass. Your glass of ice water demonstrates a fundamental principle of chemistry. A substance can be altered, using temperature or pressure, to turn it into a solid, a liquid, or a gas. The chemistry of the substance doesn't change, just its physical properties. Water molecules are always made of one oxygen atom attached to two hydrogen atoms, no matter whether it is ice, liquid water, or steam. When you heat water so that it turns into steam, the



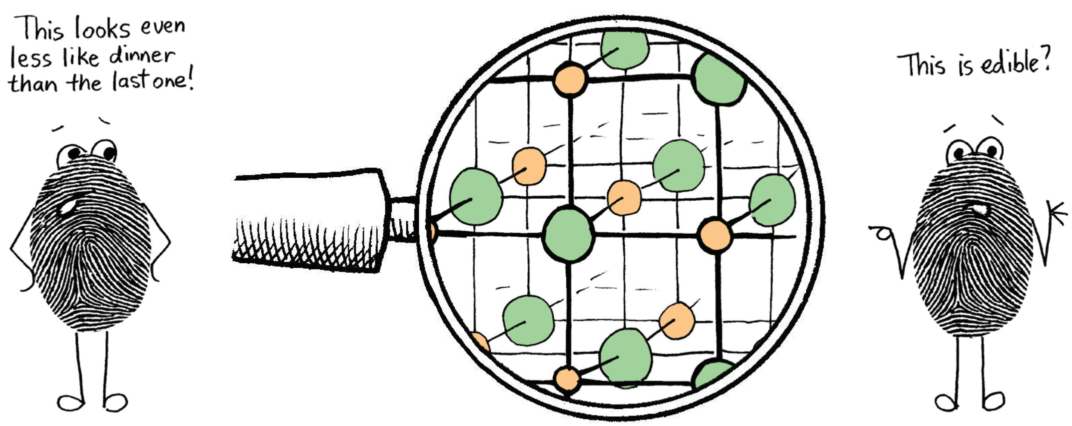
In this diagram, the dashed lines represent the electrical attraction (hydrogen bonds) holding the frozen water molecules together. These bonds (the lines) make a nice geometric pattern, and in the process they keep the water molecules farther apart than they would be if they were at room temperature and in liquid form.

water molecules themselves don't get torn apart. The heat weakens the hydrogen bonding between the molecules so that they can only form very small droplets. But the water molecules themselves remain unchanged. When water is cooled down to its freezing point, the bonds between the molecules get very strong, forming hard crystals. The water molecules actually move further apart in order to form this geometric crystal structure. When the crystals melt, the molecules move closer together again. In most other substances, it's the other way around. Usually solids are more dense (packed tightly together) than liquids. Water is backwards. It's this unusual property of water that allows ice to float instead of sink.

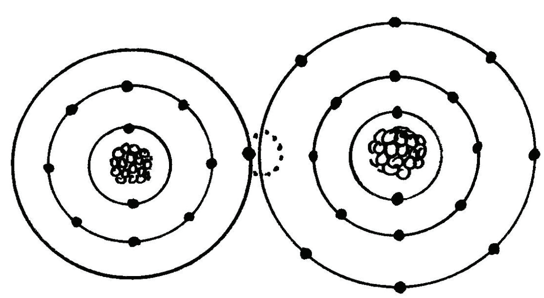
The scientific term for molecules being more or less tightly packed together is ***density***. Ice is less dense than liquid water because the molecules are more spread out, making fewer molecules per cubic measure. The densities of substances affect how they interact with other substances.

There's a lot more we could learn about water molecules, but we are going to move on now and look at what is in the salt shaker. If you look at salt under a magnifier, you'll see that the crystals look like little cubes. There is a reason for this, as we shall see.

Let's zoom in on the salt until we can see the molecules. Remember, this is something you can't see under a regular microscope. Our little Sooper Dooper Magnifier is much more powerful than any microscope you'd find in a biology classroom or even a medical lab.



Wow—how different salt is from water! What structure! We've set our magnifier on "Ball and Stick View" so that's why you see all the circles and lines. Those circles are the atoms. The lines are the invisible bonds between the atoms (the electrical attraction). It's an endless framework of atoms all lined up in a perfectly cubic form. The atoms here aren't oxygen or hydrogen; they are ***sodium*** and ***chlorine***. The circles that represent chlorine atoms are larger than the ones that represent sodium because chlorine atoms have more pull, or "electronegativity" than sodium atoms do, and thus they are often drawn a bit larger.

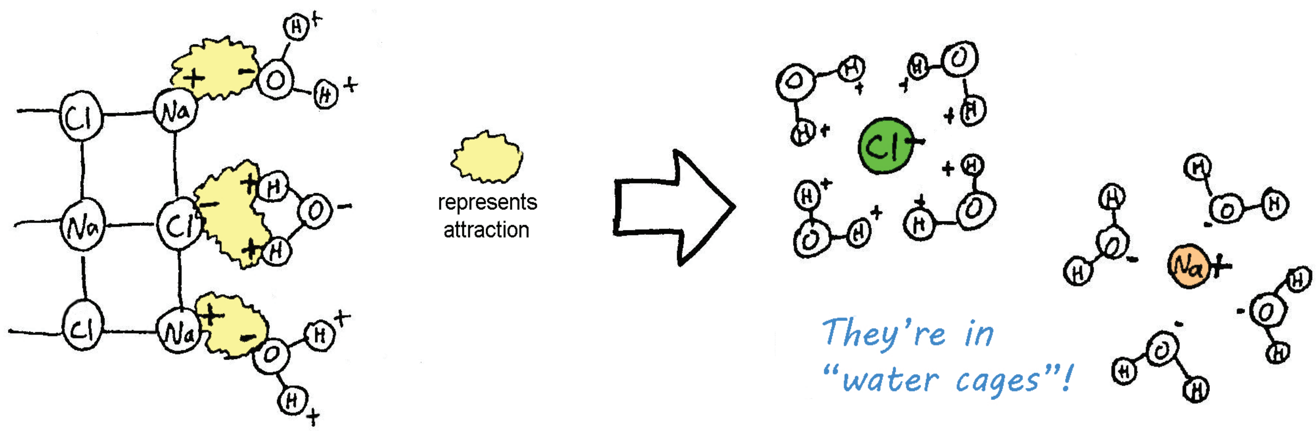


Sodium atom   Chlorine atom

Sodium and chlorine atoms stick together because sodium has an "extra" electron it would like to get rid of, and chlorine has one empty electron space it would like to fill. Atoms don't like it when their outermost ring has either an empty spot or one lonely electron. Sodium and chlorine put their two problems together to make a solution. Sodium gives its extra electron to chlorine and then they are both happy. Except that... in the process of doing this, sodium and chlorine have unbalanced themselves electrically. Sodium becomes more positive and chlorine becomes more negative. But this works out okay, because opposites attract and as long as chlorine and sodium stay next to each other everyone is (reasonably) happy.

Now... how can we dissect salt crystals? This turns out to be very easy, and you can do it without any special equipment. Just put the salt crystals into water, and presto—dissected! You won't be able to see the little atoms, though, so we'll show you an extremely zoomed-in view of dissected salt.

Remember that water molecules are "polar" and have a positively charged side and a negatively charged side. This "polarity" of water is what enables it to tear apart salt molecules. The water molecules have a stronger pull on the sodium and chlorine atoms than the sodium and chlorine do on each other. A sodium atom will leave the crystal to stick to the negative side of a water molecule. A chlorine atom will leave the crystal to stick to the positive side of a water molecule. It takes a little time for all the sodium and chlorine atoms to leave the crystal, but eventually they will all leave and the crystal will be gone. Once this has happend, we say that the salt has ***dissolved*** into the water. (NOTE: Sodium used to be called "natrium" so its symbol is **Na**.)



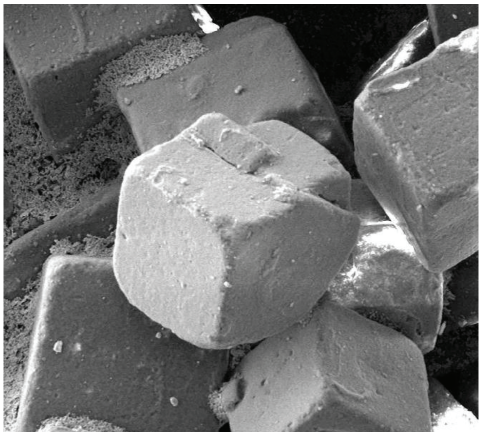
Look at the diagram on the right and notice how the water molecules surround the sodium and chlorine atoms. It almost looks like they have them imprisoned in little cages. The water molecules turn their positive sides inward to trap chlorine atoms, and they turn their negative sides inward to imprison sodium atoms. When sodium and chlorine atoms are floating around like this, unattached to anything, they are called ***ions***. An ***ion*** is an atom that has an electrical charge. Chlorine has a negative charge because it kept that electron that it borrowed from sodium. Sodium is positive because chlorine kept its electron, leaving it with 11 protons and 10 electrons.

Atoms on the Periodic Table, are listed in their "pure" form, with an equal number of electrons and protons, before they have interacted with any other atoms. In real life, you rarely find them in this state. Atoms like sodium and chlorine are almost always found as ions, having an unequal number of electrons and protons. This can be very confusing for young chemists. You help you out, if an atom has an electrical charge, it will be written in superscript, with the plus or minus symbol to the right of the number: Na^{1+} Cl^{1-}

When an ionic substance like salt breaks down into individual atoms, or ions, we say that it has been ***dissolved***. The water is called the ***solvent*** and the salt is called the ***solute***. The salt water is called a ***solution***. We'll meet some more solutions as dinner progresses.

Is the salt permanently damaged, or could the molecules be put back together again? The salt molecules can indeed be restored to their crystaline form, and this can be accomplished simply by doing nothing at all. Just let the water sit there. The water molecules will evaporate into the air and the sodium and chlorine atoms will go right back into their neat and tidy crystal lattice. (Go ahead, try it!)

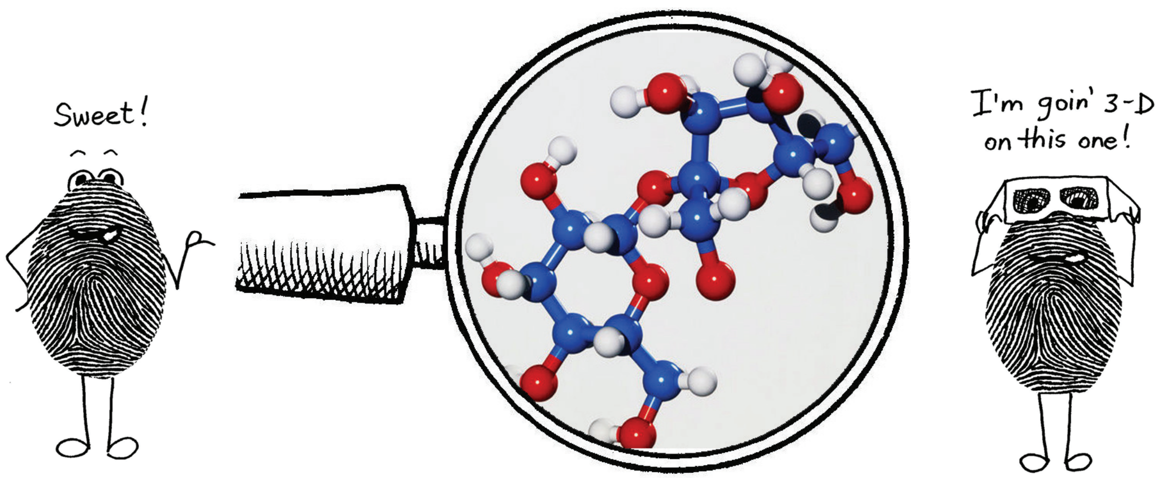
So what's left to dissect before the appetizers arrive? Let's open a packet of sugar. At first glance, it might look a lot like salt—little white crystals. But if we look at them under a magnifier (just an ordinary one this time, not our Sooper Dooper one) we can see a difference right away. The salt crystals look like little cubes, but the sugar crystals don't look cubic at all. They look more hexagonal (6-sided).



salt crystals

sugar (sucrose) crystals

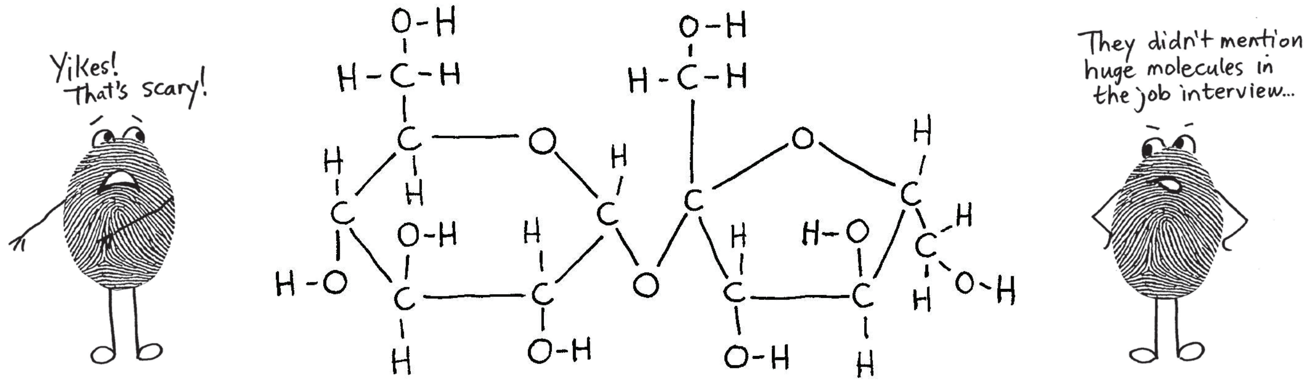
Now we'll switch to our amazing Sooper Dooper Magnifier and see what sugar molecules look like. But first, we'll toss the sugar crystals into our glass of water. Water has the same effect on sugar that it does on salt. (In fact, water has this effect in many substances. Water is sometimes called "the universal solvent" because of how many substances it can dissolve.) The polar water molecules pull on the sugar molecules, enticing them to leave their lovely crystal lattice and float around by themselves. So if we want so see just one sugar molecule by itself, the best way to do that is to dissolve the sugar into the water.



Here is just one molecule of sugar. The atoms are not lined up neatly like salt. It also looks like it should be viewed in 3D to see it properly. Some of the atoms look like they are in front or back of other atoms. To see this molecule in 3D, go to: **http://www.3dchem.com/Sucrose.asp#** Click on the molecule and it will open in a new window. If you have a touchscreen, you can interact with the molecule and rotate it. Or, you can use the commands at the bottom of this window. Look for the word "rotate," and click on the word "on." The molecule will begin to spin. There are many other options, too, listed at the bottom of the window. You can change from ball and stick model to other types of models. There are many ways to represent molecules. You can see a "stickless" (space-filling) model.

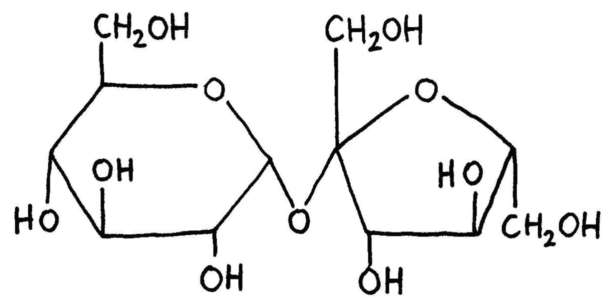
The picture in our magnifier shows the atoms as round balls. This kind of picture looks really nice, but you don't have a clue what those balls are, do you? For this reason, scientists have another way of representing molecules. They use letters, instead of circles or balls, to represent atoms. They keep the sticks, though. The letters they use to represent the atoms are the letter symbols found on the Periodic Table. The letters we will see most often in this book are: H for hydrogen, O for oxygen, C for carbon, N for nitrogen, Cl for chlorine, and Na for sodium.

These letter drawings don't look as artistic as the ball-and-stick ones, and they tend to look scary to non-scientists. This is the way that sugar molecule looks when drawn with letters:



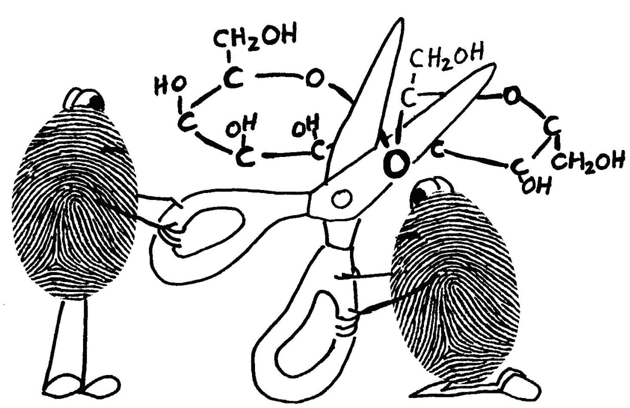
The biggest "plus" about this type of drawing is that you know exactly what type of atoms you are seeing. C is for carbon, O is for oxygen, and H is for hydrogen. These three elements are the main ingredients of most of what we eat. Another big "plus" is that it's much easier to draw or print a diagram that is nothing but letters and sticks. You lose the 3D aspect of the molecule, but this downside isn't down enough, and chemistry books almost always use these letter diagrams.

Chemists get so used to seeing these types of molecules that they don't even need all the letters in their diagrams. When they see a pentagon or a hexagon, they assume that the ***vertices*** ("corners") are carbon atoms. Compare this diagram with the one above. Where are C's missing? Can you find a few more missing letters? There are some H's missing, also. Chemists just automatically know the C's and H's are supposed to be there.



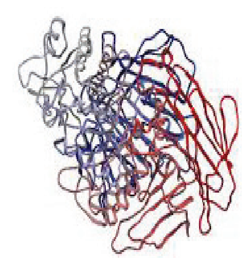
The correct name for this molecule is ***sucrose***. When we talk about putting "sugar" in a recipe, we are talking about "sucrose." In the world of science, the word "sugar" doesn't mean the stuff you bake with. "Sugar" is a more general word for a whole category of molecules that taste sweet. Sucrose is a sugar, but so are glucose, fructose, galactose, lactose, maltose, amylose and other "-ose's."

Notice that the basic structure of sucrose is a hexagon attached to a pentagon. Let's dissect sucrose by separating the hexagon and the pentagon. What is joining them? Look at the diagram and you will see that there is an oxygen atom between them. We'll have to snip off that oxygen.

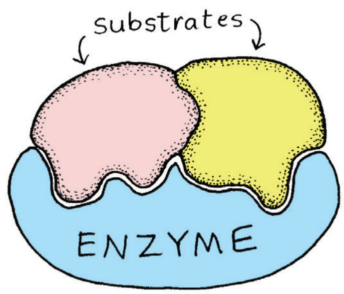


Wait a minute—SCISSORS?! Okay, okay, it works nicely in this picture and gets the point across. In real life, you need something called an ***enzyme*** to cut this molecule. An enzyme is a specialized protein molecule. Some enzymes act like scissors, but other enzymes act like staplers and fasten things together.

The enzyme represented here by our pair of scissors is called ***sucrase***. Enzymes don't have sharp blades, of course. Enzymes are able to do their job because of their special shape. On the right is a computer-generated image of sucrase. It's a long ribbon-like molecule all twisted up into just the right shape. It doesn't look like it would be able to cut apart sucrose, does it? Yet it does, and very quickly, too.

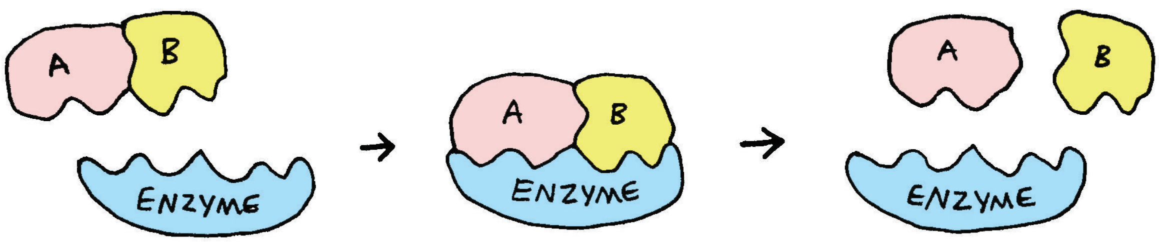


sucrase

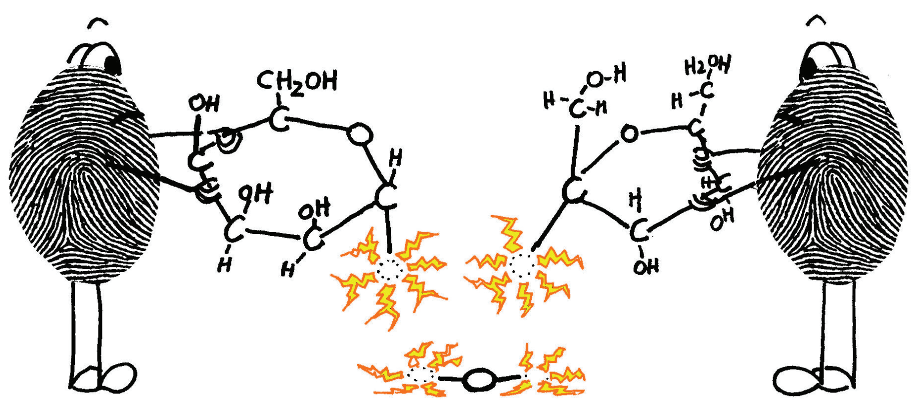


Here is the way enzymes are often look when you meet them in books. The artist makes the enzyme look like a large puzzle piece that attaches to two smaller puzzle pieces. The large piece is the enzyme and the smaller pieces are the things that the enzyme is putting together or taking apart. There's a good reason to make them look like puzzle pieces. They really do have matching shapes that fit together. The smaller pieces are called ***substrates***. (Now there's a really boring science word for you. Dull, dull, dull. You'll probably forget what a substrate is by the end of this chapter.)

This is a very typical drawing of an enzyme in action. It shows an enzyme acting like a pair of scissors, cutting apart two substrates. They almost always look like oddly shaped blobs, though occasionally you'll see them as rectangles. Blobs are closer to the truth, since they actually look like a random tangle of ribbons.



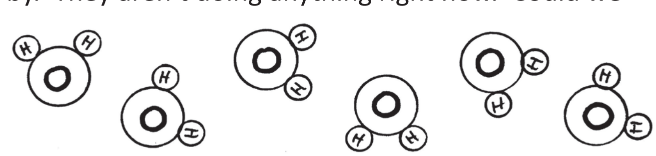
An enzyme is able to disassemble hundreds or thousands, or perhaps even millions, of substrates in its lifetime. You have sucrase enzymes in your intestines that work day and night to tear apart all the sucrose molecules you eat. Your digestive system contains many different kinds of enzymes, each one capable of tearing apart a different type of molecule.



Hmmm... it looks like your new molecules aren't very happy. Neither does that snipped off oxygen down there. In fact, those broken bonds look downright dangerous with all those zappy lines coming out.

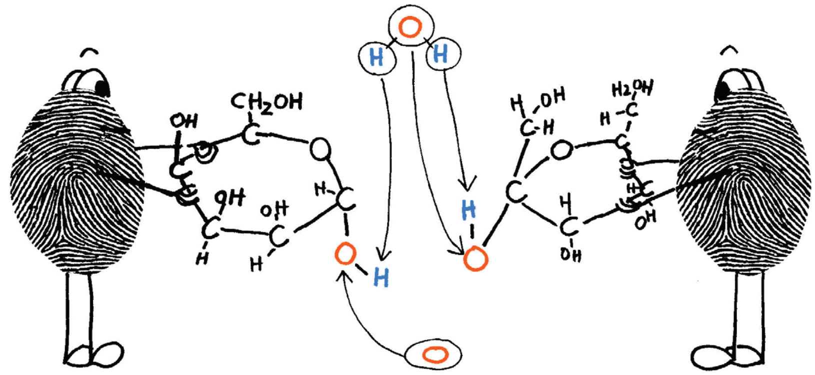
Here's what happening. Those sticks represent bonds between the atoms, right? But do you remember what a bond is? We looked at how hydrogens stick to an oxygen to make a water molecule. The "bond" was actually a place where the atoms shared an electron. It's the same with this molecule. That oxygen (O) was sharing electrons with the carbons (C) until you snipped it off. Now the oxygen is unhappy because it has two empty "holes" that are no longer filled. The carbon atoms are upset because they need to bond in four places and now they have only three of those slots filled. You've created a mess! If you walked away right now, those atoms would jump right back to where they were. If you want the molecule to stay dissected, you must patch up those broken bonds somehow. You need some spare atoms to stick onto those ragged ends. What's available?

Look! Here come some water molecules floating by. They aren't doing anything right now. Could we grab one and use it? Could hydrogens and oxygens be made into patches?



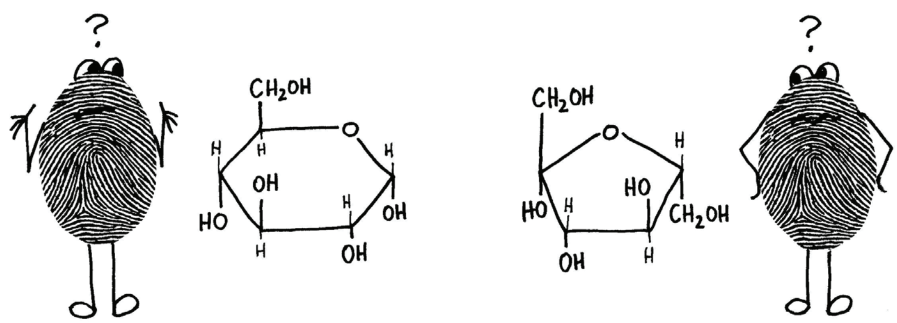
(Have you forgotten the word "substrate" yet?)

First, let's stick that snipped-off oxygen back onto one of the carbons. Now that carbon is happy again. But the oxygen is still unhappy because it is able to make two bonds and is only making one. We need an atom that only wants one bond. How about... hydrogen? Let's take a hydrogen off that water molecule and pop it onto the oxygen. There, now that molecule on the left is all patched up.

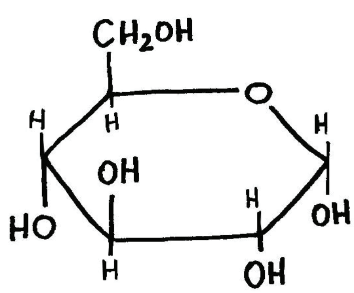


Let's try the same thing on the other side. Let's take the oxygen from water and put it onto the carbon. Then we'll patch the oxygen with the remaining hydrogen.

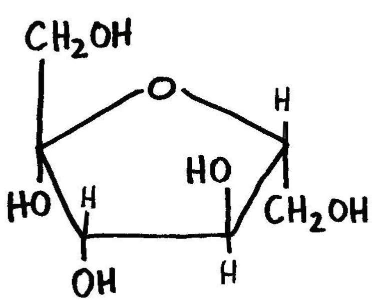
It looks like we've done it! We've separated the two rings and patched up all the bonds so that all the atoms are happy. What have we made? What are these rings?



We've turned sugar into... more sugar! All we've done is to turn a "two-ring" sugar into two "one-ring" sugars. These one-ring sugars are called ***simple sugars*** or ***monosaccharides*** *(mon-o-sack-a-rides)*. "Mono" means "one" and "saccharide" is a fancy word for "sugar." Sucrose is called a ***disaccharide*** *(di-sack-a-ride)*. "Di" means "two." (If the prefix "poly" means "many," then what would a polysaccharide look like?)



This molecule is called ***glucose***. The word glucose comes from the Greek word "glukos" meaning "sugar." Not too hard. Glucose is sometimes called "blood sugar" because it's the type of sugar that floats around in your blood. It's the sugar your cells use to harvest the energy they need to stay alive. Glucose has 6 carbons, 12 hydrogens and 6 oxygens. Can you find them all? (Remember, those "corners" have invisible carbons on them!) Chemists sometimes write glucose as $C_6H_{12}O_6$, giving the numbers of each type of atom right below its symbol.



This molecule is called ***fructose***. It's the kind of sugar found in fruit. Ripe fruit is sweet because it contains lots of fructose. That's easy to remember because "fruct" looks and sounds similar to "fruit." Fructose is the sweetest of all the sugars. Ounce for ounce it's sweeter than the sucrose in your sugar bowl. Fructose has the same number of each type of atom, and could also be written as $C_6H_{12}O_6$. Can you find all the atoms? Fructose is hard to find in crystal form. Most people are content to put sucrose in their dessert recipes.

Well, it looks like we've successfully dissected everything on the table. Before the beverages arrive, see if you can answer these questions. If you can, you've learned what you'll need to know to dissect the next stage of your dinner. If you can't remember, go back into the chapter and re-read until you find the answers.

1) What is an atom made of?

2) Which particles are in the center (the nucleus)?

3) What holds atoms together in a water moleclue?

4) How many bonds does oxygen want to make? (Look back at the picture where we patched up the molecules.)

5) Water is called a "polar" substance. Why?

6) What is the attraction between water molecules called?

7) Why do salt crystals come apart when you put them into water?

8) In salt water, which is the "solute," the water or the salt?

9) What do you call the things that attach to an enzyme? (Bet you forgot it already!)

10) What do enzymes do? (You are allowed to use the word you forgot in your answer to #9.)

11) What is the correct name for table sugar?

12) What is the name of the enzyme that tears apart sucrose?

13) Name the two simple sugars that link together to make sucrose.

14) What molecule can be used to patch up the ragged edges when you tear apart sucrose?

15) Did you ever notice that when you eat a lot of candy or sugar, you get thirsty? Can you think of a possible reason this might be so?

SUPPLEMENTAL VIDEOS FOR THIS CHAPTER

This curriculum has its own playlist on YouTube. Go to YouTube.com/TheBasementWorkshop and find the "Dissect Your Dinner" playlist. The videos are approximately in order, so the first ones on the list should correspond to topics from this first chapter. Come back to the playlist after you finish each chapter to watch the videos that go with those topics.

ACTIVITY 1.1 First installment of "Chew It Over," a group game to be played during a meal

This activity is designed to be something you do with family and/or friends during a meal. The questions are designed to be one of the following: informative, funny, challenging, or thought-provoking. Everyone will learn something either about science or about each other. You can use the questions in many ways. If you want to be the quiz master, you can simply read the questions out loud and see who knows the answer. Or, you could use scissors to cut them apart and then put them into a bag or bowl and go around the table letting each person draw out a question to answer. (If a question has a right answer, it is printed on the back of this page.)

CHAPTER 1: WATER, SALT, SUGAR 1) Can you name a natural substance other than water that is seen in all three states (solid, liquid, gas)?	CHAPTER 1: WATER, SALT, SUGAR 2) Which do you think uses less water, a bath or a shower?
CHAPTER 1: WATER, SALT, SUGAR 3) 90% of the world's fresh water is located on which continent?	CHAPTER 1: WATER, SALT, SUGAR 4) What % of your body weight is water? a) 1% b) 10% c) 60% d) 90%
CHAPTER 1: WATER, SALT, SUGAR 5) Plants release water vapor from their leaves. How much water does an acre of corn release in one day? (one gallon is about 4 liters) a) 4 gallons b) 40 gallons c) 400 gallons d) 4,000 gallons	CHAPTER 1: WATER, SALT, SUGAR 6) Can you guess which of these countries is NOT one of the top five producers of salt? USA, Russia, China, India, Germany, Canada
CHAPTER 1: WATER, SALT, SUGAR 7) Can you guess which one of these foods doesn't rely on salt as a key ingredient? cheese, yogurt, ketchup, mustard, soy sauce, olives, pickles	CHAPTER 1: WATER, SALT, SUGAR 8) Salt is often found underground in formations called salt domes. What other substance is usually found around or under the salt dome? a) oil b) water c) iron d) magma
CHAPTER 1: WATER, SALT, SUGAR 9) Which type of outdoor water do you like best? Ocean, lake, river, stream, puddles	CHAPTER 1: WATER, SALT, SUGAR 10) If you were required to give up either sugar or salt for one month, which would you choose?
CHAPTER 1: WATER, SALT, SUGAR 11) What is your favorite sweet food?	CHAPTER 1: WATER, SALT, SUGAR 12) What is your favorite salty food?

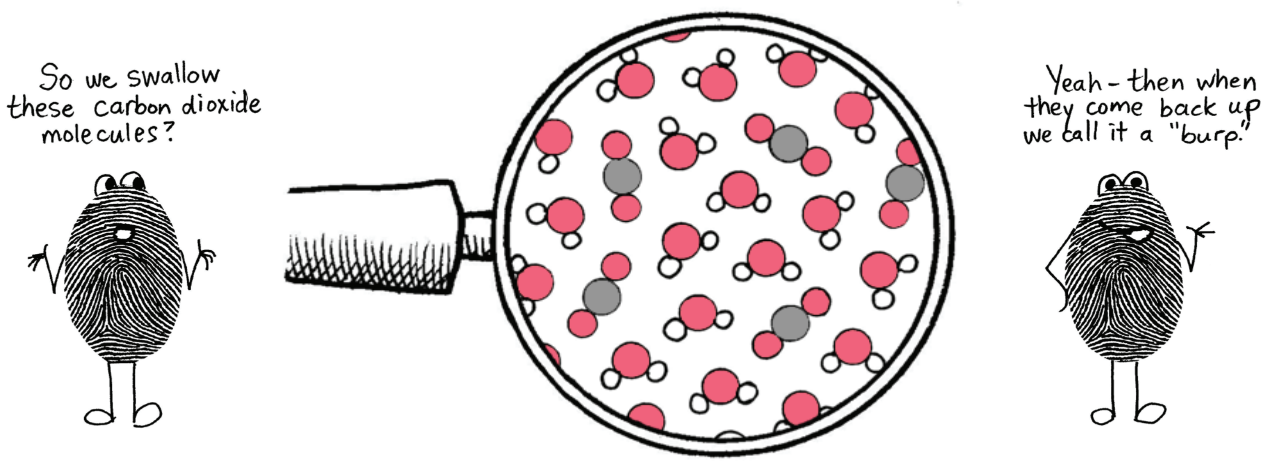
1) Probably not. Water is the only common substance found in all three states.
2) On average, a shower requires half as much water as a bath. 3) Antarctica
4) About 60% of your weight is water. On average, males have 60-65%, females 50-55%.
5) 4,000 gallons of water per day! 6) Russia
7) yogurt 8) oil (meaning crude oil, or petroleum)

2: Your Beverages Arrive

The waiters have brought your beverages. They have provided milk and a carbonated drink. You may have a special name for carbonated beverages, such as "soda," or "pop" or "coke." You can imagine this to be whatever kind you like. (If you don't drink carbonated beverages in real life, just play along and pretend you do. It's just an excuse to study more chemistry.)

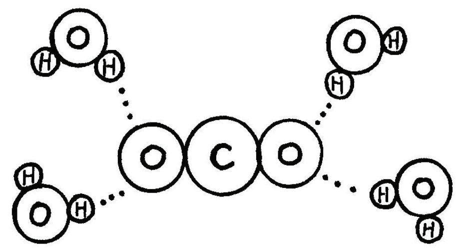
Let's look at the carbonated beverage first. Don't drink it yet—we need to dissect it first!

Most of a carbonated beverage is water. But there are a number of substances ***dissolved*** into the water. Do you remember how salt and sugar dissolved into water? The pull of the water molecules overcame the attraction that the molecules had for each other. The molecules of the **solute** (the salt or sugar) were equally dispersed among the water molecules. In this carbonated beverage we'll see that gases can also be dissolved into liquids.



You can see the red and white water molecules, easily recongizable by their Mickey Mouse ears. (No sticks between the atoms here, just to save space.) But what are those other molecules—the ones that look like water molecules that have been straightened out? Those are ***carbon dioxide*** molecules, made of one carbon atom attached to two oxygen atoms. You probably know that carbon dioxide is one of the gases that you breathe out when you exhale. There is a certain amount of carbon dioxide that floats around in the air all the time. Plants take in carbon dioxide and use it for photosynthesis. You may also know that some chemical reactions, such as combustion, produce carbon dioxide. It seems strange, though, to think of carbon dioxide, a gas, being dissolved into water in the same way that salt and sugar are. Yet that is exactly what happens. (It's even weirder to think of carbon dioxide, a gas, freezing and turning into a solid. That's what "dry ice" is.)

The carbon dioxide molecule is somewhat ***polar*** (though you will find it in lists of nonpolar molecules because its straight line geometry makes it electrically symmetric, not lopsided). The oxygen atoms are slightly heavier than the carbon atom, and therefore they can get away with being bullies and demanding to have the electrons. The electrons end up spending more time going around the oxygens than they do the carbon. Since electrons carry a negative charge, the ends of this molecule (the oxygens) become more negative. These negative ends are attracted to the positive parts of the water molecules. The dotted lines represent this attraction, which, as you will remember, is called ***hydrogen bonding***.



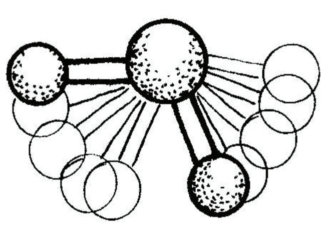
Carbon dioxide (CO_2) molecules can be dissolved into water the same way that sugar or salt can. CO_2 is the ***solute*** and water is the ***solvent***. Here's an interesting question: can you mix and match states of matter (solid, liquid, gas) to form solutions? For example, could you dissolve a liquid into a solid? Or a liquid into a liquid? Or a solid into a gas? Oddly enough, yes, you can form a solution with just about any of these. Here are some examples of solutes dissolved into solvents.

A **gas** dissolved into a **gas**: Air, but a mixture of gases isn't called a solution. It's called a ***mixture***.
A **gas** dissolved into a **liquid**: Carbonated beverages; nitrogen into blood during deep scuba dives (dangerous!)
A **gas** dissolved into a **solid**: Hydrogen can dissolve into metals, believe it or not!

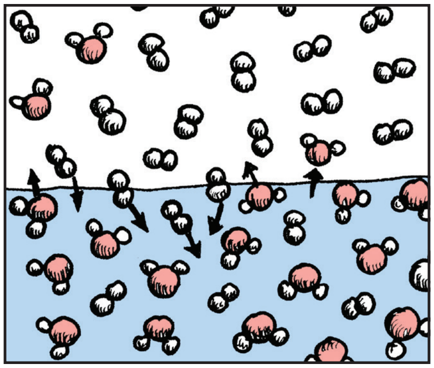
A **liquid** dissolved into a **gas**: Fog
A **liquid** dissolved into a **liquid**: Vinegar (acetic acid, water); windshield washer fluid (alcohol, water)
A **liquid** dissolved into a **solid**: Gelatin; mercury dissolved into gold (the mercury seems to be solid)

A **solid** dissolved into a **gas**: Smoke
A **solid** dissolved into a **liquid**: Sugar water; salt water
A **solid** dissolved into a **solid**: Bronze (copper and tin); steel (carbon and iron)

Returning to our carbonated beverage, how is it possible to make a gas dissolve into a liquid? Well, to begin with, gases will do this on their own to some extent. For example, the water found in lakes, rivers and oceans has some oxygen. Fish and other aquatic animals "breathe" this dissolved oxygen. The way oxygen gets into the water is based on the fact that molecules are in constant motion. The bonds between the atoms in a molecule are constantly stretching and pulling and shaking, so you've got internal vibration going on. Also, the entire molecule is in motion, bumping and banging into other molecules. Molecular motion corresponds to how much "heat" a substance has. The molecules in hot substances are moving very fast. The molecules in cold objects are moving very slowly. If we cool something down to -273° C, motion stops completely. (This is called absolulte zero.)

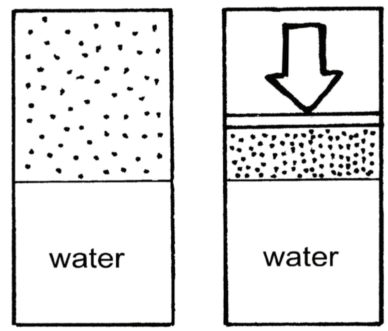

One molecule vibrating


Many molecules bumping and crashing



Oxygen molecules (O_2) are constantly going in and out of the water.

As oxygen molecules crash into the water molecules at the surface, some of them dive right in and vibrate their way down among all the vibrating water molecules. The opposite happens, too. Some water molecules move from the water to the air. Oxygen atoms in the water might go back into the air and, if conditions are right, water might move from the air back into the water. If you adjust the temperature and pressure you can control how many of each type of molecule will go in or out of the water. The faster water molecules vibrate, the more likely they are to take off and go into the air. For instance, if you turn up the heat under a pot of water on a stove, the water molecules will move faster and faster until many of them begin escaping as steam.



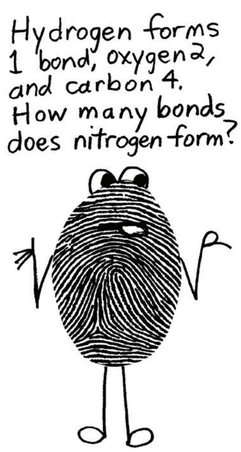
Regular water has dissolved gases in it, but it is certainly not fizzy like carbonated beverages. We need to pump lots and lots of gas molecules into water to get it to fizz. We must force those gas molecules to go in and stay there for as long as possible. One way to do this is to use pressure. If you squeeze the air above the water (using a machine a bit like a bicycle tire pump) you can force many more gas molecules down into the water. But this still might not be enough. You may also have to increase the amount of surface area (those places where the gas can touch water molecules) by creating lots of bubbles, like a water bubbler in a fish tank. But what if this still wasn't enough?

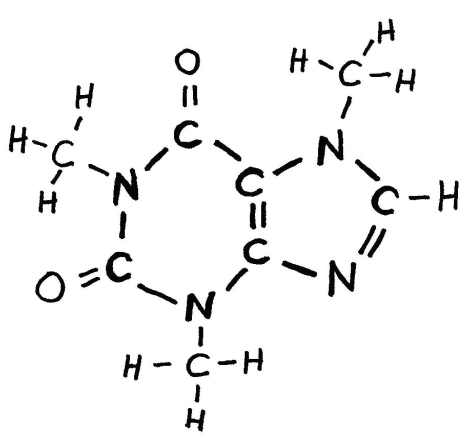
The last thing you can do to get more gas molecules into the water is to turn down the temperature. Cold water can hold more gas than hot water can. Why? Because heat is the same thing as molecular motion. The faster the molecules move, the more heat they have. The less they move, the less heat they have. So which molecules are moving faster—molecules of ice or molecules of liquid water? Liquid water, because it is warmer than the ice, and therefore its molecules are moving faster. Motion is heat. Heat is motion. More motion, more heat. Less motion, less heat.

So if we chill the water we are trying to carbonate, we will slow down the vibration of its molecules. And the slower the water molecules are going, the less they will bump into the carbon dioxide gas molecules. And the less the CO_2 bubbles are bumped, the more likely they are to stay in the water. (This is the reason that carbonated beverages go "flat" faster if they sit at room temperature than if they are kept in the refrigerator.)

What else is in a carbonated beverage, besides carbon dioxide bubbles? If you read the label, you will see that sugar, or some kind of sweetener, is a major ingredient. We'll assume that the beverage on your table has sucrose in it, which you have already dissected.

Some carbonated beverages have caffeine in them, especially colas. This is what a molecule of caffeine looks like. Caffeine is known for its ability to keep you from feeling sleepy. Food companies must think that their customers will enjoy that "wide awake" feeling and therefore want to purchase those beverages again.

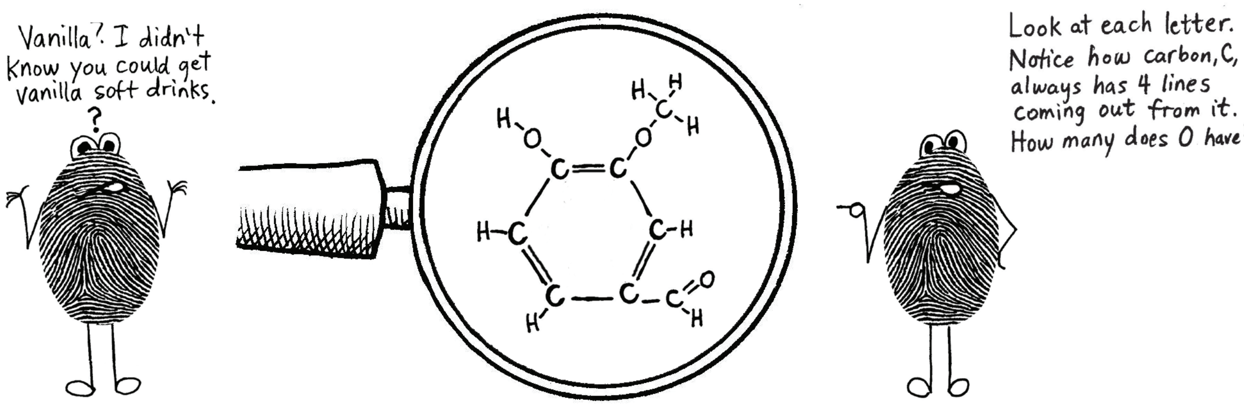




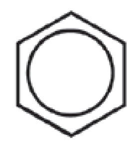
Caffeine has two rings: one pentagon and one hexagon. They might remind you of fructose and glucose. A big difference is that those rings include ***nitrogen*** atoms (N). Nitrogen molecules (as N_2) make up about 80% of the air we breathe. So what are they doing in a caffeine molecule? Just like carbon and oxygen, nitrogen is a common atom that you find in all kinds of things. Sometimes it's in a gas, and other times it's in a liquid or solid.

Caffeine is a natural substance produced by certain types of plants, especially tea and coffee plants. Plants don't need to stay awake, so why do plants make caffeine, then? For a plant, caffeine is a pesticide (a poison that paralyzes or kills certain types of insects). Fortunately, caffeine doesn't have the same effect on humans that it does on very small bugs!

What else is in carbonated beverages, besides water, fizz, sweetener and sometimes caffeine? We wouldn't want to drink them if they didn't have an enjoyable taste. Can we find any flavor molecules?



What have we got here? Looks like we've found some ***vanillin***, a common artificial vanilla flavoring used in many snacks and desserts. It must be a glass of "cream soda." (That's the name for a vanilla-flavored soft drink.) Vanillin has a hexagonal ring made of 6 of carbons, with some additional carbons, hydrogens and oxygens attached to it. This hexagonal carbon ring shows up all the time in chemistry. Six carbons joined together in a hexagon shape (with a hydrogen attached to each carbon) is called a ***benzene ring***. Many molecules have one or more (modified) benzene rings as part of their structure. Not all flavors have this ring; many have short strings of carbon, instead.

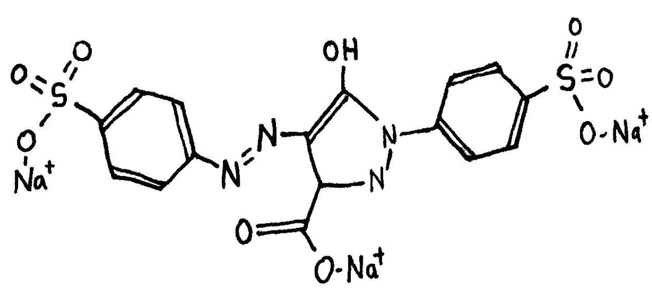


Benzene rings are sometimes drawn like this. Chemists know there are carbons at the corners and 6 invisible hydrogens.

Why does this molecule taste like vanilla? Technically, it doesn't. Most of what we think of as taste is actually smell. There are only five "tastes" that the tongue can sense: sweet, sour, bitter, salty and savory. If you've tasted vanilla flavor right out of the bottle, you know that it can't be described by one of these words. Sensing flavor is a job for the nose, not the tongue. Tiny molecules of the vanillin get up into your nose and tingle receptor sites on cells inside your nose. That's why you can't taste very well when you hold your nose; taste is mostly smell. The shape of a molecule determines which receptors it can tingle. Those tingled cells send electrical impulses to the part of your brain that interprets smells. So once again, we find that **the shape of a molecule is critical to its function**.

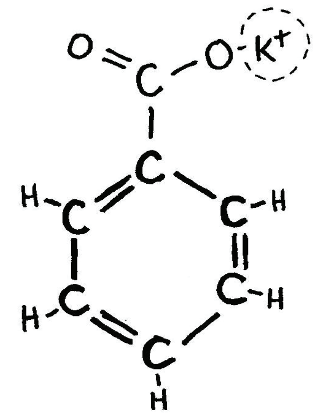
Your carbonated beverage might also have food coloring in it. Most consumers think clear liquids are boring. They are more likely to drink something bright orange or red or yellow. Most food coloring found in carbonated beverages is artificial, meaning scientists made the molecules in a lab. This doesn't mean they are poisonous, though. All colorings used in food products have been tested thoroughly to make sure they are safe. Like any food or drink, there will always be people who have allergic reactions, or sensitivities, to them.

If you want to go natural and use color that comes from plants such as beets or carrots, the color molecules will look just as complicated.

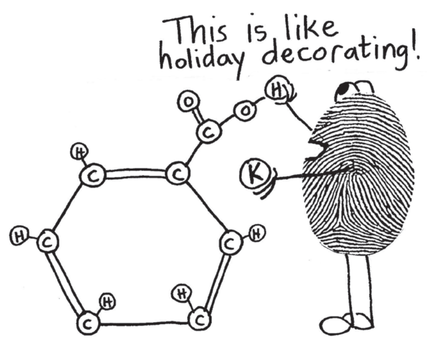


This is "Yellow #5." Other options you can legally use are Yellow #6, Reds #3 and #40, Blues #1 and #2, and Green #3. That's it. Want orange? Mix yellow with one of the reds. Purple? Mix a blue and a red. Black? Use a lot of blue with some added red, yellow and green.

Some beverages also have ***preservatives*** that discourage bacteria, molds and yeasts from living in the drink. A common preservative is ***potassium benzoate***. ***Potassium*** (symbol "K") is another type of element, and can be found on the Periodic Table at number 19. The most significant fact to know about potassium is that it has only one place it can bond, just like hydrogen. In this molecule, the potassium is hanging out with one of the oxygens.



The "benzo" part of the name comes from the hexagonal ring, which can be turned into a benzene ring if the chemistry of the solution is just right. A benzene ring by itself, with no extra atoms stuck to it is a fairly dangerous molecule named ***benzene***. Benzene is suspected to be a ***carcinogen***—a substance that causes cancer. As long as the ring in this molecule keeps those extra atoms attached to it (a carbon, two oxygens and a potassium) it's considered to be harmless to humans. If you're a microorganism, however, you are in big trouble. When put into a liquid such as fruit juice or soda, potassium benzoate drops its potassium ion and picks up a hydrogen instead, turning itself into ***benzoic acid.*** The benzoic acid goes into the cells of the microorganisms and prevents them from being able to digest sugar. Basically, the little critters starve to death while being surrounded by sugar!



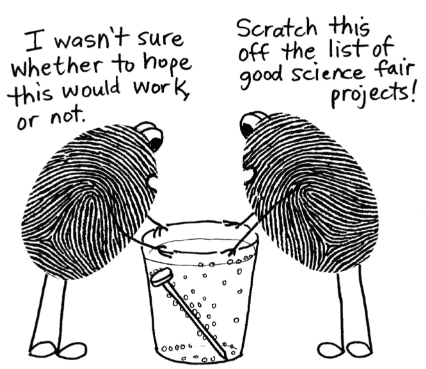
Benzoic acid doesn't affect humans the way it affects microorganisms, but there is a small potential danger to humans. If benzoic acid comes into contact with vitamin C, the vitamin C molecule strips off those extra atoms at the top (C, O and O), and thus turns benzoic acid into a benzene ring. However, the total amount of benzene formed inside a beverage can is very, very small. You get a much bigger dose of benzene by breathing the air in a big city, or by smelling gasoline fumes as you are pumping gas into your car. You'd have to drink five gallons of a carbonated beverage every day to get even close to the amount of benzene you get from other sources.

The US Food and Drug Administration runs tests on beverage products to determine if they contain unacceptable levels of benzene. Companies that produce these products are warned that they must find a way to reduce the levels down to what the FDA considers safe. In 2008, the Coca-cola® company announced that they were going to stop using benzoates in all their soft drinks except Fanta®, Dr. Pepper® and Coca-cola Zero®.

The use of preservatives is controversial, but seems to be a "necessary evil." We prefer not to have harmful substances in our drinks, but we don't want to find bacteria or mold growing in them, either. Modern food delivery systems usually require that food be able to sit in storage for a certain amount of time. Food companies get into much bigger trouble if microorganisms are found in their products than they do if they use preservatives. Of course, some products can be preserved just by keeping them cold, but this requires a lot of energy. For some products, the added energy costs would make them too expensive for the consumer.

When we talked about potassium benzoate turning into benzoic acid, we used the word "acid" without explaining it. We could do this because you are probably already familiar with the word ***acid***. You know that lemon juice and unripe apples are acidic. The acid in these fruits is what gives them their sour taste. But did you know that many carbonated beverages are just as acidic as lemons, even if they taste sweet? We already mentioned benzoic acid, but you meet other acids in carbonated beverages, too. The most common one is ***phosphoric acid***. Its name comes from the element ***phosphorus*** (P), number 15 on the Periodic Table.

Before we launch into a chemistry lesson about acids, let's ponder this question: Why do food companies put acids into carbonated beverages, anyway? They are supposed to taste sweet, not sour. Actually, there is a bit of sour "tang" to them, even if you don't notice it. Consumers prefer drinks that are sweet yet still acidic enough to make their salivary glands tingle. The acid in these beverages isn't enough to bother people who don't particularly like sour tastes, because there is so much added sugar that it covers the tartness. There is also a chemical reason to add acid to carbonated beverages: preservatives like potassium benzoate work more efficiently in an acidic environment. If you're adding potassium benzoate to natural fruit juice, the fruit provides the acid. But artificially flavored beverages need to have acid added to them in order for the preservatives to work.



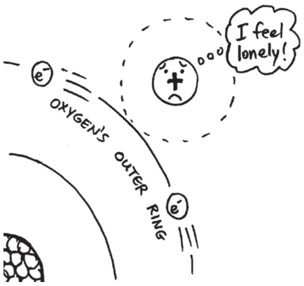
Phosphoric acid in carbonated beverages is just as controversial as potassium benzoate (or its "sister" molecule, sodium benzoate). Some people love to quote the fact that phosphoric acid can be used to remove rust from metal. One Internet rumor says that cola drinks will dissolve a nail in 4 days. That'll scare you from ever drinking a cola again, eh? (It turns out to be a false claim, of course. If you want to see the results of an experiment where someone actually tried this, you can go to: **http://joshmadison.com/2003/12/14/will-coke-dissolve-a-nail-experiment/**) Pure phosphoric acid in large amounts might be able to dissolve rust or soften a nail, but the amount that is in carbonated beverages is so low that these Internet claims are ridiculous.

Phosphoric acid has also been accused of causing children to have weak bones and cavities in their teeth. They say that the phosphorus atoms are able to grab calcium atoms out of the digestive system and blood, so that they don't get delivered to the bones and teeth that need them. It is true that phosphorus atoms can grab calcium atoms, but to what degree? Enough to harm you? Studies have been done to test whether consumption of carbonated beverages (especially colas) affects bone health. Some studies claim to have found a definite link between cola consumption and reduced bone density. Other studies claim there is no link at all. How are we to know which study is right?

All researchers agree, however, that people should not drink carbonated beverages all the time. The high sugar content provides plenty of food for the bacteria that live in our mouths, and the acids in the drinks make the environment of the mouth just right for them to multiply. Even natural fruit juices can be a problem if you sip on them all day. To get rid of this extra sugar and acid, brush your teeth as often as you can.

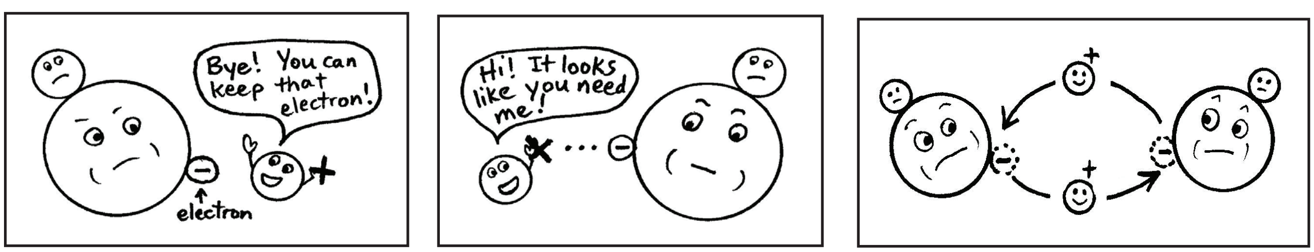
Now it's time to find out exactly what an acid is. To do this, we'll start by looking at water again.

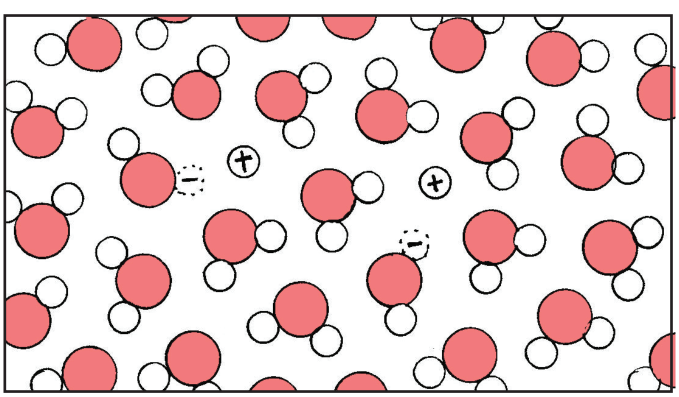
You'll remember that water molecules are made of two hydrogen atoms attached to an oxygen atom. Well, it turns out that those hydrogen atoms are not very faithful to their water molecules. They sometimes go wandering off, leaving H_2O as OH^-.



It is important to notice that once a hydrogen atom's single electron goes off to join the electrons in the oxygen atom, the hydrogen atom is reduced to being nothing but a proton. Just one proton! Can that proton still be called a hydrogen atom? Not really. We'll need to start calling it a ***hydrogen ion***. An ion is atom that has become electrically unbalanced. In this case, the imbalance is plain to see, as there is just one proton with a positive charge, and no electron to balance it. Since a hydrogen ion is nothing but a proton, we can use either word and they mean the same thing. "HYDROGEN ION" = "PROTON" (This is a very useful thing to know when studying chemistry. Many students do not realize that these words are interchangeable.)

And so it happens that once in a while the lonely hydrogen ion will leave its water molecule and go off to seek its fortune elsewhere. Before long, it runs into a sad water molecule that is limping along with only one "ear." Off to the rescue it goes, and sticks itself to this disadvantaged water molecule, restoring it to H_2O. Hmm... wonder why that water molecule was missing a hydrogen? Could it be because one of *its* hydrogens got unhappy and left? Yes, hydrogens are that stupid. They keep leaving their old water molecules to join new ones even though their new molecules are identical to their old ones. The hydrogens apparently don't understand the concept that the grass really isn't greener on the other side of the fence.

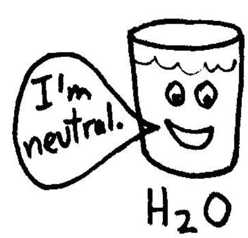




Imagine those hydrogen ions zooming around, pointlessly trading places with each other, when—SNAP! We take a picture. We have a split second of time frozen in a "photograph." Most of the water molecules are intact. But we've caught a few hydrogens mid-switch.

As you can see in this diagram, the hydrogen atom's electron stays with the oxygen atom. That little circle with the minus sign in it represents the electron that was left behind. These "broken" water molecules are no longer H_2O. They are now called ***hydroxide ions***, and are written like this: OH^-. So in this picture we have lots of regular water molecules, H_2O, two hydrogen ions, H^+, and two hydroxide ions, OH^-.

In normal water, the number of hydrogen ions, H^+, always equals the number of hydroxide ions, OH^-. The ions are leaving molecules and joining molecules at about the same rate. So overall, water is electrically balanced. The positive and negative charges sort of cancel out.



What would happen if we added extra protons to regular water? It would certainly upset the balance of positive and negative ions. Is it possible to add extra protons? What about adding extra hydroxide ions?

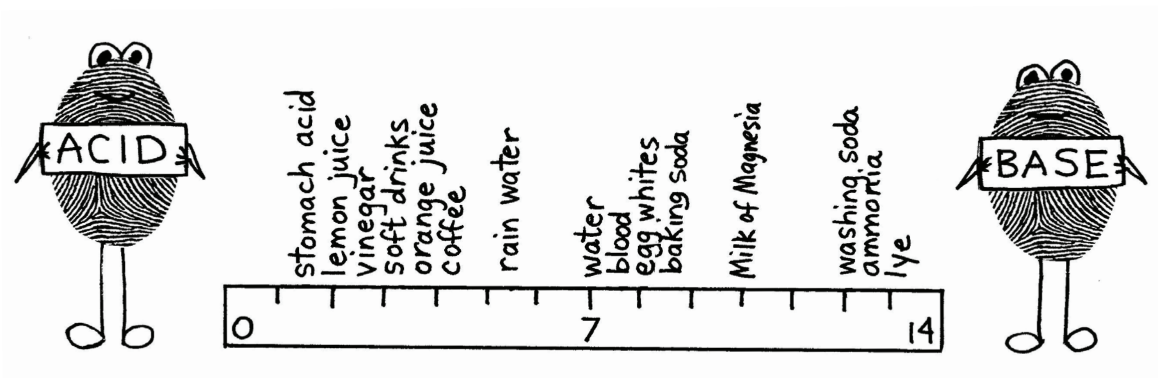
There are certain substances that release H^+ ions (protons) when they are dissolved in water. For example, if you put hydrochloric acid, HCl, into water, the ions H^+ and Cl^- would separate. The Cl^-s would quickly be surrounded by water molecules, as we saw in the salt water. The H^+s would be your source of extra protons.

A substance that can release OH^- ions is sodium hydroxide, NaOH. ("Na" is the symbol for sodium. It used to be called "natrium.") When NaOH is put into water, you get Na^+s surrounded by water cages and loose OH^- ions all over the place.

An increase in either the number of hydrogen (H^+) ions or hydroxide (OH^-) ions in a solution affects the chemistry of the solution, so this imbalance is important for chemists to measure. They use a scale called the ***pH scale***. The letters ***pH*** are most often interpreted as being an abbreviation for "**p**otential **H**ydrogen" because if a hydrogen ion (a proton) gets just one electron, it becomes an actual hydrogen atom again. That's why the H is capitalized; "H" is the symbol for the element hydrogen.

The pH scale runs from 0 to 14. The middle of the scale, 7, is defined as ***neutral.*** Numbers below 7 are ***acids***. The lower the number, the more acidic the solution is. Substances that have a pH value greater than 7 are called ***bases***. And, just to confuse you, bases have an alternate name, too: ***alkaline*** substances. You'll find these words used interchangeably in chemistry texts. One minute they'll be talking about bases and the next minute they'll be talking about how alkaline something is. These terms mean the same thing. Alkaline substances release hydroxide ions (OH^-), the counterparts (or "opposites") to the hydrogen ions (H^+).

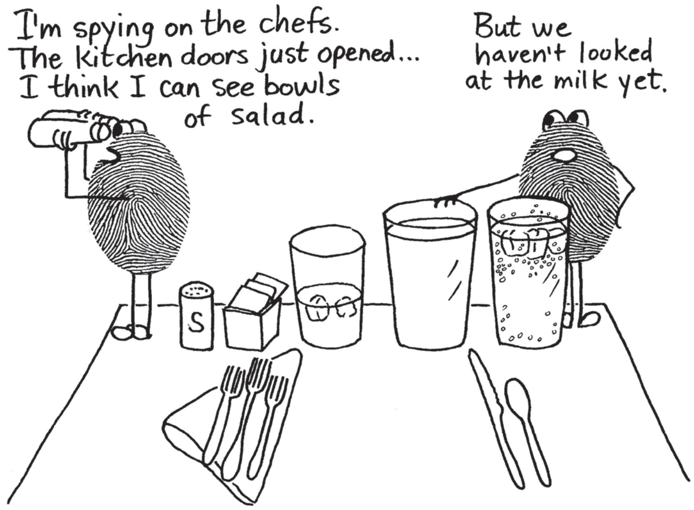
Here are the pH values of some common household substances.



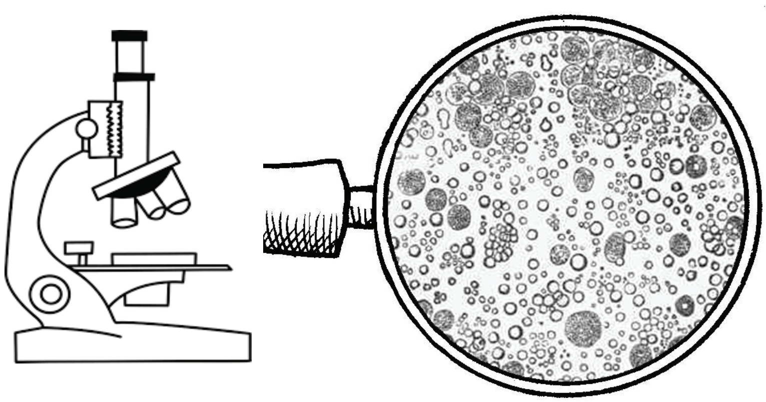
Here's a thought: If acidic substances have lots of hydrogen ions (H^+) and alkaline substances (bases) have lots of hydroxide ions (OH^-), what would happen if you mixed them together? Would all the hydrogen ions decide to attach to hydroxide ions? Yes, that's exactly what happens! And what do a hydrogen ion and a hydroxide ion make when they join together? A normal water molecule. If you put an acid and a base together, the hydrogen ions and hydroxide ions will ***neutralize*** each other, producing water molecules. Also, in the midst of this reaction, the other pieces of the molecules join together to form a salt compound. Table salt is only one kind of salt, just like table sugar is only one kind of sugar. There's a big family of related compounds that are all called salts. ***When you mix and acid and a base, you get water and a "salt***."

Many of us have mixed vinegar (an acid) with baking soda (a base) and witnessed the intense bubbling effect (carbon dioxide being given off). But most of us have never thought about the other product that is produced, a "salt" called ***sodium acetate***. You don't normally see this salt because it stays dissolved in the solution. However, if you boil the solution (after all the excitement of the bubbles is over!) to get rid of excess water, you will be left with a solution so rich in sodium acetate that it will begin to form crystals. If you pour out the solution quickly, it will appear to be "freezing" into crystals within seconds. Because the sodium acetate crystals look similar to ice, and because this reaction releases a lot of heat energy, this experiment is often called the "hot ice" experiment.

If acids and bases make salts, is there an acid/base combo that can make table salt, NaCl? Yes, but making NaCl requires chemicals that are not edible, HCl and NaOH, so it's beyond the scope of kitchen chemistry.



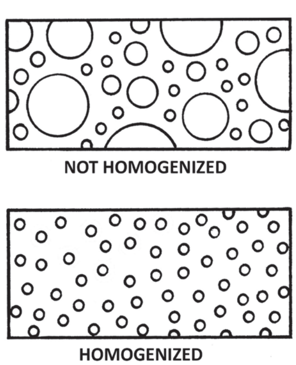
Let's take a look at your glass of milk before your salad arrives. We'll set our viewer's magnification on "regular microscope." If you could look at milk through a microscope in a biology lab, this is what you would see.



Those little round balls are blobs of fat. They're really small, about the size of a bacteria. And speaking of bacteria, if your milk had not been ***pasteurized*** (heated) at the dairy it came from, you would have seen bacteria floating amidst the fat blobs. Dairies that sell milk to the general public are required to heat the milk to a certain temperature for a certain amount of time, so that all bacteria will be killed. Pasteurization does a very good job of killing bad bacteria and keeping milk safe to drink. However, it also kills good bacteria, too. Most bacteria are harmless to people, and there even are species of bacteria that you can't live without. Your intestines are filled with "good" bacteria.

It's bacterial warfare all the time in your digestive system as the "good" bacteria try to keep the "bad" ones out. For customers who want these good bacteria in their milk, dairies often sell a type of milk that has had some of the good bacteria put back into it. The most well-known of these good bacteria is ***Lactobacillus***. *(lack-to-ba-SILL-us)* The "lacto" on the front of the word means "milk." If you see a dairy product with a label that says, "Contains live cultures," that usually means it has *Lactobacillus* in it. (The most common kind of *Lactobacillus* found in milk is called *Lactobacillus acidophilus*.)

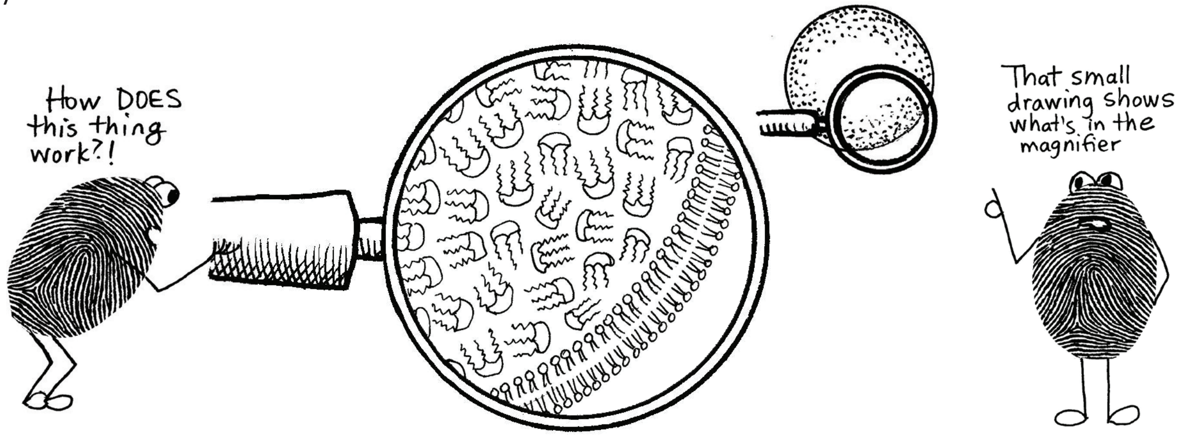
Lactobacillus acidophilus



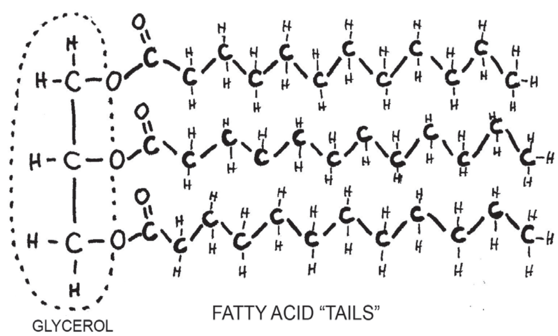
In addition to pasteurization, milk is usually ***homogenized*** *(hom-odge-en-ized)*. "Homo" means "same" and "gen" means "to make" so in homogenization you are making something the same. If you look at milk that just came out of a cow ("raw" milk) you'll find that the fat blobs are not all the same size. If the milk sits for a while, the larger fat blobs rise to the surface because fat is less dense than water. The fat blobs that collect at the top are known as cream. Farmers who drink raw milk just give their milk jug a good shake to mix the cream back into the milk before they pour it into their glass. However, most consumers don't want to do this. So the dairy presses the milk through a screen with very small holes in order to break the fat blobs into very tiny blobs that are too small to float to the surface. So in homogenization, fat blobs are made to be the same size.

Another process can take some of the fat out of the milk, creating low-fat varieties of milk, such as 2%, 1%, or skim (no fat) milk. Some dairy scientists claim that "raw" (unprocessed) milk is better for your health, but others say store milk is just fine. If milk is not pasteurized, the dairy has to be very careful to monitor the number of microorganisms in it. Rarely, people do get sick from drinking raw milk.

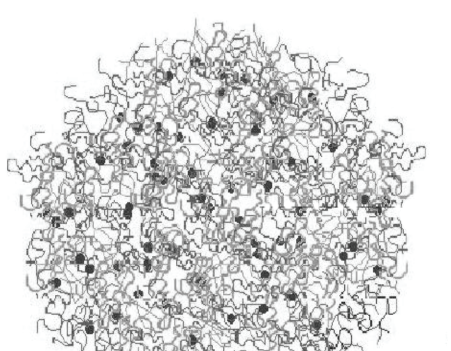
Let's take a closer look at one of those balls of fat. We'll have to switch to our super close-up view where you can see atoms and molecules.



We are looking at just one part of a fat blob so that we can zoom in enough to be able to see its molecular structure. The outer layer, or "shell," of the ball is a very thin membrane, the same kind of membrane that surrounds each cell in your body. The membrane was made by the cells inside the cow's mammary glands. It's only two molecules thick. Those things that look like balls with two tails are the membrane molecules. Inside the membrane are thousands of fat molecules that look like jellyfish with three tentacles.



Let's zoom in on one fat molecule. This type of fat molecule is called a ***triglyceride*** *(tri-GLISS-er-ide)*. The prefix "tri" means "three." The ending "glyceride" refers to that 3-carbon structure inside the dotted line, ***glycerol*** *(GLISS-er-ol)*. Glycerol is like a handle that holds on to three very long molecules called ***fatty acids***. The "fatty" part of the name comes from the long chains of carbon atoms. All forms or fat and grease are made of long chains of carbon atoms that have hydrogens attached to them. Since the word "acid" is also part of the name, this must mean that they are capable of donating hydrogen ions. It's not obvious from this picture where the hydrogens would come from. Before these tails were attached to the glycerol, there was a hydrogen stuck to the oxygen that is now sitting on the dotted line. That hydrogen comes off as the tail attaches to the glycerol.



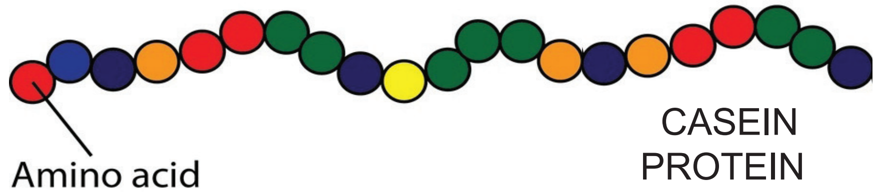
*Little clumps are called **micelles**. This word is used for other types of clumps, too.*

Let's keep going and see what else is in this milk. There are smaller blobs floating around. Let's zoom in on one of them.

There's no membrane around this ball. It looks like a clump of spaghetti and meatballs. The "meatballs" are made of a mineral called ***calcium phosphate***. You've probably been told that milk has lots of calcium in it. This is where the calcium is located—it's found in these "mineral meatballs." Milk is a good source of phosphorus, not just calcium. During our discussion of the phosphoric acid in colas, you may have gotten the impression that phosphorus is bad for you. Phosphorus is actually an essential mineral that your body can't live without. Not only is it a main ingredient in bones and teeth, it is also an important part of the ATP molecule that provides energy to all your cells. Here, we see phosphorus working with calcium to keep these protein strands together.

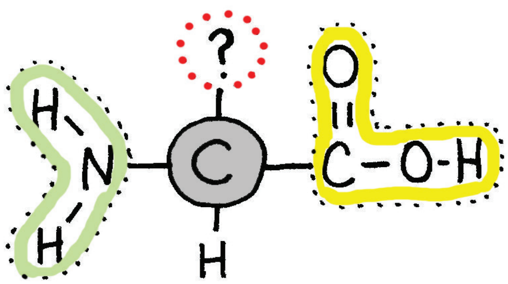
Let's zoom in closer on the "spaghetti noodles."

The "noodles" of the micelle aren't noodles, of course! They are long strings of protein called ***casein*** *(kay-seen)*. People have been extracting casein protein from milk since ancient times. They didn't know the molecular structure of the proteins, but they knew how to get them out of the milk and use them for paint and glue. Casein paint was commonly used until the 1960s when acrylic paint was invented. Milk glue was in general use until World War II. Also, casein proteins are the basis for many cheeses. (The word "casein" comes from the Greek word for cheese.) Casein has even been used to make a hard "plastic."




Casein paint was used for centuries.

If we zoom in to look at the casein, it might at first look like long strings of beads. Each bead is called an ***amino acid.*** Amino acids are the individual pieces that make ***proteins*** like casein. You are already familiar with the word protein. You probably have been told you should eat meat or eggs or beans because they contain protein. Your digestive system tears apart the protein chains until they are single units called amino acids. The digested amino acids will be used by your cells to build and maintain body parts.

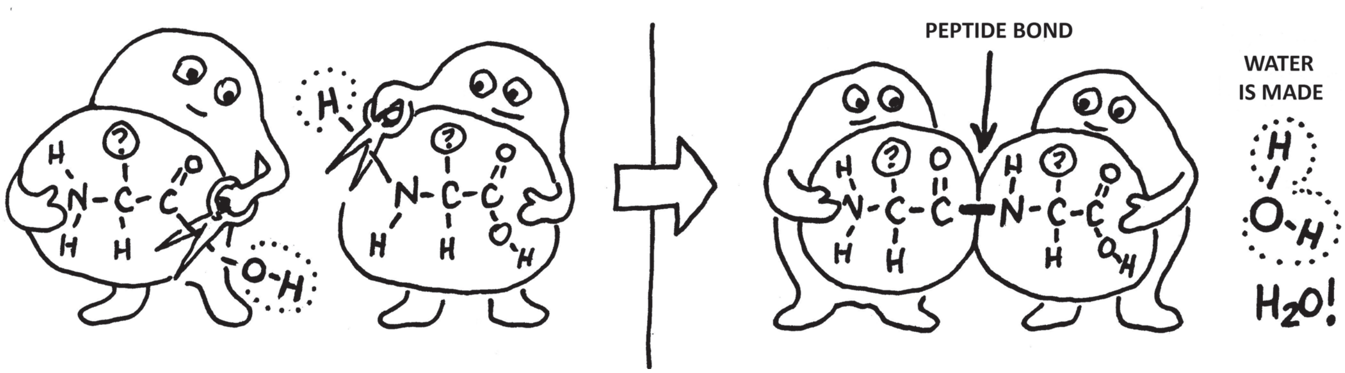


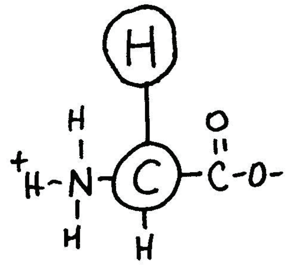
Let's use the highest power on our zoom lens and take a look at one amino acid. Since the word "acid" is in its name, we should expect to find at least one hydrogen, H, that will be able to leave the molecule in the form of a proton.

Amino acids have a carbon atom at their center. This is called the ***alpha carbon***. ("Alpha" is Greek for "A.") Imagine that the alpha carbon has four arms. The lines that represent arms are the bonds that it is making. The alpha carbon's bottom "arm" is attached to one hydrogen atom. The top arm is attached to a "wild card" that could be any one of 20 different molecules. Chemists use the letter "R" instead of our nice question mark. The R stands for "residue," but it is easier to think of it as the Rest of the molecule. More about the R in a minute. Let's look at the alpha carbon's left and right arms.

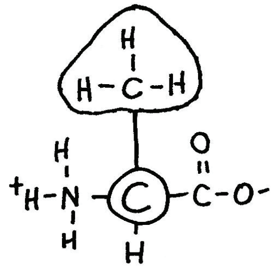
The alpha carbon's left arm is attached to a COOH. Notice the H on the end. It is sitting next to an electron-hogging oxygen atom. The oxygen atom has a strong pull on the hydrogen's only electron. From the hydrogen's point of view, its electron spends far too much time going around the oxygen atom, so the hydrogen is liable to take off and leave its electron behind. When you have hydrogen ions (protons) taking off and roaming around, then by definition, you've got an acid. The NH_2 side of the molecule (the part circled in green) is called the "amine" group. So now we know why they are called "amino acids." The "amino" is NH_2 and the "acid" is the COOH.

Amino acids are not that acidic, though. They can't be put onto the pH scale like vinegar or lemon juice. The H on the end disappears when amino acids hook together to make a chain. The bond between amino acids is called a ***peptide bond***. To make this bond, you chop an OH off one side, and an H off another, producing an H_2O.

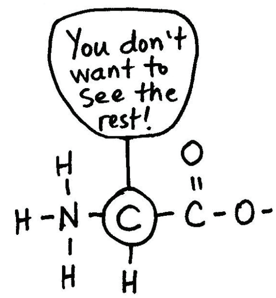




glycine



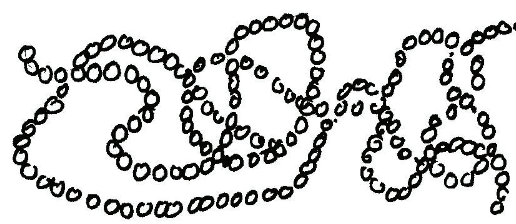
alanine



Now just a little bit of info about that "wild card" (?) at the top...

The alpha carbon (the one in the circle) will have one of 20 possible groups of atoms stuck onto that top arm. The simplest possibility is to stick a hydrogen on the end. When it does this, it forms an amino acid called ***glycine*** *(glie-seen).* Glycine is the smallest amino acid and is very useful for building things in tight spaces. It is a primary ingredient in collagen, which is found in connective tissue like ligaments and tendons, but it is also abundant in skin and bone. Collagen is like a protein "rope" that is wrapped very tightly, and glycine, because it is small, helps to get the wrap tight. If a carbon and three hydrogens are attached to the top arm, the amino acid ***alanine*** is formed. If a sulfur is added to that group, ***cysteine*** *(sis-teen)* is formed. The remaining 17 possibilities are much more complicated, but they are all based on a unique (one of a kind) arrangement of carbon and hydrogen atoms with an occasional sulfur or nitrogen added in. We'll see amino acids again in a future chapter and learn more about them.

So, back to milk... Casein protein is made of long strings of amino acids. You'll find 18 of the 20 kinds of amino acids in casein. As our enzyme guys demonstrated on the previous page, the amino acids in casein are linked together using ***peptide bonds***. Protein chains can have hundreds or thousands of amino acids in them. These long chains are called ***polypeptides***. ("Poly" means "many," and "pep" means "protein.")

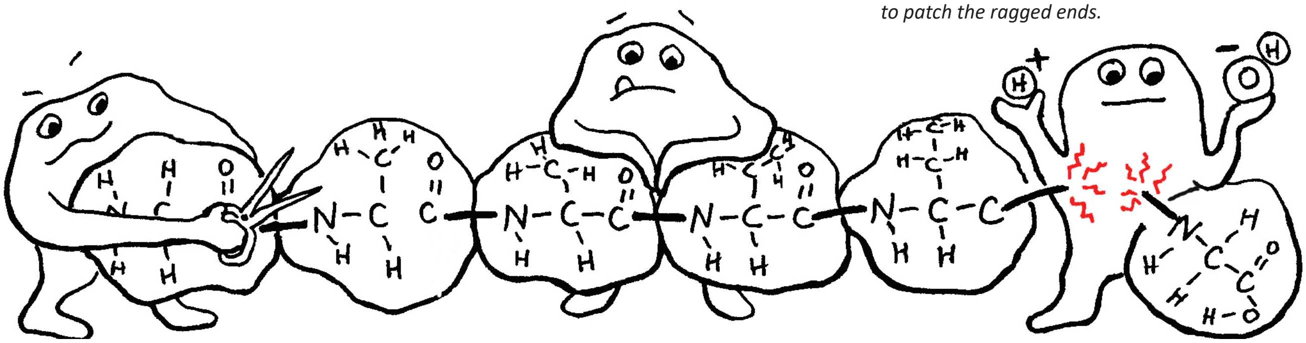


If we made a model of casein protein using colored beads, we'd have to use 18 different colors!

Enzymes that can break apart peptide bonds are called ***peptidases*** *(pep-tid-ace-ez).* The ending "***ase***" is almost always used for an enzyme that breaks things apart. Interestingly, there are several kinds of peptidase enzymes. Some peptidases can only break off the amino acids that are on the very ends of the chain. Other peptidases can get in between the amino acids in the middle of the chain and break them apart. Some can only separate certain kinds of amino acids. Enzymes are highly specialized. As a general rule, enzymes are designed to do only one job.

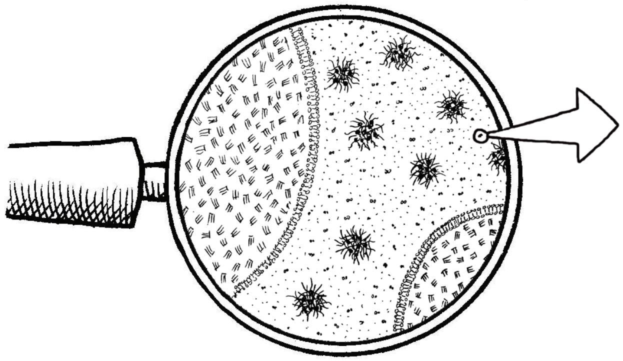
When peptidases break apart amino acids, they use water molecules to patch the unhappy broken bonds they leave behind, just like we saw in the case of sucrose being broken apart. A water molecule can be split into H^+ and OH^-, and each of these parts can be used as a "band aid" on one side of the broken bond.

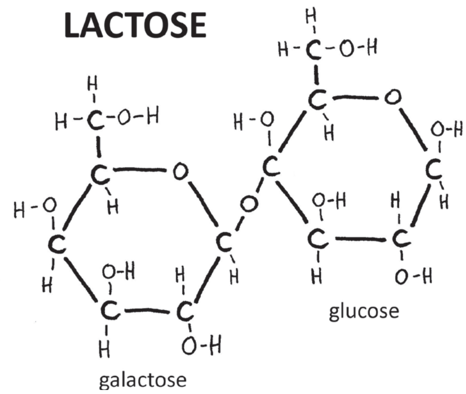
This guy is going to use a broken water molecule to patch the ragged ends.



Peptidase enzyme guys tearing apart the amino acids in a protein molecule

Let’s take one more look at the milk under our Sooper Dooper magnifier and see if we can find anything else. You can see the edges of the large fat globules with their triglycerides inside, and there's those casein "spaghetti" clumps with their calcium phosphate mineral "meatballs." The tiniest dots are water molecules. But there are some larger dots that look like they might be double rings of some kind. Let's zoom in closer.



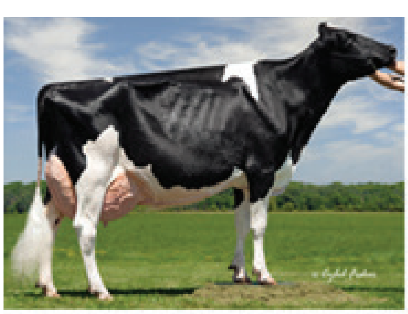


Yes, we've found some double-ring molecules. Could they be sucrose? Is there sucrose in milk? Very careful examination of the rings reveals that one of them is glucose but the other is not fructose. The other ring is a type of simple sugar that we have not seen yet. It’s almost identical to glucose except that the H and OH on one side are reversed. Seems like a small difference that shouldn’t matter at all, but in fact it changes glucose into ***galactose***. The existence of galactose was first discovered by the famous scientist Louis Pasteur in 1856. He named his newly discovered chemical "lactose" because it was in milk, but he did not know its molecular structure. Later, chemists figured out the structure and decided to use the word ***lactose*** to describe the larger two-ring structure, and created a new name, "ga-lactose," for the single ring.

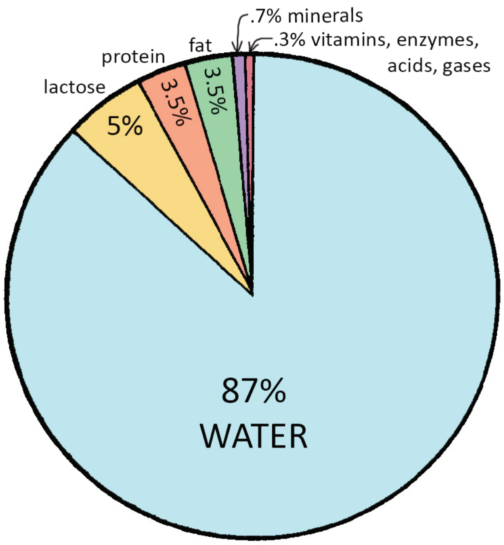
To tear apart the double-ring lactose molecule you need (no surprise) a special enzyme that can snip the bond between glucose and galactose. That enzyme is called ***lactase***. Babies of all mammals produce lactase in their digestive systems to that they can digest their mother's milk. In the vast majority of cases, mammals lose the ability to produce lactase as they get older. Not being babies anymore, they don't need to drink their mother's milk. It makes sense. This happens in most humans, too. However, in western Europe many centuries ago, a genetic mutation occurred. The genetic "switch" in the DNA that is supposed to turn off lactase production became broken. Without any instructions to stop, these people's guts go right on producing lactase as if they are still babies. This genetic mistake became very widespread and millions of people today who have European ancestors can drink milk into adulthood. (There are a few places in Africa, also, where some of the population can drink milk.) The ability to drink milk came to be seen as "normal" and therefore people who could not drink milk were considered the defective ones. In modern times, we call this inability to digest milk "lactose intolerance." (Perhaps we should switch the labeling, though, and call the milk drinkers "lactose tolerant," since they are the ones with the broken DNA!) People with lactose intolerance can often take lactase pills that will allow them to digest milk. Cheese and butter are usually less of a problem because much of the lactose has been removed.

Not surprisingly, the milk-drinking Europeans began raising herds of dairy cows to supply them with plenty of milk. They discovered that by controlling the breeding of the cows, they could create cows that could give even more milk per day. A modern dairy cow can give up to 8 gallons of milk every day. That's a lot of milk!

Holsteins are the most popular dairy cow in the world right now.



Jerseys are the second most popular dairy breed and are a little smaller.



This chart shows you an overview of what cows' milk is made of. (The numbers are averages, so different breeds of cows might have slightly different numbers.) Most of milk is water. For cows, lactose sugar is the most abundant solid substance, followed by fat and protein. Casein is by far the most abundant type of protein, but there are some other minor proteins, too. ***Whey*** *(whay)* ***protein*** is the general term for all these other smaller proteins. They include some proteins that are made by the immune system to fight germs. Others act like "taxi cabs" for transporting things like minerals. There are also are a number of different enzymes and hormones, plus some cow body proteins that leak in accidentally.

We saw the most abundant minerals in milk when we looked at those mineral "meatballs" in the casein protein. Milk also has a small amount of a few other minerals such as iron and zinc. The only category we haven't mentioned at all is vitamins. Milk has most of the major vitamins: A, B, C, D and E. We'll discuss vitamins more in aa future chapter.

This chart is only for cows. The composition of milk depends on what type of mammal is making it. Each animal has milk suited to what the baby needs in that environment. For example, animals that live in cold climates will have a lot more fat in their milk. Animals who nurse their babies for a long time will have milk lower in fat.

One final bit of chemistry before we go on to our appetizers. We need to learn the correct name for the type of liquid that milk is, because milk isn't a solution. Solutions occur when the dissolved particles are extremely small. In salt water, for example, the solute (salt) is made of individual atoms (ions). In sugar water, the sugar molecules are also very tiny. In milk, we have many different types of particles. Some, like lactose, are small. Others, like the fat globules, are large, and can even be seen under a regular microscope. Liquids that have large particles floating in them are called ***colloids***. This word comes from the Greek word "colla" meaning "glue." As we learned a few pages ago, casein protein in milk can become sticky and usable as glue. People have been making glue from milk for hundreds of years.

An easy way to determine if a liquid is a solution or a colloid is to shine a flashlight or laser pointer through it. In a solution, the particles are very small and the light will pass right through. In colloids, the particles are large enough that they reflect rays of light that hit them, so the beam of light will be visible. This is called the ***Tyndall effect***.

But why is milk white? The answer is as much about light as about milk. Natural light contains all the colors of the rainbow. If an object reflects back all the colors, it looks white. Each tiny particle of fat or protein in the milk is reflecting all of the light that hits it, so the milk looks white. Skim milk, which has had the fat removed, will reflect blue light a little more than the other colors, so it can look slightly blue.

solution ***colloid***

Comprehension self-check

See if you can answer these questions. If not, go back into the chapter and find the information.

1) How does water dissolve something? (What do the water molecules do?)

2) Fat is not a polar molecule. Would it dissolve in water?

3) To encourage carbon dioxide to dissolve into water, should the water be hot or cold?

4) In carbon dioxide, which element gets the electrons more of the time—oxygen or carbon?

5) When molecules begin to move faster, does their temperature go up or down?

6) Which senses flavor, the tongue or the nose?

7) Is benzoic acid harmful to humans? To microorganisms? Why is the FDA concerned about benzoic acid?

8) Which do consumers get more upset about—preservatives in their food, or microorganisms in their food?

9) Why do food companies put phosphoric acid into cola drink?

10) Another name for a hydrogen ion is a __________.

11) When a water molecule breaks apart, what is the OH part called?

12) If a substance has too many protons, is it an acid or a base?

13) Is baking soda acidic or basic?

14) What is the other word that means "basic"?

15) What number is neutral on the pH scale?

16) When an acid and a base combine, they produce _________ and a ________. (page 22)

17) What happens when milk is pasteurized?

18) What happens when milk is homogenized?

19) The most abundant protein in milk is called ___________. The strands form a clump called a m___________.

20) What kind of enzymes takes apart proteins?

21) How many amino acids are there?

22) Which part is the "amine" end of an amino acid– the NH_2 end or the COOH end?

23) Lactose is made of what two simple sugars?

24) Two-ring sugars are called disaccharides. Can you name another one, besides lactose?

25) The Tyndall effect is used to tell the difference between a ___________ and a __________. (Milk is which?)

DONT' FORGET about the supplemental videos for this chapter on the "Dissect Your Dinner" playlist at YouTube.com/TheBasementWorkshop

ACTIVITY 2.1 Root beer float word puzzle

"Floats" are a combination of the two things we learned about in this chapter: carbonation and milk (in the form of ice cream). Fill in the correct answers below, then transfer the letters to their places on the float puzzle.

1) The things that are dissolved in solvents. ___(14) ___(65) ___(25) ___(16) ___(11) ___ ___

2) Attraction between water molecules is called ___(77) ___ ___ ___(84) ___ ___ ___(5) ___   ___(31) ___(8) ___ ___ ___(75) ___ ___

3) Plants make caffeine as a ___ ___(68) ___(28) ___(55) ___ ___(81) ___ ___ ___ (a chemical to kill insect pests).

4) The number of carbon atoms in a glucose molecule: ___(21)   5) The number of tastes your tongue can sense: ___(34)

6) This ring molecule has this formula: C_6H_6. ___(67) ___(57) ___ ___ ___(52) ___ ___(95)   7) Unprocessed milk is "___(135) ___(46) ___(112)."

8) Substances that might cause cancer are called ___ ___(10) ___(96) ___ ___(129) ___ ___(12) ___ ___(24) ___(130) ___(133)

9) This element has the symbol K: ___ ___(50) ___(78) ___(36) ___(115) ___(86) ___(71) ___(18) ___(124)

10) Benzoic acid will turn into benzene if it comes into contact with ___(26) ___ ___(9) ___(2) ___(94) ___ ___(85)   ___

11) This acid, found in cola drinks, doesn't dissolve nails! ___(138) ___ ___(49) ___(56) ___ ___(82) ___ ___(30) ___(97) ___ acid

12) The correct name for OH^- is the ___(79) ___ ___ ___(69) ___(60) ___ ___(61) ___ ___   ___(91) ___(29) ___

13) When you combine an acid and a base you get ___(23) ___(15) ___ ___ ___(140) and a ___(41) ___(54) ___ ___(20).

14) Things that are 7 to 14 on the pH scale are described as ___(58) ___(142) ___(43) ___(93) ___(37) ___ ___(109) ___(27)

15) When milk has been heated to kill germs we say that it's been ___(7) ___(100) ___(51) ___(22) ___ ___(83) ___(70) ___ ___ ___ ___(126)

16) When milk has been pressed through a screen it's been ___(4) ___(89) ___(48) ___ ___(17) ___(125) ___(64) ___ ___ ___(72) ___

17) The smallest amino acid is called ___(35) ___(38) ___ ___(98) ___ ___(40) ___(13)

18) In a triglyceride fat molecule, the fatty acid "tails" are attached to ___ ___(59) ___(114) ___ ___(80) ___(121) ___(39) ___(62)

19) Strings of casein protein are clumped together in little balls called ___(1) ___(127) ___ ___(32) ___ ___(88) ___ ___(3) (page 24)

20) Enzymes that can tear apart proteins are called ___ ___(131) ___ ___(33) ___ ___(6) ___(99) ___(19) ___ ___(117)

21) The shape of a molecule determines its ___(53) ___(90) ___ ___(128) ___(87) ___ ___(110) ___ (page 18)

22) This agency regulates food and drugs in America. ___(120) ___ ___

23) Glucose, fructose and galactose are ___ ___ ___ ___ ___(143) ___   ___(92) ___(44) ___ ___(113) ___(111) ___(102).

24) Triglycerides are made of three ___(74) ___(116) ___(45) ___(103) ___   ___(108) ___ ___ ___ ___(63).

25) This molecule can be used to patch the unhappy ends of broken bonds. ___(66) ___(42) ___ ___ ___(104)

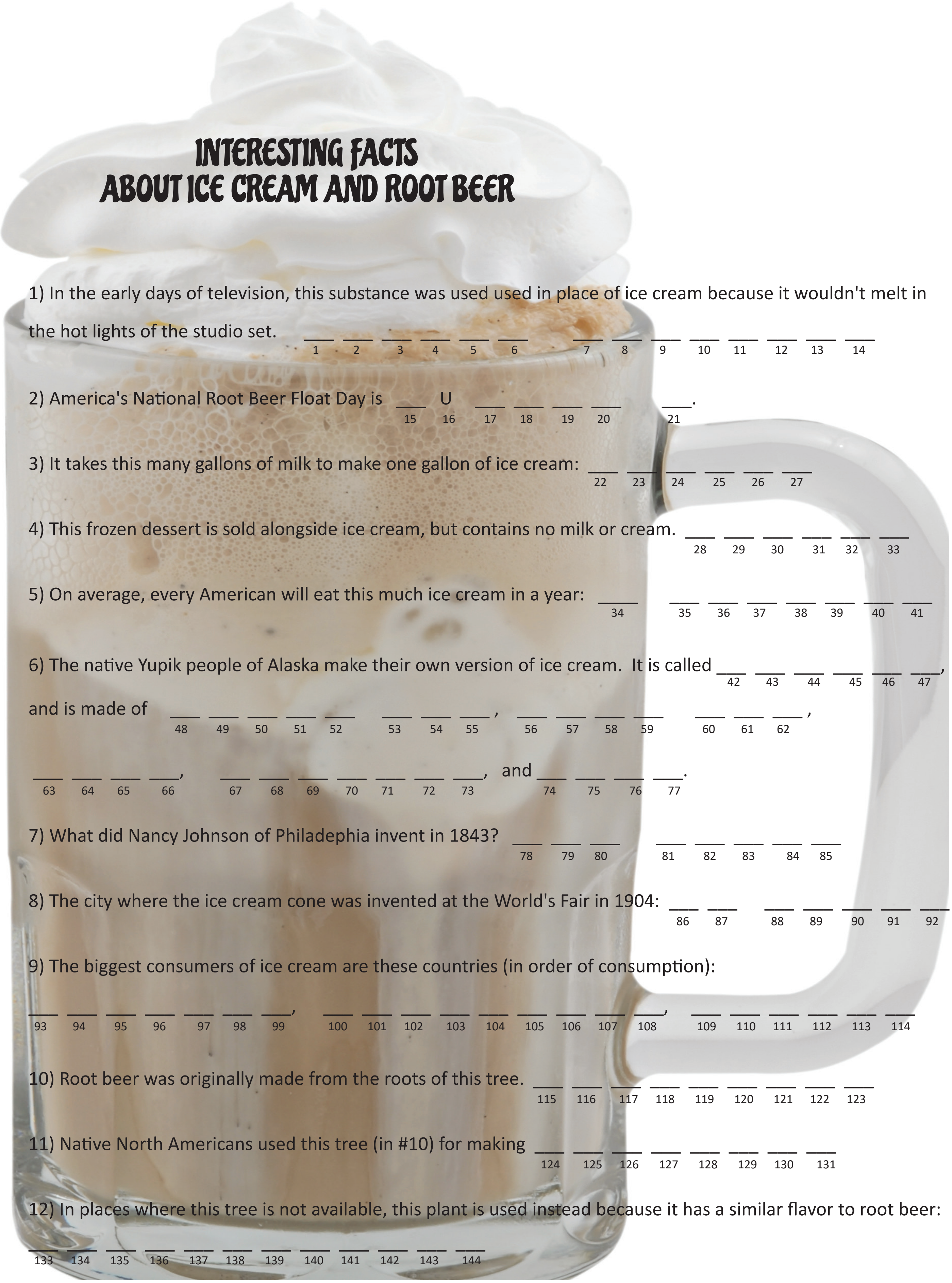
26) Carbonation is an example of a ___ ___(105) ___(73) (CO_2), dissolved into a ___(106) ___(141) ___(47) ___ ___(107) ___ (water).

27) Industrial carbonating machines use high ___ ___ ___ ___(118) ___ ___(101) ___ ___ to push the CO_2 into the cold water.

28) (We need more A's!) Woodstock, Ontario, is the dairy farming capital of the country of ___ ___(122) ___ ___(134) ___ ___(144)

29) (We still need more A's, and another S!) These yellow fruits grow in bunches. ___ ___(137) ___ ___(139) ___ ___(119) ___(136)

30) (More A's and another S!) Beverages are served in ___ ___ ___(105) ___(123) ___(73) ___ ___(76).



INTERESTING FACTS ABOUT ICE CREAM AND ROOT BEER

1) In the early days of television, this substance was used used in place of ice cream because it wouldn't melt in the hot lights of the studio set. ___ ___ ___ ___ ___ ___   ___ ___ ___ ___ ___ ___ ___ ___
1 2 3 4 5 6   7 8 9 10 11 12 13 14

2) America's National Root Beer Float Day is ___ U ___ ___ ___ ___   ___.
15 16 17 18 19 20   21

3) It takes this many gallons of milk to make one gallon of ice cream: ___ ___ ___ ___ ___ ___
22 23 24 25 26 27

4) This frozen dessert is sold alongside ice cream, but contains no milk or cream. ___ ___ ___ ___ ___ ___
28 29 30 31 32 33

5) On average, every American will eat this much ice cream in a year: ___   ___ ___ ___ ___ ___ ___ ___
34   35 36 37 38 39 40 41

6) The native Yupik people of Alaska make their own version of ice cream. It is called ___ ___ ___ ___ ___ ___,
42 43 44 45 46 47

and is made of ___ ___ ___ ___ ___   ___ ___ ___,   ___ ___ ___ ___   ___ ___ ___,
48 49 50 51 52   53 54 55   56 57 58 59   60 61 62

___ ___ ___ ___,   ___ ___ ___ ___ ___ ___ ___, and ___ ___ ___ ___.
63 64 65 66   67 68 69 70 71 72 73   74 75 76 77

7) What did Nancy Johnson of Philadephia invent in 1843? ___ ___ ___   ___ ___ ___ ___ ___
78 79 80   81 82 83 84 85

8) The city where the ice cream cone was invented at the World's Fair in 1904: ___ ___   ___ ___ ___ ___ ___
86 87   88 89 90 91 92

9) The biggest consumers of ice cream are these countries (in order of consumption):

___ ___ ___ ___ ___ ___ ___,   ___ ___ ___ ___ ___ ___ ___ ___ ___,   ___ ___ ___ ___ ___ ___
93 94 95 96 97 98 99   100 101 102 103 104 105 106 107 108   109 110 111 112 113 114

10) Root beer was originally made from the roots of this tree. ___ ___ ___ ___ ___ ___ ___ ___ ___
115 116 117 118 119 120 121 122 123

11) Native North Americans used this tree (in #10) for making ___ ___ ___ ___ ___ ___ ___ ___
124 125 126 127 128 129 130 131

12) In places where this tree is not available, this plant is used instead because it has a similar flavor to root beer:

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
133 134 135 136 137 138 139 140 141 142 143 144

ACTIVITY 2.2 Mammal milk trivia

All female mammals make milk. The chemistry of each animal's milk is just what its babies need. See if you can match these descriptions with the correct mammals. They aren't easy! Use any clues you can in the descriptions, including geography and animal behavior.

Possible answers: sheep, goat, donkey, whale, seal, horse, black rhino, wallaby, hippo, rabbit

1) The milk of this mammal holds the record for being highest in fat content. The mother only feeds her baby for about a week, but during that time the baby will double its weight, as well as putting on a thick layer of fat under the skin. The baby will need a lot of fat to protect it from the cold. _________________

2) The milk of this endangered mammal holds the record for being lowest in fat content. The mother's body can't put a lot of energy into the fat content of the milk because her pregnancy lasted for over a year, and then she will nurse her baby for over two years. _____________________

3) The milk of this mammal is excellent for making cheese because it is high in both fat and protein. (It has twice the fat content of cow's milk.) Cheeses often made with this milk include feta (Greece), Roquefort (France), and ricotta (Italy). This mammal only produces milk naturally at certain times of the year because of seasonal breeding. To get year-round milk production, farmers must give hormone shots to these animals. ________

4) This mammal produces milk that has one of the highest protein levels in the animal kingdom. The milk also has twice as much fat as cow's milk. The mother only nurses her babies in the morning and evening and spends all day foraging for food (in gardens if she gets the chance). Mammals that only nurse their babies once or twice a day often have milk that is high in protein and fat. Those few meals have to be good ones! ____________

5) This mammal's milk is the subject of an untrue "fact" that circulates on the Internet. The Internet rumor says that this mammal's milk is pink. Supposedly the milk mixes with a red body chemical, and the red and white combine to make pink. The part about the red chemical is mostly true, although it is clear when it is secreted by the skin. This chemical acts as a natural sun screen, turning red and then brown as it absorbs UV rays. The milk produced by this mammal is white, as is the milk of every mammal on the planet, although direct studies of the milk have rarely been done because of the ferocity of the animal. It would be very hard to get close enough to a nursing mother without being injured or killed. _________________

6) The milk of this mammal does not separate into milk and cream. The fat globules are bound to the other solids in the milk so they are not able to float to the top. Milk experts say that this is one of the most digestible milks and one of the most similar milks to human milk. It is often used to make cheeses. The milk has a strong flavor to it (tasting a bit like the animal smells), which makes it less popular than cow's milk. ______________

7) It is critical that this mammal's milk be high in fat so that the milk won't mix with the water around it. If the milk was low in fat it could more easily mix with water, making it difficult for the baby to get enough of it into its mouth. The mother's teats are not visible most of the time and only come out when the baby nudges them. ____________

8) This mammal's milk was first recommended by Hippocrates in 400 BC. In the ancient world it was used both as a health remedy for sick infants and as a skin cosmetic product for women. Right up until modern times this milk has been used to feed orphaned human babies if no source of human milk was available. The nutritional content of this milk is very similar to human milk except that it is slightly lower in fat. The babies would be given liquid fats such as olive oil to make up for this difference. _______________

9) In central Asia and Mongolia, the milk of this animal is used to make a fermented drink called kumis. ________

10) This mammal can produce different types of milk in different teats because she can have babies of different ages both suckling at the same time. The teats that are suckled by the tiny infant in her pouch will produce milk high in sugar. The teats for the older babies will produce milk low in sugar but high in fat and protein. ____________

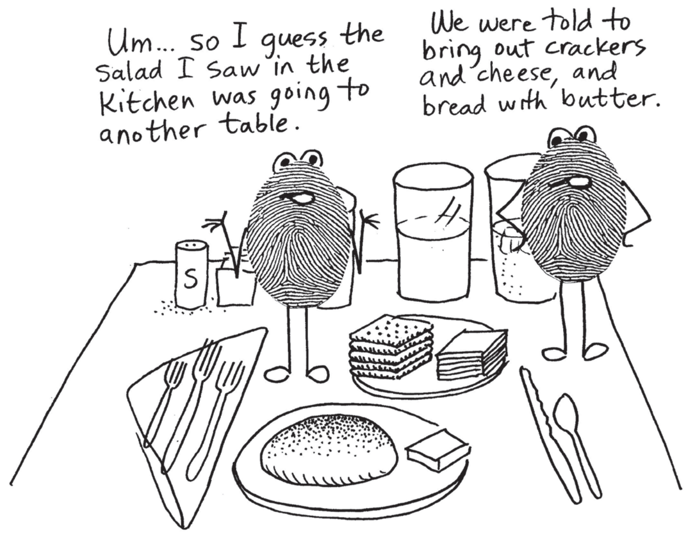
ACTIVITY 2.3 Second installment of "Chew It Over," a group game to be played during a meal

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 2: CARBONATED BEVERAGES and MILK 1) The average cow can produce about how many glasses of milk each day?	CHAPTER 2: CARBONATED BEVERAGES and MILK 2) In the U.S., which month is National Dairy month?
CHAPTER 2: CARBONATED BEVERAGES and MILK 3) There are some pretty strange soft drink flavors around the world. All of these are real flavors except one. Which one is not a real flavor? a) Black Garlic b) Onion c) White Fungus d) Mustard	CHAPTER 2: CARBONATED BEVERAGES and MILK 4) Until 1950, this carbonated drink contained lithium citrate, which is today used as a brain medicine: a) Coke b) Pepsi c) 7-Up d) Dr Pepper
CHAPTER 2: CARBONATED BEVERAGES and MILK 5) About how many teaspoons of sugar are in a can of soda (pop/coke)?	CHAPTER 2: CARBONATED BEVERAGES and MILK 6) Which of these frozen desserts does not contain milk? a) sherbet (sherbert) b) sorbet c) spumoni d) gelato
CHAPTER 2: CARBONATED BEVERAGES and MILK 7) The name of the orange-flavored soft drink "Fanta" is a German word for what? a) imagination b) happiness c) intelligence d) courage	CHAPTER 2: CARBONATED BEVERAGES and MILK 8) Years ago, there was a rumor that ship-wrecked sailors from France used the milk of one of the native animals on the island to make some cheese. Can you guess the animal? a) mice b) rats c) pigs d) rabbits
CHAPTER 2: CARBONATED BEVERAGES and MILK 9) Have you ever tasted goat milk or goat cheese? Would you recommend it?	CHAPTER 2: CARBONATED BEVERAGES and MILK FUNNY FACT: When Pepsi's slogan "Come alive with Pepsi" was translated into Chinese, it said, "Pepsi brings your ancestors back from the grave."
CHAPTER 2: CARBONATED BEVERAGES and MILK 11) What is your favorite carbonated beverage?	CHAPTER 2: CARBONATED BEVERAGES and MILK 12) Which is your least favorite carbonated beverage?

1) About 100	2) June
3) Mustard	4) 7-Up
5) 10 teaspoon	6) sorbet
7) imagination	8) rats

3: Appetizers

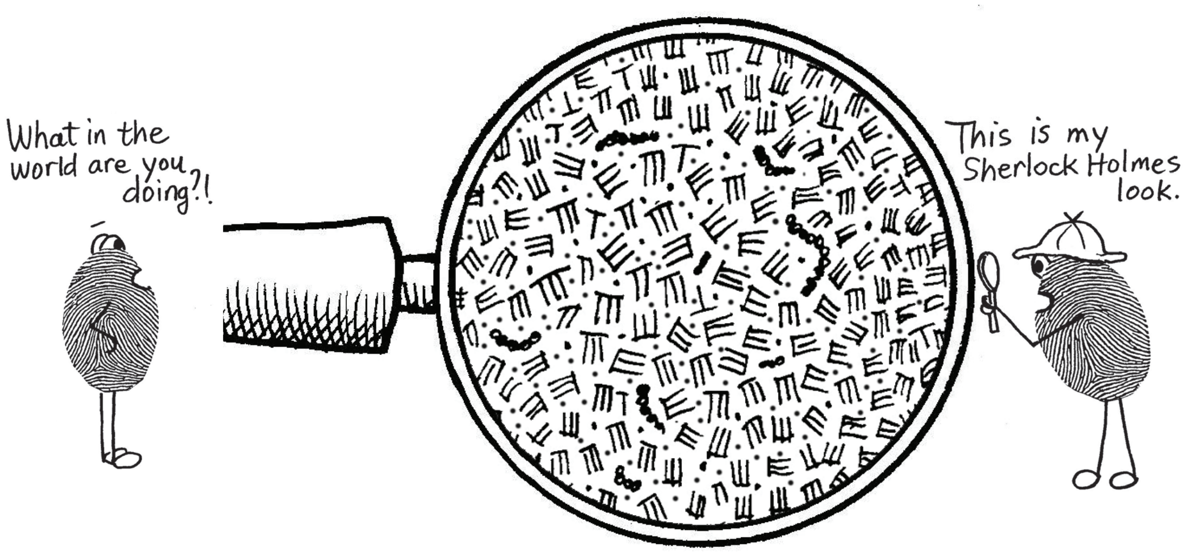


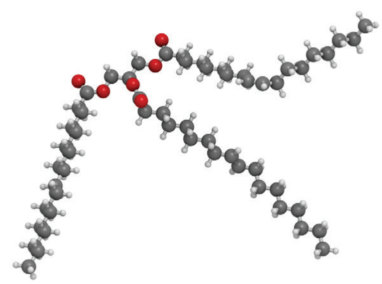
That's okay. There is plenty here to dissect! It will take a whole chapter to get through all the chemistry found in butter, cheese, crackers and bread.

Good idea. Let's start with the butter. Since butter is made from milk we should see lots of familiar things.

The word "butter" is a very old word. It can be traced back to the Latin word for butter, "butyrum," which came from the ancient Greek word "bouturon" meaning "cow cheese." ("Bous" was "cow," and "turos" was "cheese.") We also saw that the word "casein" came from a Greek word for cheese. There were many kinds cheese back then, just like there are now, so it's not surprising to find more than one word for cheese. Without refrigeration, milk was hard to keep. The natural bacteria found in raw milk made it spoil within a day or two. Ancient peoples found that turning the milk into butter, cheese or yogurt made the milk stay edible for weeks or even months. When butter does finally spoil, we say it goes "rancid." This is due to a smelly acid substance produced by bacteria living in the butter.

Let's get out that Sooper Dooper magnifier and take a look at our butter.




a model of a tryglyceride

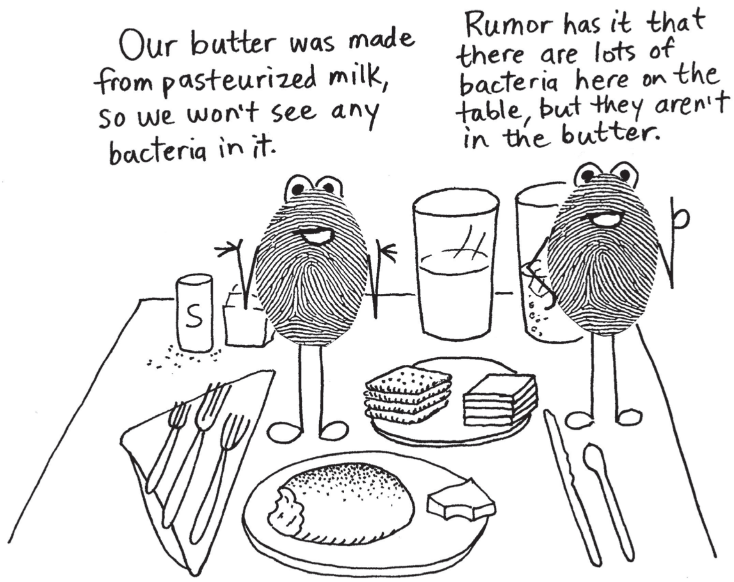
Do you recognize those things that look like stretched out letter E's? (We called them weird-looking jellyfish in the last chapter.) Most of them have three "tails." They're triglycerides. The "tri" part means "three" and the "glyceride" part refers to the hanger that the tails are attached to. The tails are called fatty acids and they are made of long strings of carbon atoms with hydrogens attached. They are the smallest type of fat. When we looked at milk, we saw triglycerides inside those big, round globules. Here, the triglycerides are just scattered about everywhere, not inside globules. What happened?

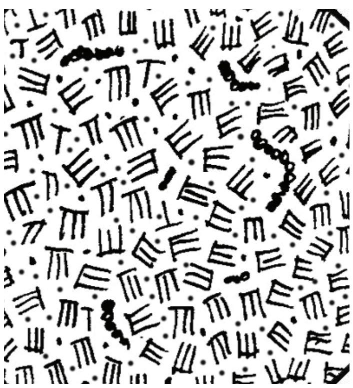
The process of churning butter is all about destroying those fat globules. You bang and smash those globules around as if they were microscopic piñatas filled with fats instead of candy. Once they are all broken open and the triglycerides are no longer contained inside the globules, the fats stick together to form one solid mass. That's butter.

As the fats stick together, most of the water that was between the fat globs gets squeezed out. Part of the butter-making process includes draining off water. This water won't be pure water, however, but will still have a little bit of fat, protein and sugar in it. Dairies usually save this drained off water and either sell it as "buttermilk" or use it as an ingredient in other products such as ice cream.

In the past, buttermilk was used as a source of acid to either curdle milk for cheese, or to react with baking soda in biscuit and bread recipes. But wait... milk as a source of acid? Fresh milk is definitely not sour tasting. How can a milk product be a source of acid? The answer lies in the label on the buttermilk carton. It might say "cultured" buttermilk. In food science, "culture" doesn't refer to great art and literature. A "culture" is a source of microorganisms, often bacteria. So "cultured" buttermilk means it contains bacteria.

These milk bacteria are not harmful like the ones that give you strep throat or pneumonia. Most of the bacteria found in milk are very good for us. We want them to live inside us because they fight against any bad bacteria that might get into our intestines. But even good bacteria need to eat, and these ***Lactobacillus*** *(LACK-toe-ba-SILL-us)* bacteria eat the lactose sugars in the milk. As part of their digestion process, the bacteria produce a chemical called ***lactic acid***. This acid isn't nearly as acidic as lemon juice or vinegar, but it's acidic enough to cause milk to ***curdle*** (form solids). Nowadays, most milk is pasteurized, so dairies must add a bacterial culture to their buttermilk in order to sell it as "cultured" buttermilk. Some cooks prefer to make instant buttermilk in their kitchen by adding lemon juice to fresh milk.

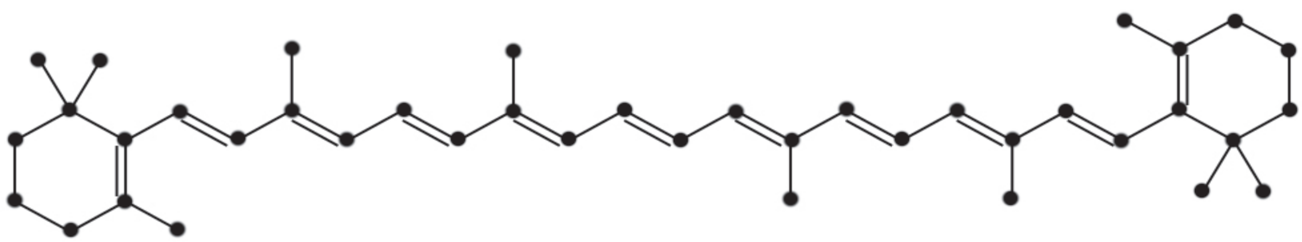




Let's look closer at the magnified butter. What are those other blobs and dots, in and around the triglycerides? A few of them look like tiny bits of protein—chains of amino acids. They could be little pieces of casein that broke off the micelles, or they could be some of those smaller milk proteins, the miscellaneous ones that came from the mother cow. There aren't very many of them, so butter isn't a very good source of protein.

The tiniest dots might represent lactose sugars, but just a few of them. Most of the lactose molecules would have stayed down with the liquid milk and not floated to the top with the cream. When the cream was taken off the top, most of the lactose stayed behind. Butter has a small enough amount of lactose that people who can't digest lactose can often still eat butter.

The rest of the dots represent molecules that give butter its yellow color: ***beta-carotene***.



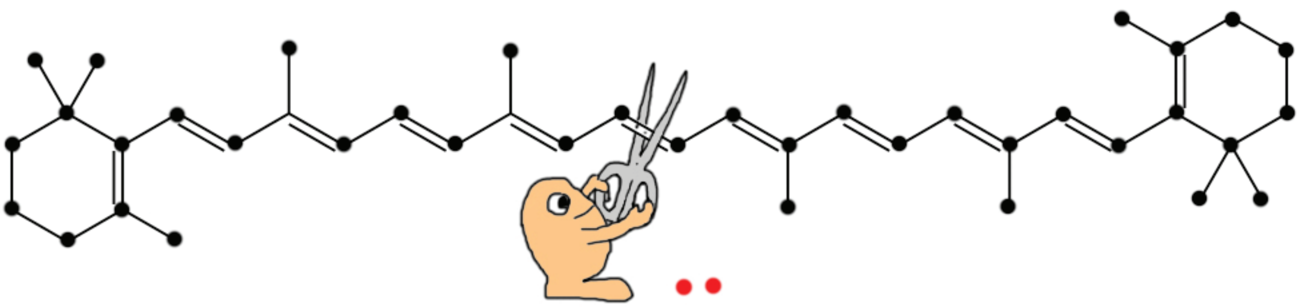
The dots are carbon atoms. There are also many hydrogen atoms attached to the carbons, but all chemists know that the H's are there, and they get lazy and don't bother drawing them. The double lines represent places where carbon atoms are double-sharing their electrons. Notice the pattern of the bonds across the middle of the molecule: double, single, double, single, double, single, etc. This is important. Molecules that have this pattern often reflect light. In this case, beta-carotene ***reflects*** orange and yellow light. Of greater importance is the fact that it ***absorbs*** violet, blue and green light. Beta-carotene is part of the light-collecting system in leaves. The light that is collected is used in the process of photosynthesis, where sunlight, CO_2 and water are turned into glucose sugar.

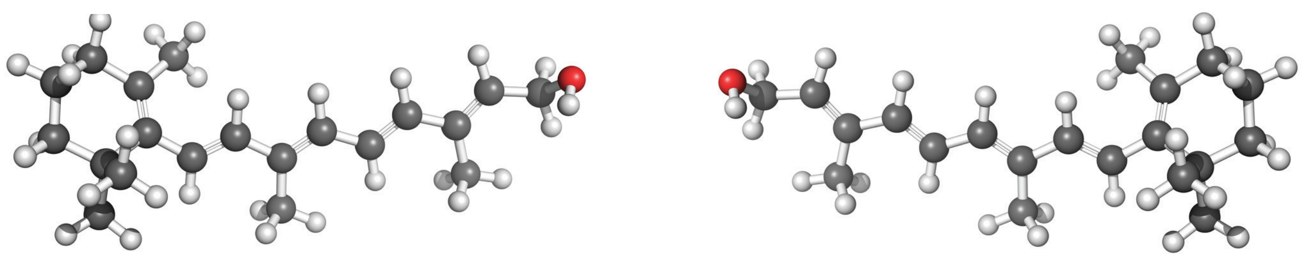
You might have wondered if the name "carotene" has anything to do with carrots. Yes! Carotenes were named after carrots. As a general rule, orange or yellowish-orange colors in plants are caused by the presence of beta-carotene molecules. Other sources of beta-carotene include cantaloupes, sweet potatoes, mangoes and pumpkins. But how did these plant molecules get into the butter?

The milk that the butter was made from came from cows who ate leaves that had beta-carotene molecules in them. (Green leaves often contain orange or red pigments, but the green "drowns them out.") The leaves were digested in the cow's stomach, releasing the beta-carotene molecues from the plant cells. The beta-carotene molecules then went floating around inside the cow's body, looking for a place to stay. Since the beta-carotene molecule is rich in carbon atoms, it is naturally attracted to other molecules that have a lot of carbon atoms. Triglycerides have three long strings of carbon atoms, so beta-carotene molecules feel right at home in and among them. A lot of animal fat is light yellow in color, due to the presence of these beta-carotenes. The yolks of chicken eggs are rich in beta-carotenes for the same reason.

As long as the beta-carotenes stay inside the fat globules in milk, the rays of light can't reach them very well. The outsides of the fat globules scatter all the colors of light equally, so the milk looks white. However, when you make butter, you must smash all those globules open. The triglycerides come spilling out, and so do the beta-carotenes. Once the beta-carotenes are out, they begin to reflect yellowish-orange light, so the butter looks light yellow. People who make their own butter from their own cows notice that the color of their butter changes from season to season, depending on what plants the cows are eating. The butter is more or less yellow at certain times of the year.

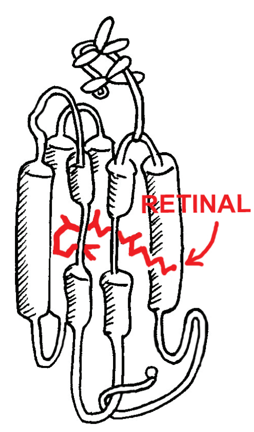
The cow's body (and your body) hang on to these molecules of beta-carotene so that they can be used to make ***vitamin A***. Beta-carotene can be cut in half by a scissor enzyme to make two molecules of vitamin A. Those two red dots are oxygen atoms that will be used to patch the ends.





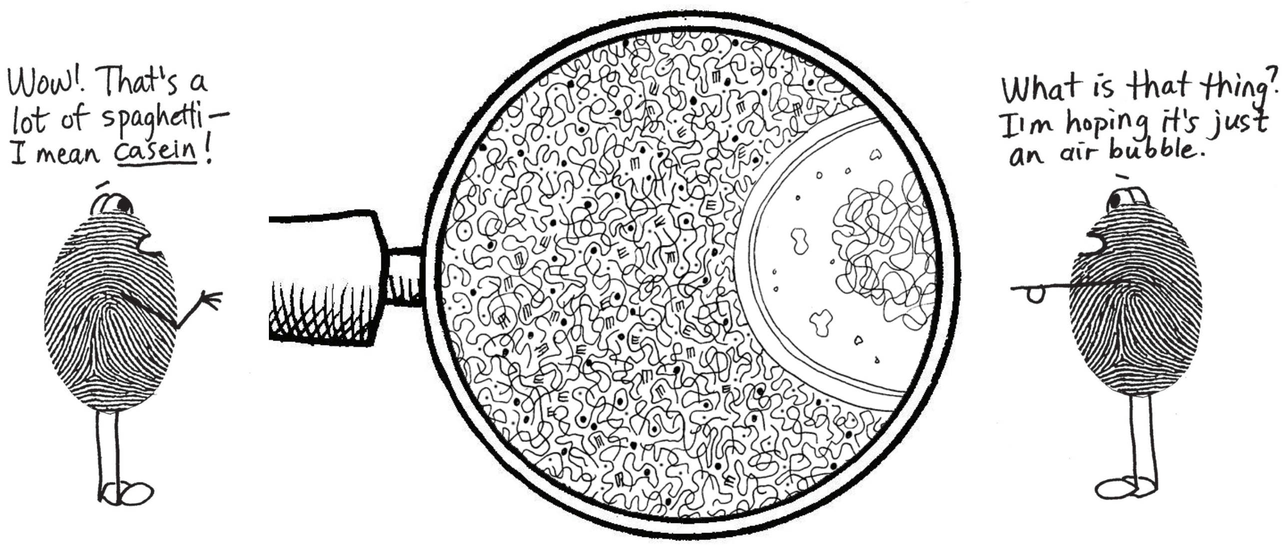
Here are the two halves of beta-carotene, shown as ball and stick models. Now you can see all the hydrogens, and you can see the two oxygens that the enzymes used to patch the cut ends. Each half is now a molecule of ***retinol***, a form of vitamin A. Sometimes other enzymes come over and "tweak" the retinol molecule, making tiny changes that will turn it into different versions of vitamin A.

The most well-known of these variations is called ***retinal***. Retinal is used in the cells of your retina, the area at the back of your eye that senses light. Retinal becomes part of a molecule that absorbs photons of light. (This makes sense, since beta-carotene absorbs light in plant leaves.) Retinal sits inside a special holder made of protein. Without retinal, the holder is useless. There are billions of these holders in the cells of the retina and they must all be filled with retinal. If you don't eat enough beta-carotene or vitamin A, the retina won't work right and your vision will be affected. This is why people say carrots are good for your eyes. However, a little beta-carotene goes a long way, and over-eating carrots isn't going to give you super-power vision.



After beta-carotene is chopped in half, the resulting retinols don't reflect as much yellow and orange light. Animals that store retinol (vitamin A) in their fat, instead of beta-carotene, will produce milk that makes white butter instead of yellow. Butter and cheese made from goat and sheep milk is white. Consumers seem to prefer yellow butter over white, so beta-carotene is often added to sheep butter to make it yellow.

Since cheese is made from milk, will we find the same molecules and structures that we found in milk and butter? Let's take a look.

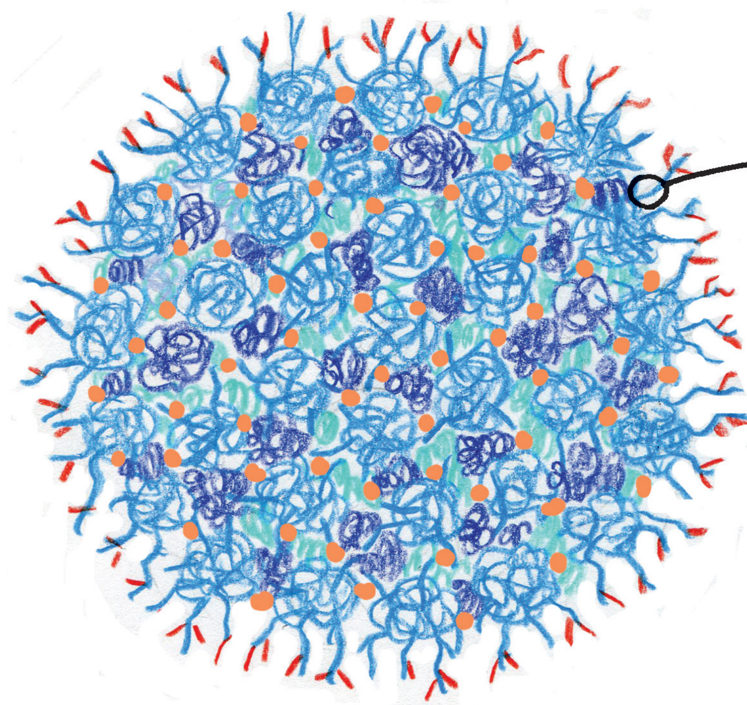


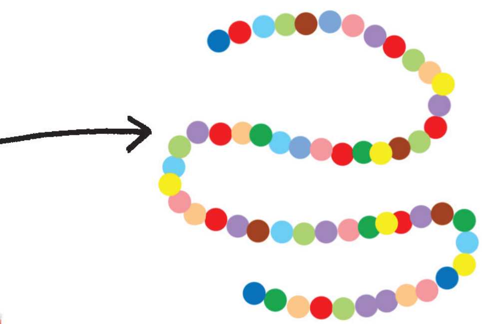
What happened to the casein "spaghetti" balls we saw in the milk on page 24? This is a mess! Casein "noodles" are all over the place! We can see some triglycerides in there, too, so this cheese has some fat in it. Those really tiny dots might be beta-carotene molecules helping to give the cheese its orange color. But what is that HUGE thing sticking into the picture? It looks like part of something that's bigger than our viewing area. We'll have to reduce the magnification a bit in a minute to get a better image of it.

Let's find out what happened to our casein micelles first, then we'll delve into the mystery of that huge whatever-it-is.

So what did happen to the casein micelles? To understand what happened, we need to learn a little more about the micelles.

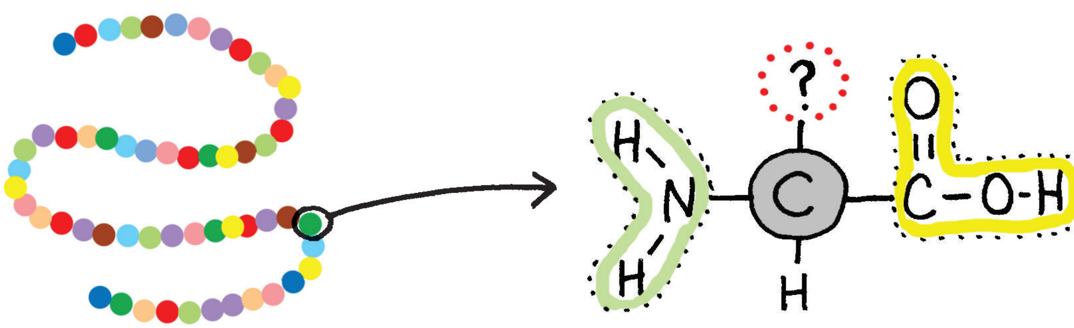
Imagine that our micelle is made of yarn instead of protein, and let's use blue as our color scheme. We'd need to use four different shades of blue because there are four different types of casein protein in our micelle. We'd wind many small balls of yarn and then stick them together. (The small balls are called sub-micelles.) A real casein micelle might have as many as 500 of these smaller balls. One of these types of casein has long fringes that hang off, making the ball look furry. We can stick little orange beads between the balls to represent those mineral "meatballs" made of calcium phosphate. These calcium phosphate balls act sort of like magnets to keep the micelles together.





Since the yarn represents protein, and proteins are made of amino acids, we could improve our model by stringing tiny beads onto all the pieces of yarn. The beads could represent the amino acids. We'd need 20 different colors of beads because there are 20 possible amino acids to choose from.

Now, we must remember that amino acids aren't really little balls. Although chemists represent them as circles, you will remember that they are really groups of atoms. There's a carbon atom in the center, with a COOH on one side, and an NH_2 on the other.



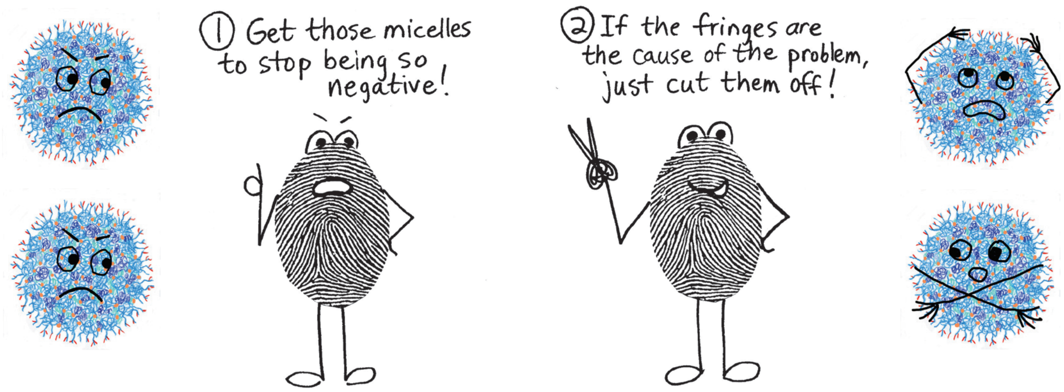
That (?) at the top of the molecule turns out to be very important. That's the part that makes each amino acid different from the others. We saw that glycine, the smallest amino acid, has only an a hydrogen atom, H, in that place. That makes glycine special because it the smallest amino acid. Some amino acids have a chain of carbon atoms hanging off, looking like the fatty acids we saw on the triglycerides. Amino acids that have extra strings of carbon atoms (where the "?" is) hate water and want to hang out with fats. Other amino acids are just the opposite and have extra atoms (where the "?" is) that love to be around water. A few amino acids have an atom of sulfur hanging off, which makes them good at building bridges. We'll meet an amino acid with sulfur when we dissect the bread. Here, in the fringy casein proteins, we find the amino acid ***threonine***, which is particularly good at attaching itself to sugar molecules.

When a string of amino acids grabs and hangs on to some sugar molecules the result is a molecule that is a combination of protein and sugar, and we call it a ***glycoprotein***. ("Glyco" comes from "glucose" but it can mean any kind of sugar molecule.) Those red strings hanging off the blue yarn are glycoproteins. These glycoprotein molecules are largely responsible for the ability of the casein micelles to float around in the milk without clumping together. Which is a good thing while the milk is in the cow.

The red fringes help to give the casein micelle a negative electrical charge. "Like" charges repel, so the micelles stay away from each other because they are all negative. The same thing would happen if they were all positively charged. But in this case we see negative charges.

The first step in making cheese, yogurt and some milk-based desserts is to get those casein balls to clump together. We call this ***curdling*** the milk. Depending on how it is done, the milk will either turn lumpy, like cottage cheese, or it will get thick, like yogurt and custard. In cottage cheese, the curds are large and very visible. In yogurt or custard, the curds stay so small that the texture remains smooth and creamy.

There are basically two ways to make these casein micelles clump together (curdle).



1) How To Stop Casein Micelles from Being So Negative

Put some positives into their environment! Why don't we toss in some positive hydrogen ions (protons) and have them go over and cancel out some of the negativity? And where do we get a good supply of protons? From acids! That's the definition of an acid—something that gives away protons. Acids that are right there handy in the kitchen are vinegar and lemon juice. Vinegar is the most common substance used for curdling milk to make cottage cheese and Ricotta cheese.

2) How To Cut Off the Negative Fringes

When you need to cut molecules, what do you use? Enzyme scissor guys, of course. You just need the right little enzyme robot, and he'll go over and snip those fringes right off. Where would we find this particular robot? Well, since baby cows' stomachs are good at digesting cow milk, perhaps this would be a good place to look. And, in fact, we will be successful, because people have been extracting this enzyme from baby cow stomachs for thousands of years. Chemists call it ***chymosin***, but food scientists and chefs usually cal it ***rennet***. Rennet is the word you will hear more often. The most famous brand name of rennet is Junket®. (NOTE: There are now plant-based sources of rennet, too.)

Junket tablets and rennet liquid drops

2.5) Another Source of Acid: Bacteria

When milk goes sour on its own, you still see curdled white solids and clear whey. In this case, the bacteria that are making the milk go rotten are producing acids. They are eating the lactose sugars and making lactic acid as a waste product.

Some cheeses require just this first step. Put in some acid and let the milk curdle. After you see the white clumps of casein forming, you can strain them out and use them for your cheese. The watery stuff that is left over is called ***whey***. Whey still has some protein in it, mainly those smaller proteins that aren't casein. Whey proteins can be taken out and dried into a powder. (Some people are really into eating powdered whey protein, and you'll see it sold in health food stores mainly as a supplement for athletes.) In ricotta cheese, the whey is strained off and only the solids are used. In cottage cheese, the whey can be part of the final product. In commercial cottage cheese, the whey often has a thickening agent added, as people don't tend to like watery whey.

Cottage cheese is made of curds and whey.

Hard cheeses—the ones that come in blocks that you can slice—have had a second ingredient added: microorganisms in the form of either ***bacteria*** or ***mold*** (or both). The first cheeses ever made contained the natural bacteria and molds that were in that environment. The microorganisms would have come from places like the skin of people or animals, from plants or dirt, or from barns and houses. Each part of the world had its own unique blend of microorganisms. The spores from these microorganisms would go into the air and float around, and if a pot of milk or curds was left sitting out for a while, it would collect spores that fell out of the air. The bacteria and mold would start to grow in the curds and eventually turn them into a hard cheese.

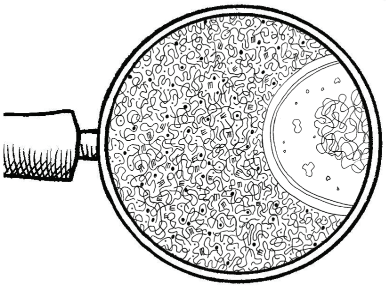
As time went on, cheese makers discovered that they didn't need to wait for spores to fall out of the air. All they needed to do was to save a bit of the last batch of cheese, and add it to the new batch. They didn't understand that they were saving microorganisms, though, because they didn't have microscopes and had no idea that tiny living things were inhabiting their cheese. They also discovered that cheeses made in different places had different flavors. Often, a cheese would be named after the town where it was first made. Cheddar, for example, started out in the English town of Cheddar. This type of cheese became so popular that people outside of Cheddar wanted to make it. They bought cheese in Cheddar, then went elsewhere and added the Cheddar cheese culture to their own curds. Now, Cheddar cheese is made all over the world, but the original culture came from England.

Scientists can now analyze and identify the exact species of microorganisms found in each type of cheese. Cheddar and Colby have *Lactococcus lactis, Lactobacillus casei, Streptococcus cremoris,* and *Streptococcus durans*. (You don't have to try to pronounce those!) Blue cheese has a blue mold called *Penicillium roqueforti*. Swiss cheese has an unusual bacteria that produces carbon dioxide as a waste gas. The carbon dioxide forms bubbles and gives Swiss cheese its holes. Limburger cheese has a species of bacteria that is extremely similar to the bacteria found on human feet. No wonder Limburger cheese smells like stinky socks!

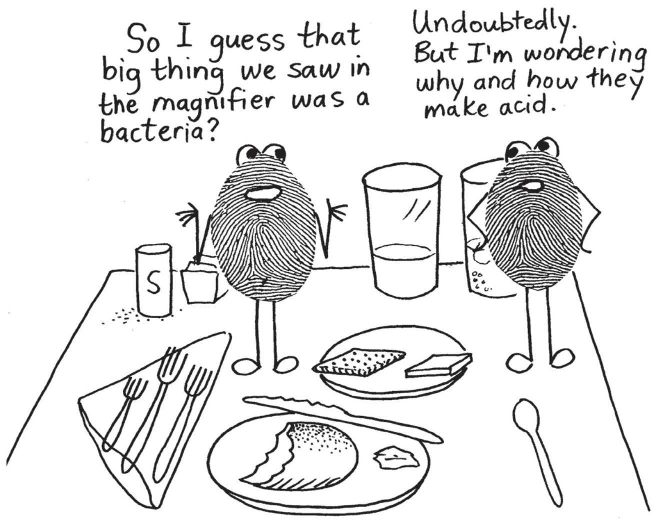
A cheese with blue mold in it.

New cheeses are still being invented. For example, a cheese called Cornish Yarg (that's "Gray" spelled backwards) was first made in Cornwall, England, in 1984. Some Cornish cheese-mongers (that's what you call professional cheese makers) found a very old recipe and decided to try it. They added garlic to their cheese and then wrapped the blocks of cheese in the leaves of the nettle plant. Another new English cheese is called "Stinking Bishop," inspired by the cheese recipes of monks during the Middle Ages who washed their cheeses in pear juice.

Photo credit: Tristan Ferne, UK, from Wikipedia article on Cornish Yarg

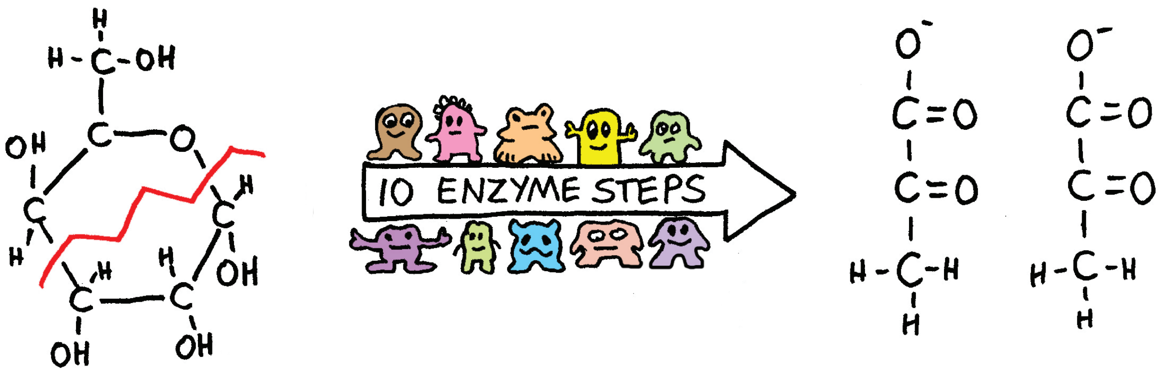


We just saw one end of the bacteria.



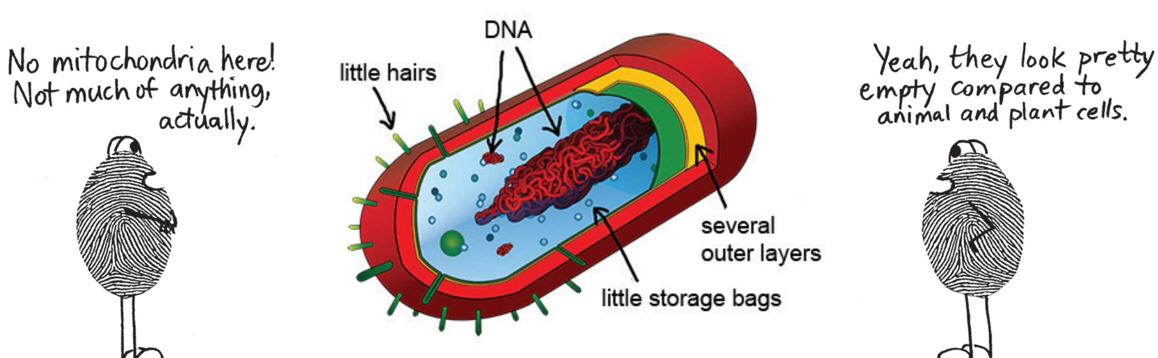
Bacteria make acid as a waste product when they eat. All living things make waste products as a result of eating. Some of the waste products are obvious, like... well, you know... we flush them. Others are not so obvious, like the carbon dioxide that goes out of your lungs when you exhale. Or the lactic acid produced in your muscles when you push them to their limit. Here in our cheese, the bacteria have been doing exactly the same thing that your tired muscles do; they are producing lactic acid as a result of burning glucose molecules for energy.

Glucose is our body's primary source of energy. There is energy locked up in the bonds that hold the carbon atoms together. If you break those bonds, you can release the energy. The first step in using glucose for energy is cutting it in half. As you might guess, you'll need enzyme scissors to help with this process. However, you won't need just one enzyme, but TEN of them! The glucose must be snipped, twisted and patched until two molecules of ***pyruvate*** *(pie-RU-vate)* are formed.



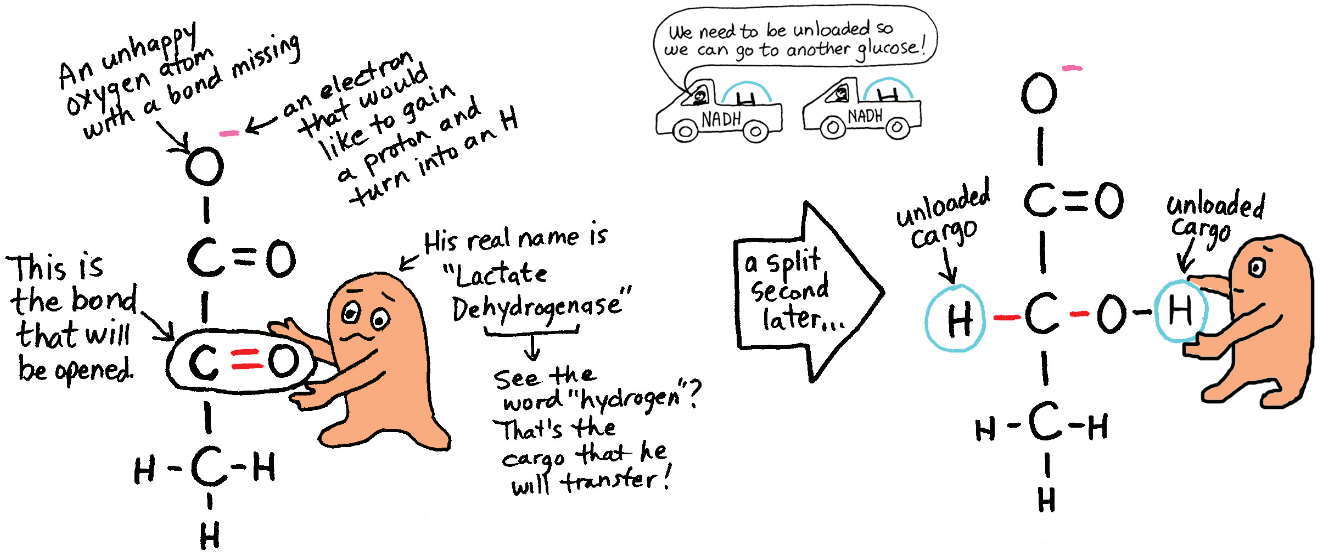
GLUCOSE **2 PYRUVATES**

At this point, animal cells (including yours) send these pyruvates to special organelles inside the cell called the ***mitochondria***. Inside the mitochondria, the rest of the bonds between the carbon atoms will be broken to release the remaining energy. Bacteria don't have mitochondria, though, so they can't cut apart those pyruvate molecules. They use them for a different purpose.



A "bacillus" bacteria

The bacteria living in our cheese use the pyruvate molecules to get rid of some atoms are that preventing them from splitting more glucose molecules. We didn't show you all the complicated chemistry going on in those 10 steps. We just drew some cute enzyme guys and let it go at that. But if we showed you every single atom coming and going in this process, you'd see that part of the process involves putting electrons into molecules that act like shuttle buses. The shuttle buses have to be emptied before they can be loaded again. If the shuttle buses are all sitting there full, the process of splitting glucose will stop. So the bacteria have enzyme guys that can unload the shuttles and put their cargo onto the pyruvates. The cargo that is transfered is electrons and protons. The end result is that pyruvate gains 2 hydrogen atoms.

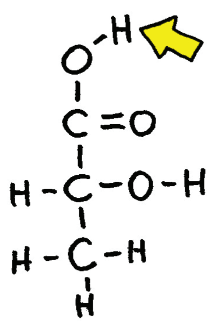


PYRUVATE **LACTATE**

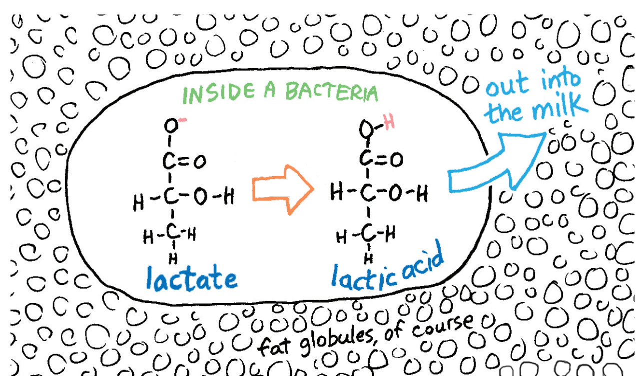
With the H cargo unloaded onto pyruvate, those shuttle bus molecules will now be able to help with the splitting of another glucose molecule. Mission accomplished! (The splitting of glucuse will release come energy.)

Now.. what about the "acid" part of this process? We keep talking about ***lactic acid***, but so far all we have is something called ***lactate***.

That lonely pink electron on the O at the top of the molecule is bound to pick up a passing hydrogen ion (proton). The electron and proton will join together to make a hydrogen atom, and then we'll be able to draw an H connected to that O. (The yellow arrow is pointing to this newly formed H.) The molecule will then officially become lactic acid. It's an acid because that proton that just came in could just as easily decide to go wandering off again. Protons change their minds a lot. By definition, an acid is a molecule that has wandering protons.



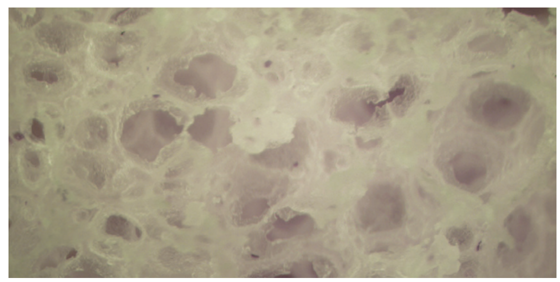
LACTIC ACID



The lactic acid molecules then go out of the bacteria and into the milk around it. Once in the milk, guess what that proton decides to do... yep, it leaves the molecule and goes off to seek its fortune elsewhere. Loose protons wandering about make a substance taste sour.

Before we turn our attention to bread and crackers, we need to burden you with two vocabulary words. (Most biology courses require students to memorize the definitions of these words.) The process of splitting glucose in half is called ***glycolysis*** *(glie-KOL-i-sis).* ("Glyco" means "glucose," and "lysis" means "to break apart.") The process of turning pyruvate into lactic acid is called ***fermentation***, or, more correctly, ***lactic acid fermentation***. When we dissect bread, we'll see another type of fermentation where an alcohol molecule is produced instead of lactic acid.

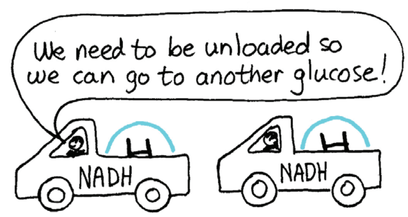
What is bread made of? If we look at bread under a magnifier, we'll see something like this. It looks a bit like a sponge. When the dough was first made, it was smooth and dense. The kneading process forced out any air that was in the dough. But when the bread came out of the oven it was fluffy and spongy. What happened? After we find out the answer to this question, we'll use the Super Duper magnifier to find out what the molecules look like.

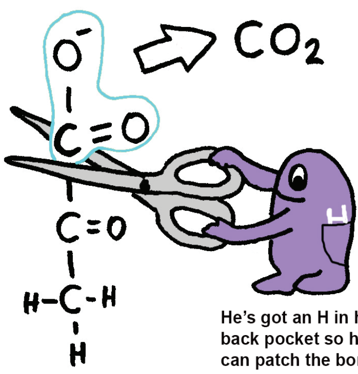


The tiny air holes in the dough were created by another type of fermentation: ***ethanol fermentation***. This fermentation is done by ***yeast*** instead of bacteria. The yeast cells "eat" the sugars in the bread and produce ***carbon dioxide*** and ***ethanol*** as waste products. The carbon dioxide bubbles into the bread dough and produces those holes. The bread hardens as it bakes, so the holes are preserved long after the carbon dioxide is gone.

Ethanol *(ETH-uh-noll)* is a type of alcohol. It is found in alcoholic drinks such as beer and wine, and it can also be used as a fuel. Many gas stations now sell gasoline (petrol) that has ethanol in it. If you see "E10" written on a gas pump that means that the gasoline contains 10% ethanol. In bread, the alcohol evaporates during baking, so the final product doesn't actually contain any alcohol.

The yeast cells produce ethanol for exactly the same reason that bacteria produce lactic acid. Eating sugar always starts out with glycolysis—splitting a glucose molecule in half. Two of those ten steps of glycolysis involve filling a shuttle bus (shown as a pick-up truck) with an H atom. After completing glycolysis they must find a way to empty their little shuttle trucks so that they can fill them again. The bacteria had an enzyme guy who could open up the double bond on the middle carbon atom and then transfer the two hydrogen atoms from the trucks to the pyruvate molecule, turning it into lactate.

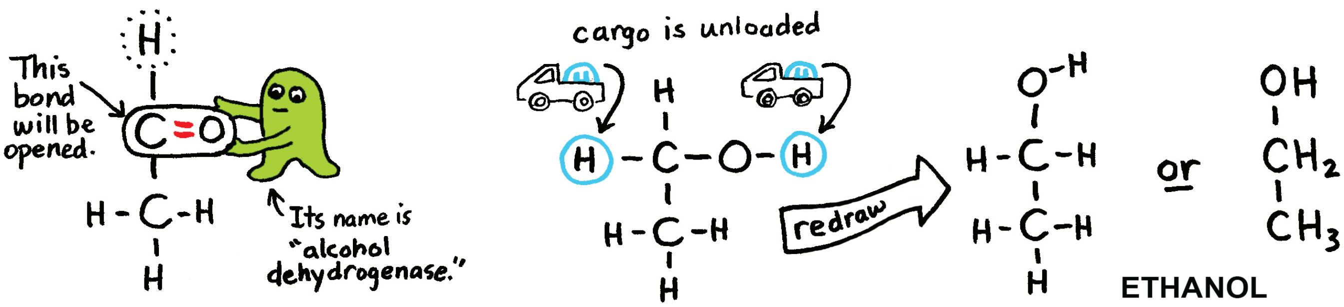




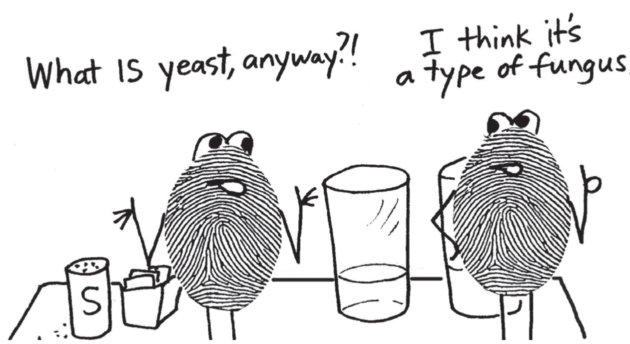
He's got an H in his back pocket so he can patch the bond.

The yeast cells have a similar enzyme guy: ***pyruvate decarboxylase***. This name isn't as hard as it looks! "De" means "from," "carboxyl" is the correct name for COOH, and "-ase" is the label for "enzyme." So the name means "the <u>enzyme</u> that takes <u>COOH</u> <u>from</u> <u>pyruvate</u>." However, you'll notice that the COOH has already been the victim of hydrogen unfaithfulness, and is only COO^-. The hydrogen went wandering off as nothing but a proton, leaving its electron behind. (We'll be nice and still refer to it as "carboxyl," politely ignoring its recent loss.) When the COO^- is clipped off, it goes floating away as CO_2, carbon dioxide. That's how the bubbles in bread are produced.

Now it's time to make ethanol. Another enzyme comes along and opens the double bond on the carbon. If you look back to page 44, you'll see an orange enzyme doing basically the same thing. In this case, though, our enzyme worker is going to transfer the hydrogen cargo in such a way that the molecule will turn into ethanol.



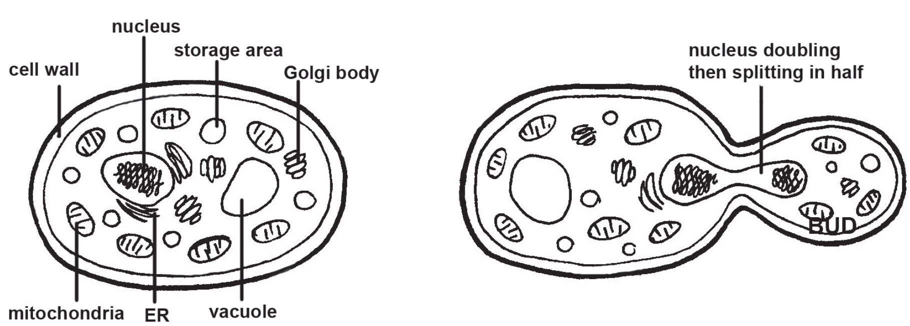
The ethanol in bread is destroyed as it is baked. When bread comes out of the oven the ethanol is gone. However, in other foods the ethanol is an essential ingredient. In beer and wine, the ethanol stays. Alcoholic drinks can be made from just about any type of plant. Yeast isn't too picky about where it gets its sugar. Wine is made from grapes, beer can be made from grains such as wheat or barley (and often with hops flowers added), rum is made from sugarcane, hard cider is made from apples, and mead is made from honey (with water added). Corn, rice, and potatoes can also be fermented into alcohols.



Yes, yeast is a type of fungus, but it is obviously not closely related to mushrooms. Yeast is a unicellular organism (made of single cells), whereas most other types of fungi are multicellular (made of many cells). Yeast cells are more complicated than bacteria cells, and have pretty much all the same cells parts as our human cells. In fact, sometimes research on yeast cells can shed light on things that go on in human cells. If scientists can use yeast cells instead of human cells, the research goes faster because yeast cells are so easy to work with. They can't file a lawsuit if the experiment ends up harming or killing them!

Yeast cells have all the standard cell parts: nucleus with DNA, Golgi bodies, mitochondria (energy makers), endoplastic reticulum, vacuoles (empty "bubbles") and storage areas (similar to vacuoles).

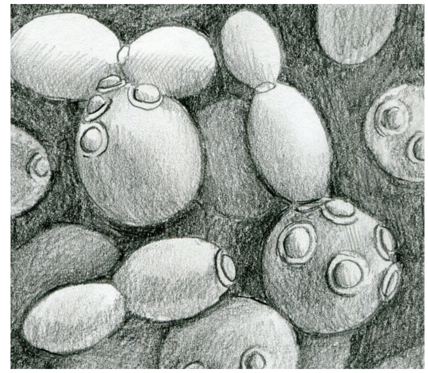
If you have never studied cells, don't worry about this list. All you need to know is that they are different from bacteria.



Yeast cells don't come in male and female—they have no gender. They reproduce by growing a bud. As the bud grows, the yeast cell duplicates all of its cells parts and puts some of them into the bud. The nucleus of the cell (containing the DNA) also is duplicated and an exact copy goes into the bud. When the bud reaches almost the same size as the original cell, it splits off and becomes an independent cell. The bud can actually start to form its own bud even before it reaches its full size. The budding process can be done in just an hour or two.

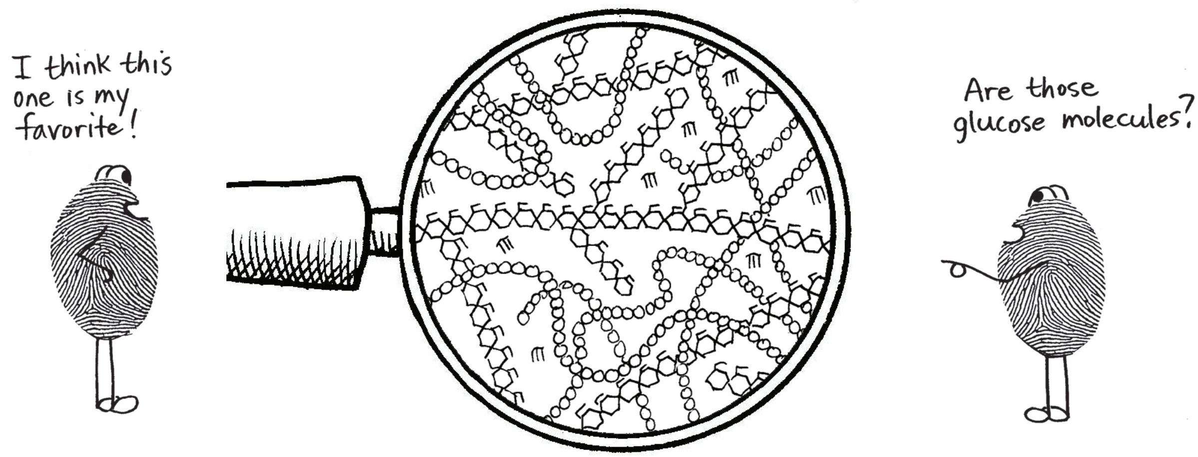
The lifespan of a yeast cell is determined by the number of times it can form a bud. When a bud finally separates from the "parent," it leaves a scar. Yes, even single-celled organisms can have scars. The scar is a place that has been damaged (though healed over) and will not be able to form a new bud. The parent yeast ends up with scars all over its body. When it is completely covered with scars and has no place left to form a new bud, it will stop dividing and die. When single-celled organisms die, they just dissolve and disappear.

Though they do not have genders, yeast can still do a very simple form of sexual reproduction where two cells will join together and combine their DNA. There is a survival advantage to mixing up their DNA. Normally, when conditions are good, yeast will just bud. But when conditions around them are not ideal (not enough food, too hot or cold, too dry, etc.) they will switch over to reproducing by trading their DNA. Small differences in DNA could possibly make some yeast cells better at surviving, and by sharing DNA, these advantages can be passed along to new generations.



This is an artist's sketch of a photograph of yeast cells. Those little rings on some of them are bud scars. Look at the cell that has the most scars It has a new bud growing on top, and the new bud is also starting to grow a new bud!

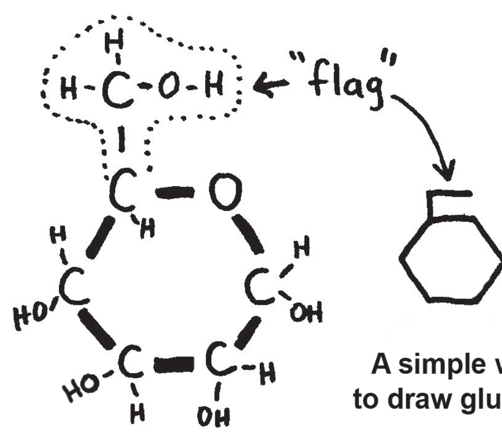
Now let's get out the Super Duper Magnifier and zoom in to the molecular level.



Our magnifier has simplified the molecules for us. We see a few tiny triglycerides here and there, but not a lot. We know there must also be water molecules scattered around, but our viewer has taken them out so they don't clutter the picture. Those strings of beads are actually protein chains made out of amino acids. You'll remember that very often amino acids are drawn as circles or balls. The lines of hexagons are glucose molecules all strung together. Let's start with these hexagons and do the proteins last.

We've already studied glucose. We saw how glucose and fructose can join to form sucrose. We also saw glucose bond to galactose to form lactose. Here we see only glucose molecules, but wow, are there a lot of them!

Glucose molecules are often shown as hexagons, with each vertex (corner) representing one of the atoms that make the ring. Glucose can also form a straight line, but the ring form is what is generally drawn. Sometimes a "flag" is drawn on top of the hexagon to represent that top carbon atom that is not part of the ring. This helps us keep track of "which end is up." Knowing which way the flag is pointing will be very important when we look at lettuce and spinach in the next chapter.



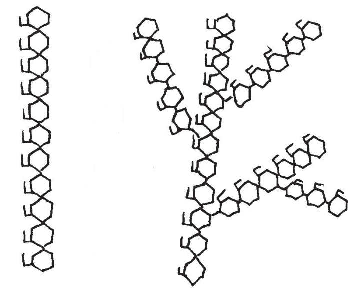
A simple way to draw glucose

Strings of glucose molecules are called ***starch***. There are different types of starch, depending on whether the chains are just straight or whether they have branches coming off. The straight chains with no branches are called ***amylose***. When the chain has branches, it is called ***amylopectin*** *(am-ill-o-peck-tin)*. We can draw these in various ways, depending on how much detail we want to show.

We can keep it very simple and just show them as lines.

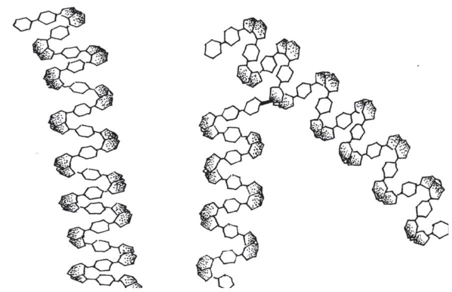
amylose *amylopectin*

We can be more accurate and show all the "flags."



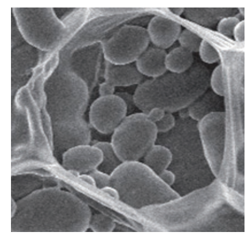
amylose *amylopectin*

Or, we can decide to show the way they curl into helix shapes.



amylose *amylopectin*

Starch molecules are made by plant cells as a way to store food. First, the cells use the process of photosynthesis to turn carbon dioxide and water molecules into glucose molecules. Then the glucose molecules are assembled into long strings, and these strings are then put into storage "bags" called ***starch granules***. Starch granules are sort of like a plant cell's pantry or storage cupboard. When the cell needs energy, it can take some starch out of storage and use enzymes to break apart the string, then split the glucose molecules, releasing energy. Plant cells can do glycolysis, but they can also tear apart the pyruvates if oxygen is available. Plant cells don't have to use any type of fermentation. Animal cells are the same way—they can deal with pyruvates if oxygen is available.



starch granules in a plant cell

The strings of starch in our bread came from wheat seeds. The wheat plant stored lots of energy in its seeds. When a seed falls to the ground and starts to grow, the baby plant will use some of the starch energy in the seed. However, a farmer got there first and harvested the wheat seeds. The seeds were ground into a fine powder that we call "flour."

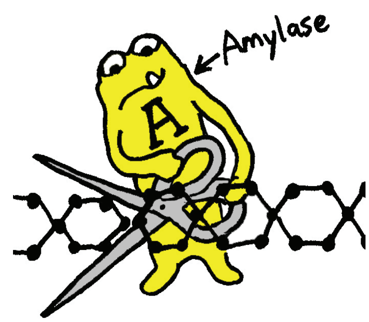
Plants cells usually make more amylopectin than amylose. The ratio is typically 4 to 1. That means there are 4 amylopectins for every 1 amylose. The amount of amylose in a starch will cause it to behave in a certain way when it is cooked. Starch granules absorb water when they are boiled. They swell and grow larger and larger. Like an over-stretched balloon, they eventually burst. When they burst, the wet starch molecules come pouring out and start sticking together. This is why rice, pasta and potatoes can feel sticky. The temperature at which they burst will depend on what type of starch is being stored. Amylose is more resistant to boiling, so granules that have a lot of amylose will not burst as easily.

Rice is made of the seeds of the rice plant.

Rice is a good example of how starch ratios affect cooking. Long grain rice contains a lot of amylose, so when it is boiled, fewer granules break open. Less breaking means fewer loose starch molecules escape. Long grain rice tends to be fluffy and not stick together. Short grain rice, however, has very little amylose and a lot of amylopectin. When you cook short grain rice, it becomes so sticky that it will form balls very easily. This can be helpful if you are making sushi and you need the rice to form a solid layer in the sushi roll. Chefs can choose which type of rice they want to use in a recipe. If they want "not-to-fluffy-not-to-sticky," they can use a medium grain rice.

Yes, when you eat starch, your body breaks apart the molecules into individual glucose molecules. How fast this breaking down process happens is called the ***glycemic index***. ("Glyc-" means "sugar.") Foods that are very high on the glycemic index are broken down into glucose very quickly. This would include white crackers, white potatoes, white rice, and white breads. Seeing a pattern there? Starches that are white tend to be easier to digest and therefore put more glucose into our systems in a shorter amount of time. Starches that are brown —the ones we call "whole grains"—take longer to digest. Whole grains include the brown layer that covers the seed, and this brown layer is not really digestible. Besides whole grains, other low glycemic starches include sweet potatoes, oatmeal, barley, and most vegetables. Why does this matter? As a general rule, it's best to keep the amount of glucose in our blood low and steady.

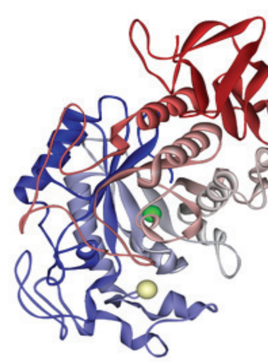
Starches are digested by enzymes. Amylose is taken apart by ***amylase***. Amylase is found in both plants and animals. We can easily forget that from the plant's point of view, those starches are supposed to be used by the baby plant that will grow from the seed. Therefore, the plant must produce not only the starch but also the enzyme that will break it down. Amylase is found in seeds and fruits right there next to amylose, but it doesn't begin working until after the seed has fallen and is ready to begin growing. Part of the ripening process in fruit involves amylose breaking down starches.



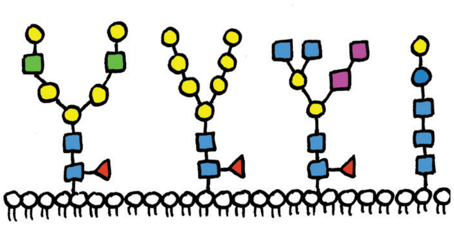
Animal and human bodies make amylase, too. It's the main enzyme found in human saliva. We start digesting those starches even before we swallow them. You can test this by holding a cracker in your mouth without chewing. Not onlyl does it ges soggy and start to fall apart, but it begins to taste sweeter, too.

Amylase has the perfect shape for snapping apart the glucoses. The true shape of amylase is shown here on the right. It is made of amino acids but the artist has simplified the shape and not shown the amino "beads." Those curly places show that proteins, like starches, can form coils.

What would happen if we did not have an enzyme that could disassemble amylose? The long string would pass all the way through our digestive system, unchanged. In the next chapter we will meet a starch molecule we can't digest, though, oddly enough, it is still beneficial to eat lots of it.



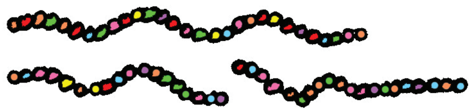
amylase



What will happen to the glucoses after they are snapped apart? Many of them will get used for energy, but not all of them. Glucose molecules are also used to build molecular structures. Strings of glucose molecules show up in a variety of places both inside and outside a cell. For example, they are part of the "post office" system inside a cell, being used in a way similar to address labels. Glycoproteins are used on the surface of a cell as identification markers.

Most people are surprised to find out that bread has a lot of protein in it. We tend to associate the word "protein" with foods like meat, fish, eggs, milk, and perhaps beans and nuts. Grains have quite a bit of protein in them, though. The protein is stored as long strings of amino acids, but we don't have a nice catch-all name for them like we do for glucose strings ("starch"). Storage proteins in plants can be called "storage proteins" but are usually known by their own names. For example, "avenin" is oat protein and "zein" is corn protein. We are going to look at two proteins found in wheat: ***glutenin*** *(GLUE-ten-in)* and ***gliadin*** *(GLIE-ah-din)*. Glutenin is usually shown as a long, straight molecule, and gliadin is usually shown as a curvy shape, or even sometimes as a circle.

GLUTENIN

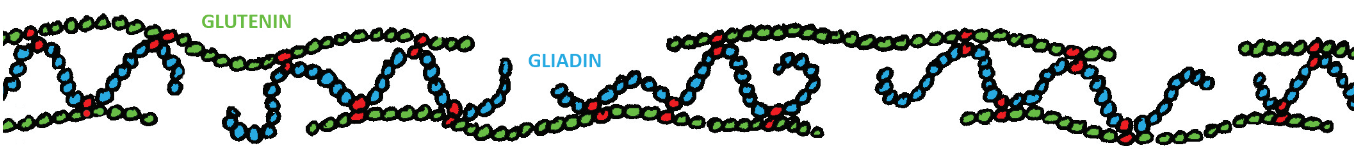


GLIADIN

You may be thinking that "glutenin" sounds a lot like a word we hear all the time now: "gluten." With all the hype about products being "gluten-free" you'd think that gluten was some kind of poison. Gluten is just the combination of the proteins glutenin and gliadin. It's actually gliadin, not glutenin, that causes problems for some people, but before we get into why gluten can be a problem, let's look at the positive side and find out what gluten does in bread.

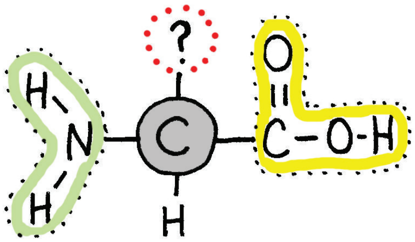
If you've ever seen an expert pizza maker tossing a crust, you've seen what gluten can do. It's amazing to see that thin crust swirling around in the air, getting thinner and thinner yet not tearing apart. Gluten is stretchy and tough. Chefs can choose flours that have more or less gluten, and for pizza dough you definitely want a lot of gluten. Gluten is also what catches the carbon dioxide bubbles made by yeast, so it is a key factor in the fluffy texture of breads and rolls. Manufacturers of gluten-free bread must try to find a substitute for gluten. Often, sticky starches from potatoes or tapioca are added to the mix to increase the stretchy qualities of the dough. But if you've ever worked with gluten-free flour, you know that there really isn't a good substitute for gluten when it comes to making bread. Those gluten-free loaves of bread sold in stores are marvels of food engineering!

In dry flour, glutenin and gliadin are separate proteins. When water gets mixed into the flour, a major change happens. The water allows bonds to form between these two proteins. The amino acid responsible for this bonding is ***cysteine***. Cysteine has, as part of its R group ("?"), a sulfur atom. Sulfur atoms like to bond with each other and form a ***disulfide bond***. ("Di" means "two.") These disulfide bonds acts like bridges between the strands of protein. When a lot of glutenins bond to a lot of gliadins, we call the resulting substance ***gluten***. The disulfide bonds are very strong so these long strands are stretchy and tough.



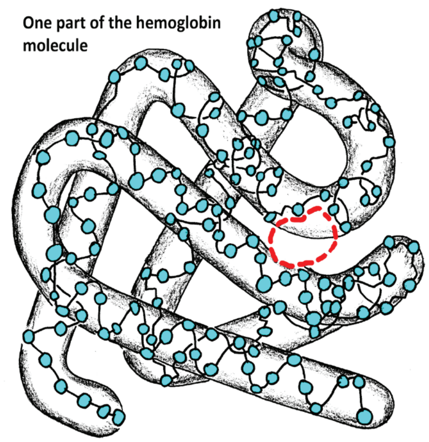
This illustration shows how glutenin and gliadin strands might interact. Glutenin is represented in green, and gliadin in blue. The red dots represent cysteine. This picture makes it easy to see how the cysteines form bonds that are like bridges. When you knead the bread dough, you are moving the protein strands around, and making more and more cysteines come into contact, so you get more bridges. More bridges means more stretchiness. Once the two proteins merge together, we stop naming each separate protein and just call the whole thing "gluten."

To understand why gluten can be harmful, we need to have a good understanding of how proteins work. You will remember that there are only 20 different kinds of amino acids. We briefly met a few of them in the last chapter, and we just met cysteine again on the previous page. Other amino acids you run into a lot include lysine, alanine, proline, valine, serine and glutamine. The amino acids are joined, end to end, to make a long string called a polypeptide. Glutenin and gliadin are polypeptides.



As we learned in the last chapter, each amino acid has parts that are the same: 1) a central carbon atom with an H attached, 2) a COOH (carboxyl) group, and 3) an NH_2 (amine) group. Every amino acid has these parts. What makes them different is the R group, represented here by a question mark. (Think of "R" as standing for the Rest of the molecule.) It is the R group that gives an amino acid its "personality." Some R groups have a small chains of carbon atoms and cause the amino acid to love fats and "hate" water, and therefore try to hide in the center of the protein molecule. Other R groups cause the amino acid to love water and be happy on the outside of a molecule. Some R groups are negatively charged and will be attracted to things that are positively charged. Some R groups are acidic or basic. A few amino acids have an extra amine (NH_2) group. Some have a benzene ring as part of their R group.

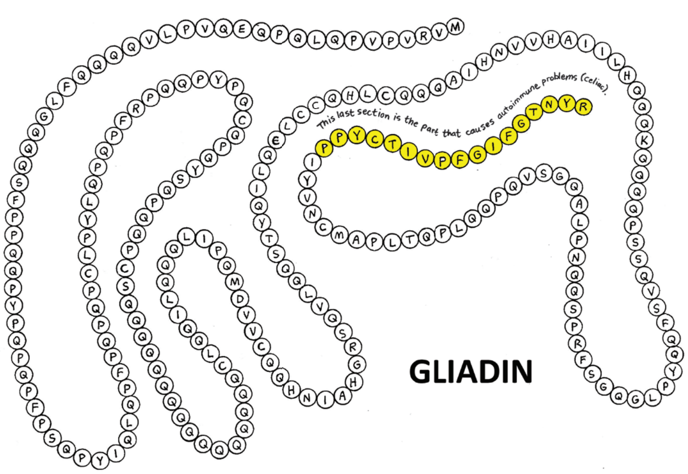
One part of the hemoglobin molecule



The interaction of all these various amino acid "personalities" will cause the protein to bend and twist and fold up into a specific shape. The number and order of the amino acids on the string determines the final shape of the protein. That shape will be useful somewhere in the organism that produced the protein, perhaps as an enzyme or a molecular shuttle bus, or as part of a muscle fiber or a strand of hair.

The protein shown here is part of the hemoglobin molecule that carries oxygen in your blood. You can see the chain of amino acids, though all the amino acids are colored blue instead of being different colors. The amino acids are arranging themselves, each one trying to get into a comfortable spot, and the result is this particular shape. The dashed red line shows where a "pocket" has formed. This pocket is where an iron-based molecule will sit. It will hold the oxygen atom.

Storage proteins like glutenin and gliadin are meant to be nothing more than a source of food. They must have an arrangement that **does NOT** fold up to be anything special. They must be random "nonsense" that is only good for being digested and recycled. They should **NOT** resemble any real proteins.

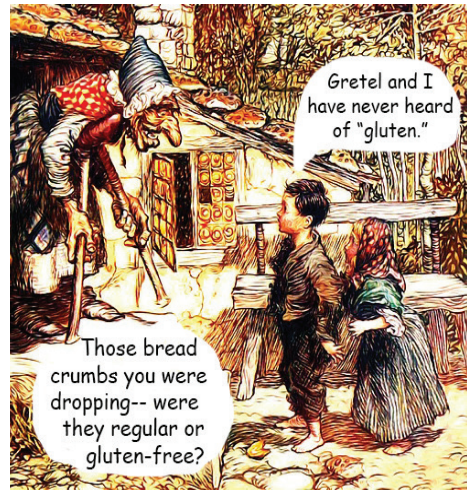


Each letter represents an amino acid. Some letters make sense, such as P for proline, A for alanine, and C for cysteine. Some seem random, such as Q for glutamine. Look at how many Q's there are! Can you find the C's for cysteine? When two C's are close enough, they will try to bond. Where would cysteine bonds occur in this picture?

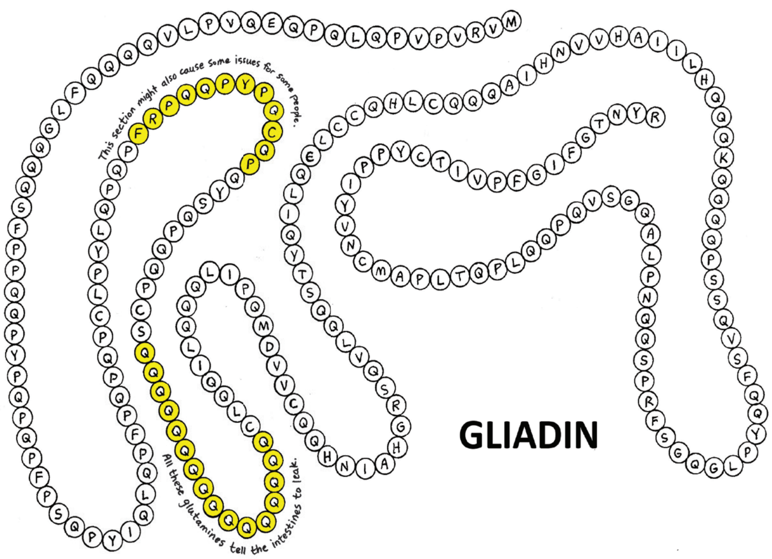
What would happen if a storage protein DID resemble a meaningful protein? This is the problem with gliadin. There is one place, at the end of the string, where the sequence of amino acids is too similar to a meaningful protein sequence.

We have white blood cells all through our body whose job it is to constantly be on the lookout for strange proteins that might be part of something that might hurt us—a toxin (poison), or a bacteria or virus. We call this army of white blood cells our ***immune system***. Unfortunately, the end part of the gliadin molecule is recognized by some people's immune systems. The white blood cells don't have eyes or brains, so they can't see the sequence for what it is—just the end of a food protein molecule. To them it feels like an invader. This mistake happens in about 1 in every 100 people. The white blood cells begin a complicated attack process that ends up destroying innocent body tissues. When our immune system attacks normal, healthy body cells this is called an ***autoimmune disease***. The autoimmune reaction to gliadin is called **celiac** *(SEAL-ee-ack)* ***disease***. People with celiac disease can be quite sick with not only intestinal problems, but also fatigue, headaches, muscle and nerve problems, and brain problems. The cure is to never again eat even one crumb of gluten.

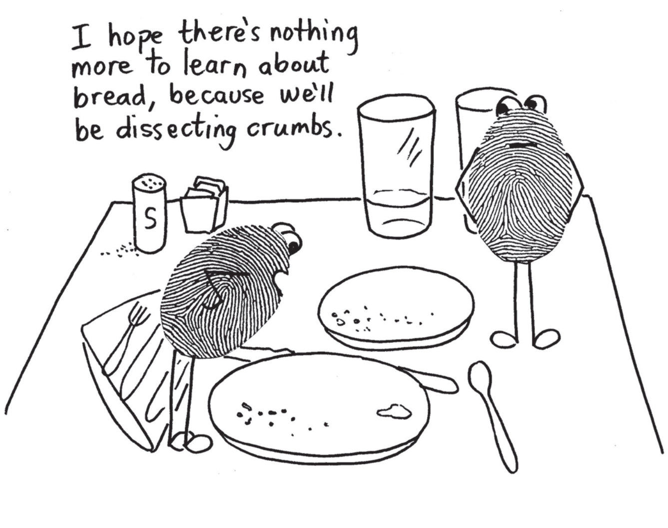
Some people who don't have celiac disease also react badly to gluten. There isn't any name for this condition yet, so it is simply called "non-celiac gluten sensitivity." The most mysterious thing about gluten sensitivity is that before the 1980s, it was almost unknown. And now we have 7% of the population who can't eat gluten? What happened? No one knows for sure. Could it be human genetics? Plant genetics? Are plant scientists changing the sequence of the amino acids on the gliadin molecule? Some people blame a chemical named ***glyphosate***, the active ingredient in the popular weed killer *Round-Up®*. Researchers are actively working to try to solve this mystery, and perhaps by the time you read this book, they will have found a good answer.



Interestingly, almost 23 percent of the population thinks they are sensitive to gluten but when they undergo very accurate testing, it turns out that they aren't. They might be reacting to something else in their food and just blaming it on gluten because we hear so much about it.



Gluten sensitivity involves a different place on the gliadin polypeptide, not the end that causes celiac. There are some places in the middle of the gliadin molecule that mimic another body protein, called ***zonulin***. Zonulin is a messenger protein that tells the intestines to leak. Leaky intestines? This sounds like a very bad thing! However, there are times when you want your intestines to leak. As part of our immune defense system, white blood cells can be allowed to leak out of the blood and into the intestines to attack harmful bacteria. The cells of the intestines are very good at repairing the leaks, and most of the time things are quickly patched up. Unfortunately, 6 out of every 100 people have intestinal cells that aren't patching the leaks fast enough. Zonulin continues to be released and their intestines continue to leak, allowing molecules that normally stay in the intestines to get out into the blood. These molecules cause problems in various parts of the body.



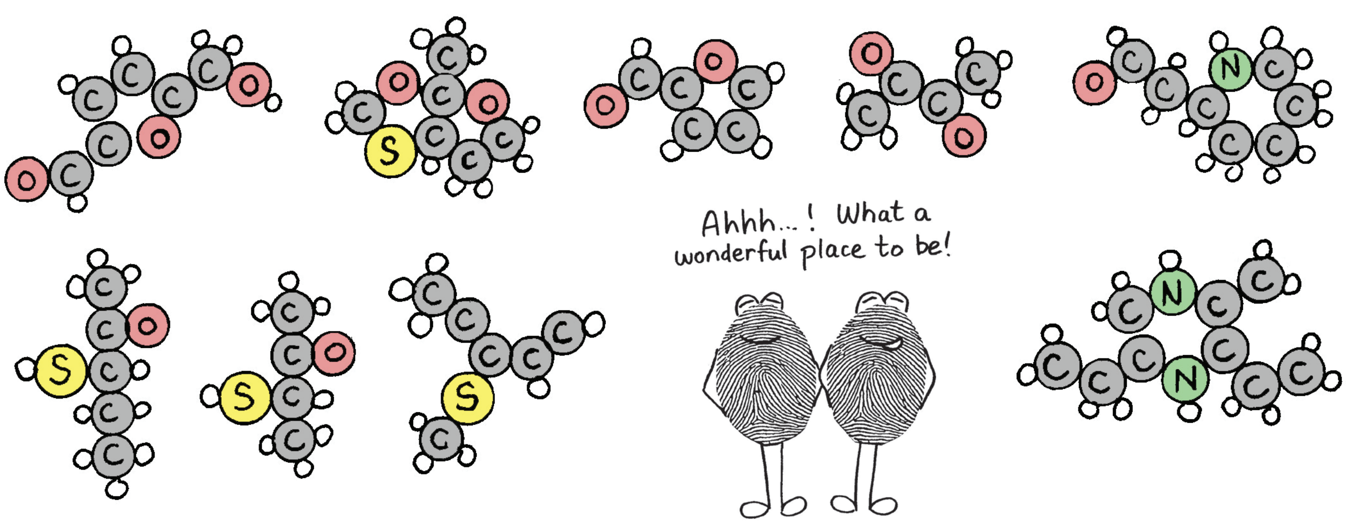
There's one last thing we really must mention. Did you notice how golden brown the top of the roll was? We take "browning" for granted and don't realize that there is some complicated and interesting chemisty going on. This type of browning is known as the ***Maillard reaction***. (Maillard is a French name, and is pronounced (*my-YAR)*. The "d" on the end is silent. This name gets pronounced wrong very often, and it's easy to find bad examples on Internet videos.) The Maillard reaction is also responsible for the browning of meat. If you are a meat fancier, you might enjoy those cripsy browned edges where the meat was "seared" on the pan. The Maillard reaction can be quite delicious.

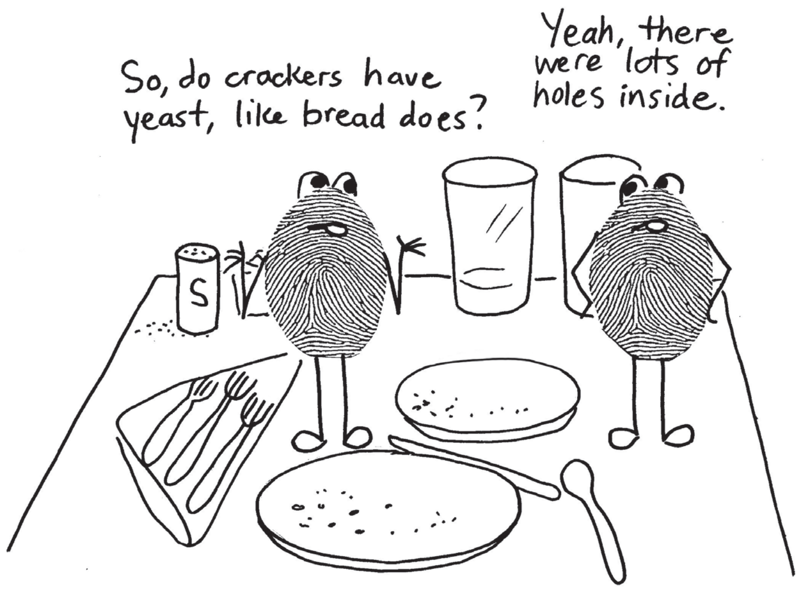
The Maillard reaction happens when sugar molecules get mixed up with amino acids and form bizarre "mutant" molecules. As the temperature rises in the oven, or in the pan, glucose molecules can open up and become a straight line instead of a circle, and amino acids can break apart. Amino acids, or parts of amino acids, start bonding to the sugars, making bizarre, nonsense molecules that are half-amino, half-sugar.

It would be like combining toys with appliances. Chop a bunch of toys in half, chop a bunch of appliances in half, then join them together randomly. What would we call these? They have no purpose. You can't call them toys anymore, and you can't call them appliances, either.

Real Maillard molecules don't look funny, like these crazy household combos do, but can still be interesting if you try to identify any remaining recognizable parts of sugars or aminos (such as R groups). Any of the 20 amino acids can be involved in a Maillard reaction, and the molecules can split and recombine in many different ways. The resulting molecules can then split and recombine yet again, so it's like a molecular "free for all" where mutant molecules zip about, combining and recombining to make hundreds of weird, unidentifiable molecules. The final result of this molecular chaos is... delicious smells and tastes!

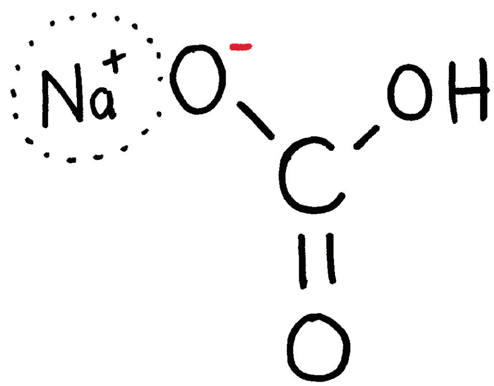
Where might the sulfur atoms have come from in these Maillard molecules? And the nitrogens?





Crackers belong to a large category of baked goods called "quick breads." They are "quick" because in comparison to bread, they can be made very quickly. Yeast takes a long time to make bread rise. All those little single-celled yeast critters have to duplicate their DNA and their organelles and form buds that will become new yeast cells. This process can take several hours—which is pretty fast when you consider the complicated biological processes involved in cell division. But sometimes you need a method of making batter fluffy almost instantly.

Anything that will make a batter or dough fluffy (due to gas bubbles being created) is called a ***leavening*** *(lev-en-ing)* agent. Yeast is one of the slowest leavening agents. The fastest leavening agents are ***baking powder*** and ***baking soda***. They are used in muffins, biscuits, cookies, cakes, pancakes, and some types of crackers.

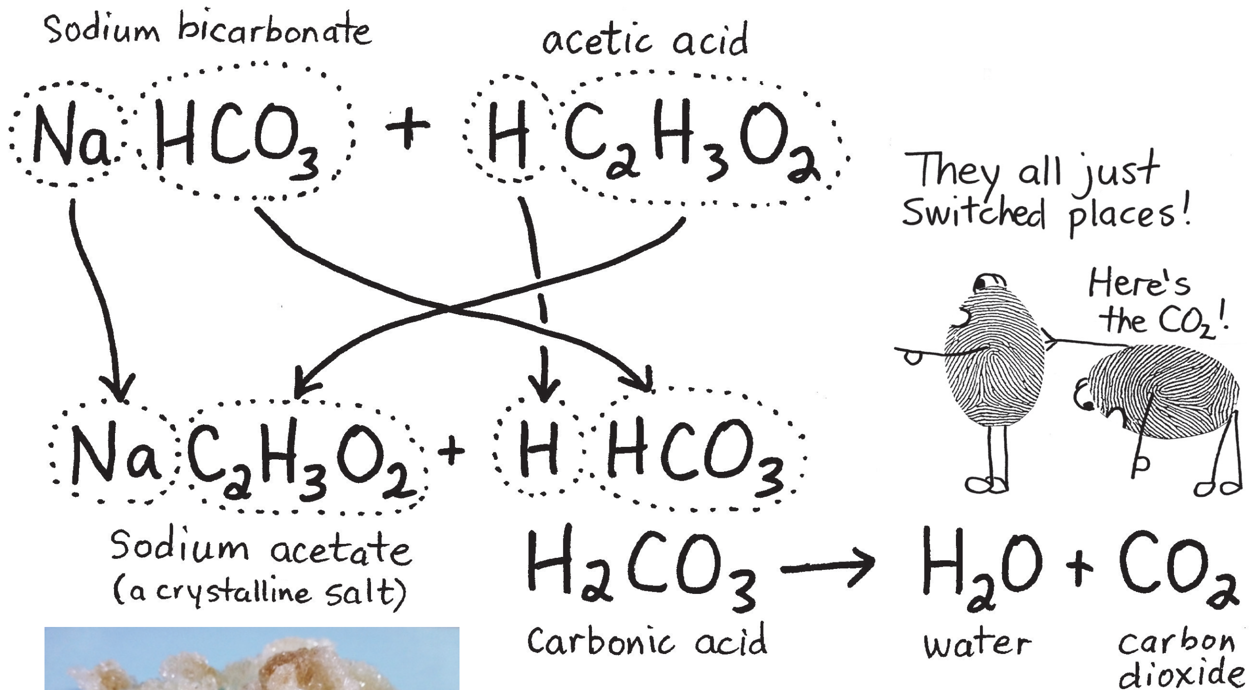


Baking soda (also known as "bicarbonate of soda") is a white powder made of molecules with the chemical formula $NaHCO_3$. From the name, "bi-carbon-ate," we would expect to find two carbon atoms in the molecule, since "bi" means "two." But alas, the name was created using an outdated naming system and was never updated, so we are stuck with a name that does not seem to match the chemical formula. It's one of the rare oddities that chemistry students have to just accept and memorize.

The (HCO_3^-) part of the molecule is called the ***bicarbonate ion***, and it shows up quite frequently in the world of chemistry. As you can probably guess, this used to be a happy molecule with two hydrogens, H_2CO_3, then one of the hydrogens got fed up with never getting to have its electron, so it left the molecule and wandered off as nothing but a proton. The oxygen held on to H's electron, and there it is, in red, giving the oxygen a negative charge. Along comes a positively charged sodium ion (Na^+) and, as they say, "Unlike charges attract." (The sodium atom can't form the same type of bond that carbon does with oxygen. There isn't any sharing of electrons going on, just a strong electrical attraction.)

Where does $NaHCO_3$ come from? Though it might possibly be manufactured in a lab now, it was first discovered underground as a mineral rock, and is still mined today. The baking soda you buy in the store probably came from an underground mine. They send hot water down, dissolve the minerals, then pipe it up. A processing plant takes the water back out, and then puts the dry powder into boxes.

How does baking soda produce bubbles in batter or dough? You probably know the answer. Undoubtedly, you've seen what happens when you mix baking soda and vinegar—lots of bubbles form in just a few seconds. When baking soda is used in a recipe, you must also add an acid for it to react with. This is what happens when baking soda is combined with acetic acid (vinegar):



At the top are the formulas for baking soda and vinegar. (Vinegar is acetic acid in water. The water doesn't participate in the chemical reaction, so we can ignore it in this equation.) The arrows show you how the molecules rearrange themselves when given the chance. An H at the beginning of a molecule (as in $HC_2H_3O_2$) is likely to leave the molecule and wander off to join another molecule. Here, we see the H in acetic acid attaching itself to the bicarbonate ion, HCO_3^-, to form carbonic acid, H_2CO_3. Now we have two H's at the beginning of a molecule—double trouble! The carbonic acid molecule is very unstable and quickly falls apart to become H_2O and CO_2.

When we combine baking soda and vinegar, we get so excited about all the bubbles that we never think to look for anything else. As you can see from the equations above, a substance called ***sodium acetate*** is formed. (We already met this substance briefly on page 22 when we learned that when an acid and a base combine, water and a salt are produced.) Normally, the sodium acetate is dissolved in the water that is formed in the reaction, so we can't see it very well. However, if you boil down the leftover solution, taking all the water out, the sodium acetate will form beautiful crystals, as shown in the photograph. These are salt crystals, but not the kind we put in shakers. Food scientists do use sodium acetate in food products, however. "Salt and vinegar" flavored potato chips owe part of their flavor to sodium acetate. It is widely used (in small amounts) in many food products.

Baking powder is a combination of baking soda (sodium bicarbonate) and a powdered acid, such as ***tartaric acid*** (cream of tartar). When you add water to baking powder, the dry acid powder turns into a wet, highly active acidic solution which will begin to interact with the sodium bicarbonate. If you see the words "double-acting" on your can of baking powder, this means that the food chemists have designed the powder to be temperature sensitive. When you first add the water (or milk), you get a first round of CO_2 bubbles. Then, when you put the food into the oven, the heat will cause a second round of CO_2 bubbles to form while it is baking. Hopefully, the dough will become firm during the time when the reaction is at its peak, producing the maximum amount of bubbles. The trapped bubbles create a fluffy texture.

Comprehension self-check

1) The fats found in butter are mainly triglycerides. A triglyceride has three "tails" that are made of long chains of ____________ atoms (with hydrogens attached).

2) The process of churning cream to make butter does what to the fat globules in it?

3) What comes out of the butter as the fats get packed together? __________ that has a tiny amount of protein and sugar floating in it.

4) What creates the acid found in "buttermilk"?

5) What does lactic acid do to milk?

6) What type of sugar is found in milk?

7) Why is butter yellow? It contains this molecule:

8) Name three foods that contain the molecule in #7.

9) Retinol is a form of vitamin ____, and is essential for the proper functioning of the __________ in your eye.

10) What is the most abundant protein found in milk?

11) This protein (in #10) floats around in milk in balls called ________________ and the balls don't stick together because the all have a ______________ electrical charge created by sugar/proteins called ____________________

12) When these protein balls are forced to clump together, this is called _________________ milk. You can do this using a source of positive protons such as _____________ or ________________, or you can use an enzyme called _______________ which comes from the stomach of a baby __________. This process also happens naturally when milk goes sour. What causes milk to go sour? ________________ in the milk

13) When you make cheese, the watery stuff left over is called:

14) When "Little Miss Muffet sat on her tuffet, eating her curds and whey," what was she eating?

15) What microorganisms are used to make hard cheeses? _____________ and/or _______

16) What do you call the process of splitting a glucose molecule, and what two molecules are the result?

17) Bacteria in milk produce __________ acid during the process called f__________________.

18) The gas bubbles that make bread rise are made of ____________________ produced by ___________ cells.

19) The cells in #18 also produce a waste product called ____________, which disappears when bread is baked.

20) The cells in #18 are not bacteria. They are a type of:

21) Amylose and amylopectin are types of ______________ and are made of ____________ molecules.

22) The enzyme that can break apart amylose is called _____________. Do plants make this enzyme?

23) Gluten is made of two proteins, called _______________ and _________________.

24) The sulfur-containing amino acid responsible for the creation of stretchy gluten is called:

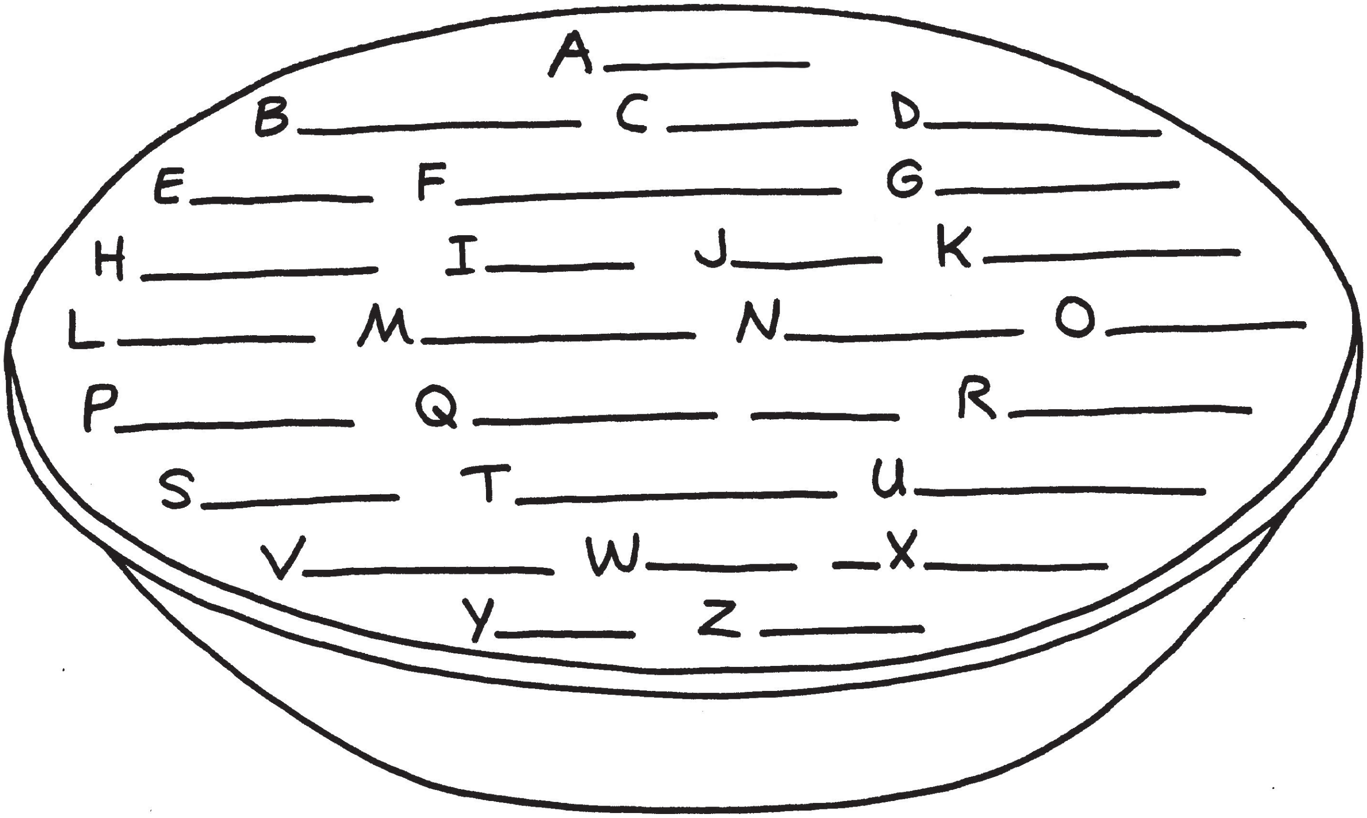
25) People who are sensitive to gluten have immune systems that release too much ______________, a messenger molecule that tells the intestines to become temporarily leaky.

26) This reaction is caused by broken pieces of sugars and amino acids bonding together: ________________

27) If you use baking soda ($NaHCO_3$) in a recipe, what must you also add in order to get bubbles?

ACTIVITY 3.1 ALPHABET SOUP

Fill in a word for each letter of the alphabet. The clues below are in random order. Cross them out (or put a mark next to them) as you use them.



The tiny mineral clumps found in casein micelles are mostly made of calcium ________.
Beta-carotene makes food yellow or _______.
This amino acid is found in the strings hanging off casein micelles and it is very good an hanging on to sugars.
This molecule is created when enzymes add hydrogens to pyruvate.
Milk can be curdled instantly by using vinegar or lemon _______.
If you give an electron to a proton, you have made a ______.
Long strings of glucose molecule that can be broken apart by amylase
Oat protein
Corn protein
The watery liquid that is created during the cheese making process
The amino acid cysteine contains the element sulfur which allows proteins to form _______ bonds.
This is the room in your house where you do food chemistry experiments.
This organelle is found inside of animal and plant cells and harvests energy from pyruvate molecules.
An enzyme called Lactate Dehydrogenase puts H's onto pyruvate in order to __________ "shuttle bus" molecules.
Cornish ______ is a type of cheese.
Watery substance left over when butter is made.
This atom is used to patch the ends of the beta-carotene molecule when it is chopped in half.
The correct name for COOH
The part of gluten that causes problems
The casein micelles are surrounded by a _______ electrical charge.
Each of the 20 amino acids has a unique group of atoms located at the place where we put a ___________ _______.
An empty bubble inside a yeast cell
The rate at which a starch can be broken down and absorbed by the body is called the glycemic ______.
A protein with a special shape that allows it to do a particular job
The molecule that fits into a protein holder in the cells in the retina of your eye
The process of turning pyruvate into lactic acid

ACTIVITY 3.2 STINKY CHEESE PUZZLE

Bacteria can be blamed for a lot of smells in the natural world—stinky feet, smelly arm pits, intestinal gas, bad breath, rotting meat, fermenting sauerkraut, and more. However, not all bacteria smell bad; a few actually smell flowery or fruity. But that's no fun. Smelly bacteria are more interesting. It's not just bacteria and molds that are used to make cheese—insects and arachnids are used, too. Yuck!

Learn the names of the stinkiest cheeses by using the key words at the bottom.





1) ___ ___ ___ ___ ___ ___ ___ ___ ___
16 10 5 4 8 17 20 14 17

Made using *Brevibacterium linens*, a bacteria found on our feet, so it smells like stinky socks and armpits. Has been made for centuries in Belgium and Germany, and is probably the most famous stinky cheese.

2) ___ ___ ___ ___ ___ ___ ___ ___ ___
18 21 5 14 5 4 14 17 13

This cheese is said to smell like a barnyard or like stinking laundry with hints of garlic. It uses raw, unpasteurized milk and is very runny because of the fluids produced by the fermentation process.

3) ___ ___ ___ ___ ___ ___ ___ ___
14 1 2 10 22 22 14 22

Made with raw milk and rinsed in brandy. Internet rumors say it is so smelly that it was banned from public transport in France. So runny it has to be sold in boxes. Napoleon loved it.

4) ___ ___ ___ ___ ___ ___ ___ ___
13 21 16 14 20 20 10 2

Made in Italy, smells like a combination of wet socks and wet grass. Is one of the oldest soft cheeses, dating back to the 10th century. Washed in seawater once a week. The taste is not so bad, a bit salty and fruity.

5) ___ ___ ___ ___ ___ ___ ___ ___   ___ ___ ___ ___ ___ ___
22 13 10 11 6 10 11 20   4 10 22 15 2 1

Smells like wet hay, or the changing room of a football team. Based on a recipe that dates back to 1615. Uses milk from a rare breed of cow. The curing cheeses are washed in fermented juice made from "Stinking bishop" pears.

6) ___ ___ ___ ___ ___ ___ ___ ___ ___
17 2 7 8 14 12 2 17 13

Made using a blue *penicillium* mold that was orignally found in caves in southern France. Some people think it smells like rotten butter. Uses unpasteurized sheep milk so there is a small risk of *Listeria* food poisoning.

7) ___ ___ ___ ___ ___ ___ ___ ___
17 21 18 16 14 13 13 14

This is one of the runniest cheeses in the world. It is served warm, which makes is even runnier. It comes from the Alps of Switzerland where it is most often eaten at social gatherings. Some people think it smells like dirity feet.

8) ___ ___ ___ ___ ___ ___ ___ ___ ___
5 10 5 2 16 14 13 13 14

Made in France. It is formed into balls that look like cantaloupes. One of the key ingredients in its fermentation is the presence of mites, a tiny member of the spider family. The mites secret chemicals that give it flavor.

9) ___ ___ ___ ___   ___ ___ ___ ___ ___
18 21 22 8   5 21 17 9 8

Made on the island of Sardinia, this cheese contains live maggots (larvae) from the cheese fly. The maggots can jump as far as 15 cm, so you have to hold your hand over the cheese as you eat. Or, you can put the cheese in a plastic bag an hour before you want to eat the cheese and the maggots will die.

10) ___ ___ ___ ___ ___ ___ ___ ___
1 21 17 5 14 22 21 11

This Italian cheese is very smelly, but you have probably eaten some of it and enjoyed it. It is a very hard cheese, so hard that it must be shredded with a grater before eaten. It is often sprinkled over spaghetti.

KEY WORDS:

Amino acids are bonded together to make a ___(1) ___ ___(2) ___ ___ ___ ___(3)

The watery stuff leftover during the process of making butter: ___(4) ___ ___ ___ ___ ___ ___(5) ___ ___ ___(6)

Whey is the ___ ___ ___(7) ___(8) ___ ___ leftover when producing curds.

This messenger molecule tells the intestines to leak, to allow immune cells to enter. ___(9) ___ ___ ___ ___ ___(10) ___(11)

Beta-carotene ___ ___ ___(12) ___ ___ ___ ___(13) ___ orange and yellow light but absorbs green and blue light.

This alcohol is produced by yeast as they harvest energy from pyruvate molecules. ___(14) ___ ___(15) ___ ___ ___ ___(16)

When butter goes bad we say that is has gone ___(17) ___ ___ ___(18) ___ ___(19)

White butter can be made from the milk of sheep and ___(20) ___ ___(21) ___ ___(22)

ACTIVITY 3.3 Third 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 3: BUTTER, CHEESE, and BREAD

1) What makes the holes in Swiss cheese?

CHAPTER 3: BUTTER, CHEESE and BREAD

2) Which state in the U.S. is famous for its cheese making?

CHAPTER 3: BUTTER, CHEESE and BREAD

3) Queen Victoria received a giant wheel of Cheddar cheese as a wedding gift. About how much did it weigh?

a) 50 lbs (23 kg) b) 500 lbs (225 kg)
c) 1,000 lbs (450 kg) d) 10,000 lbs (4,535 kg)

CHAPTER 3: BUTTER, CHEESE and BREAD

4) How many varieties of cheese are there in the world?

a) 100 b) 2,000 c) 10,000 d) a million

CHAPTER 3: BUTTER, CHEESE and BREAD

5) What is the most popular (and most used) type of cheese in the world?

CHAPTER 3: BUTTER, CHEESE and BREAD

6) "Pule," the most expensive cheese in the world (300 US dollars per pound) comes from Serbia and is made from the milk of:

a) sheep b) donkeys c) elephants

CHAPTER 3: BUTTER, CHEESE and BREAD

7) What did ancient Egyptians use moldy bread for?

a) making soup b) feeding cats
c) treating wounds d) temple offerings

CHAPTER 3: BUTTER, CHEESE and BREAD

8) Where was a 2,000 year old loaf of bread found?

a) volcanic ruins in Italy
b) pyramid in Egypt
c) under a glacier in Norway

CHAPTER 3: BUTTER, CHEESE and BREAD

9) Many words are used to describe the smells of stinky cheeses. If you had to eat a stinky cheese, which of these would you choose?

funky, musty, goaty, tangy

CHAPTER 3: BUTTER, CHEESE and BREAD

STRANGE FACT: During World War II, when food was rationed, it was illegal to sell fresh bread in the UK. They thought the delicious smell of the fresh bread would cause people to too much all at once. The bread had to sit for 24 hours before it could be sold.

CHAPTER 3: BUTTER, CHEESE and BREAD

11) How many people do you know who don't eat gluten?

cCHAPTER 3: BUTTER, CHEESE and BREAD

12) Go around the table and try to guess each person's favorite starchy food. (anything made from rice, corn, wheat, or various types of flour)

1) Carbon dioxide bubbles from the bacteria that ferment the cheese as it hardens.
2) Wisconsin
3) 1,000 lbs (450 kg)
4) 2,000
5) Mozzarella
6) donkeys
7) treating wounds
8) volcanic ruins in Italy