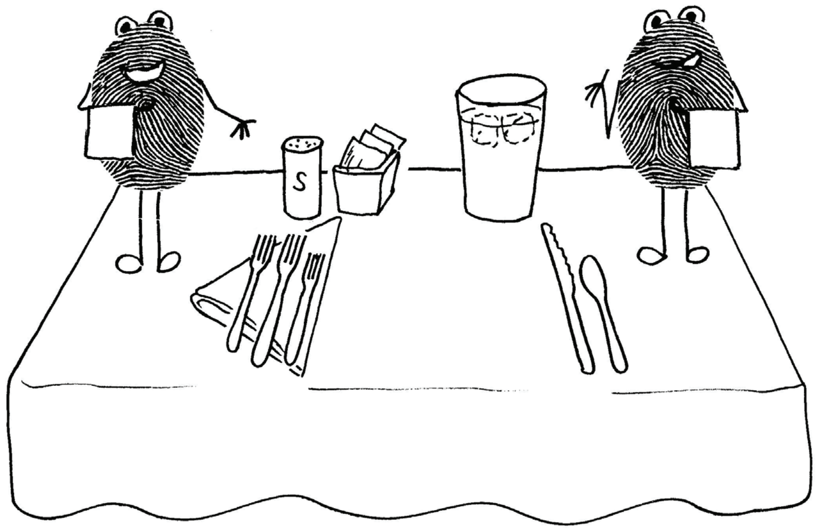
# 1: Before Dinner Begins

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.

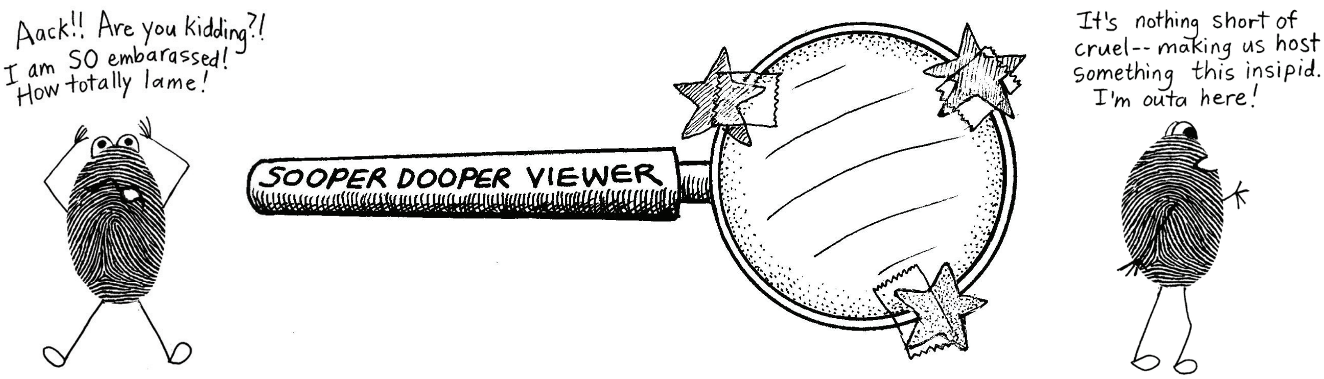



We will begin the dissection of your dinner even before the appetizers arrive. There are three edible things on your table already: water, salt and sugar. Let's start with your glass of water.

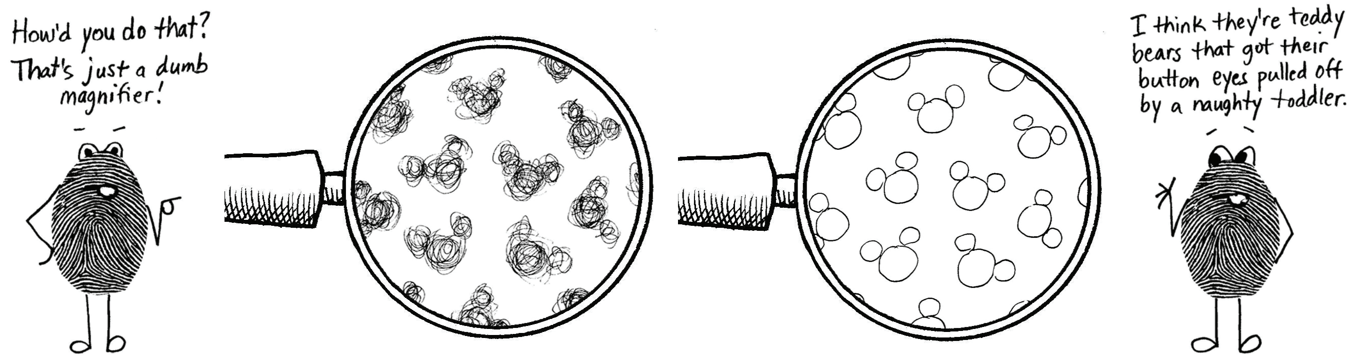

Yes, to dissect things down to the molecular level, we'll need some special equipment. Your ordinary scalpel and forceps won't be adequate. We'll need an amazing magnifying machine that will let us zoom in at ridiculously high levels of magnification, making things look up to one million times larger. 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.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hydrogen 1 H 1.0079 | | | | | | | | | | | | | | | | | | helium 2 He 4.0026 |
| lithium 3 Li 6.941 | beryllium 4 Be 9.0122 | | | | | | | | | | | | boron 5 B 10.811 | carbon 6 C 12.011 | nitrogen 7 N 14.007 | oxygen 8 O 15.999 | fluorine 9 F 18.998 | neon 10 Ne 20.180 |
| sodium 11 Na 22.990 | magnesium 12 Mg 24.305 | | | | | | | | | | | | aluminium 13 Al 26.982 | silicon 14 Si 28.086 | phosphorus 15 P 30.974 | sulfur 16 S 32.065 | chlorine 17 Cl 35.453 | argon 18 Ar 39.948 |
| potassium 19 K 39.098 | calcium 20 Ca 40.078 | | scandium 21 Sc 44.956 | titanium 22 Ti 47.867 | vanadium 23 V 50.942 | chromium 24 Cr 51.996 | manganese 25 Mn 54.938 | iron 26 Fe 55.845 | cobalt 27 Co 58.933 | nickel 28 Ni 58.693 | copper 29 Cu 63.546 | zinc 30 Zn 65.39 | gallium 31 Ga 69.723 | germanium 32 Ge 72.61 | arsenic 33 As 74.922 | selenium 34 Se 78.96 | bromine 35 Br 79.904 | krypton 36 Kr 83.80 |
| rubidium 37 Rb 85.468 | strontium 38 Sr 87.62 | | yttrium 39 Y 88.906 | zirconium 40 Zr 91.224 | niobium 41 Nb 92.906 | molybdenum 42 Mo 95.94 | technetium 43 Tc [98] | ruthenium 44 Ru 101.07 | rhodium 45 Rh 102.91 | palladium 46 Pd 106.42 | silver 47 Ag 107.87 | cadmium 48 Cd 112.41 | indium 49 In 114.82 | tin 50 Sn 118.71 | antimony 51 Sb 121.76 | tellurium 52 Te 127.60 | iodine 53 I 126.90 | xenon 54 Xe 131.29 |
| caesium 55 Cs 132.91 | barium 56 Ba 137.33 | 57-70 * | lutetium 71 Lu 174.97 | hafnium 72 Hf 178.49 | tantalum 73 Ta 180.95 | tungsten 74 W 183.84 | rhenium 75 Re 186.21 | osmium 76 Os 190.23 | iridium 77 Ir 192.22 | platinum 78 Pt 195.08 | gold 79 Au 196.97 | mercury 80 Hg 200.59 | thallium 81 Tl 204.38 | lead 82 Pb 207.2 | bismuth 83 Bi 208.98 | polonium 84 Po [209] | astatine 85 At [210] | radon 86 Rn [222] |
| francium 87 Fr [223] | radium 88 Ra [226] | 89-102 ** | lawrencium 103 Lr [262] | rutherfordium 104 Rf [261] | dubnium 105 Db [262] | seaborgium 106 Sg [266] | bohrium 107 Bh [264] | hassium 108 Hs [269] | meitnerium 109 Mt [268] | ununnilium 110 Uun [271] | unununium 111 Uuu [272] | ununbium 112 Uub [277] | | ununquadium 114 Uuq [289] | | | | |

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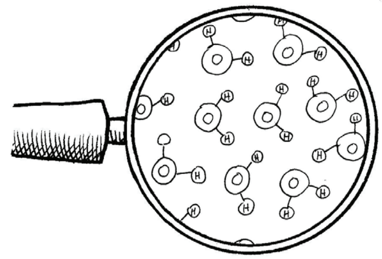
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lanthanide series | lanthanum 57 La 138.91 | cerium 58 Ce 140.12 | praseodymium 59 Pr 140.91 | neodymium 60 Nd 144.24 | promethium 61 Pm [145] | samarium 62 Sm 150.36 | europium 63 Eu 151.96 | gadolinium 64 Gd 157.25 | terbium 65 Tb 158.93 | dysprosium 66 Dy 162.50 | holmium 67 Ho 164.93 | erbium 68 Er 167.26 | thulium 69 Tm 168.93 | ytterbium 70 Yb 173.04 |
| **Actinide series | actinium 89 Ac [227] | thorium 90 Th 232.04 | protactinium 91 Pa 231.04 | uranium 92 U 238.03 | neptunium 93 Np [237] | plutonium 94 Pu [244] | americium 95 Am [243] | curium 96 Cm [247] | berkelium 97 Bk [247] | californium 98 Cf [251] | einsteinium 99 Es [252] | fermium 100 Fm [257] | mendelevium 101 Md [258] | nobelium 102 No [259] |

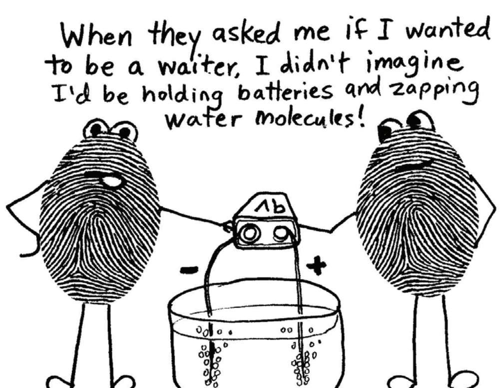


*In this view, the molecules are shown as little balls stuck together with sticks. The balls are atoms. O stands for "oxygen" and H stands for "hydrogen." The sticks represent the bond that keeps the atoms together (in this case. by sharing electrons).*

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.

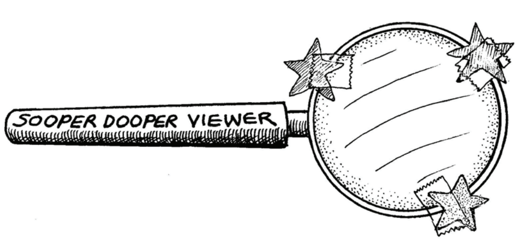
Just like an ***atom*** is a single particle of an ***element***, a ***molecule*** is a single unit of a ***compound***. ***A compound is a large amount of similar molecules, with each molecule being made of at least two different elements.*** Is water a compound? Yes, because all the molecules look 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!

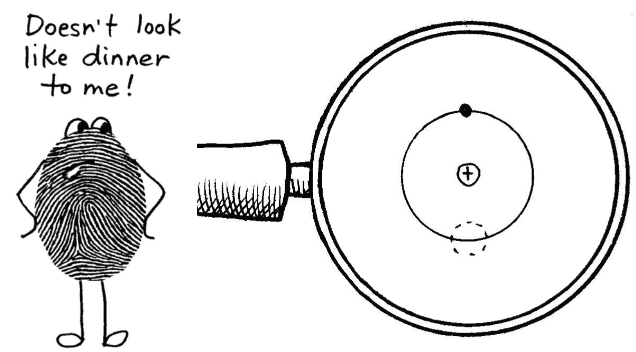



If we put electrodes from a battery into a glass of water and add a tiny pinch of salt or some other substance that conducts electricity, we will see bubbles forming on the electrodes. Bubbles of pure hydrogen gas will form on the negative electrode and bubbles of pure oxygen gas will form on the positive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

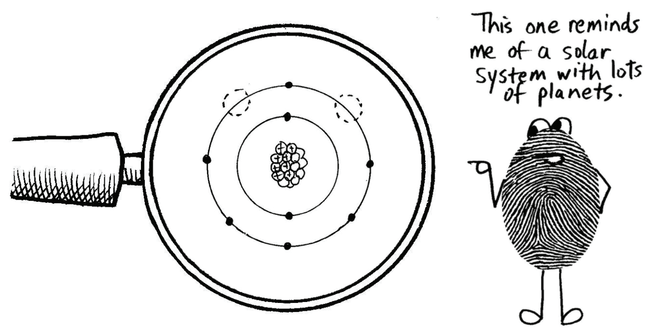



Here is a hydrogen atom. In reality, you can't actually see an atom. Atoms are just too small to see. Scientists figured out the structure of atoms using math and logic more than anything else. We draw diagrams like this one to represent atoms, but real atoms don't look like circles and dots. The dot 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.

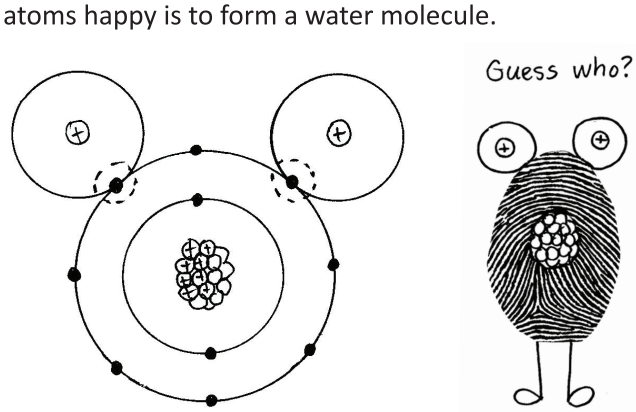
The dot represents an ***electron***. An electron is a particle with a ***negative*** charge. The circle around the proton represents an over-simplified "orbit" in which the electron travels. The electron actually whizzes around the proton in a three-dimensional way, being everywhere and nowhere all 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.

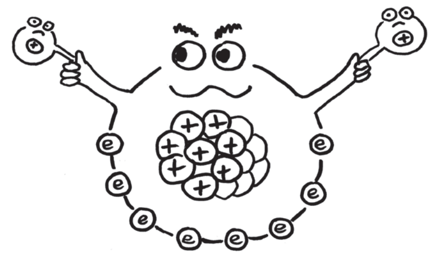


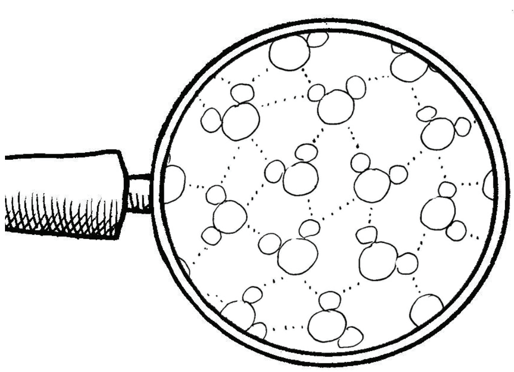

In this magnifier view, you see a representation of an oxygen atom. It's a bit more complicated than a hydrogen atom, but it's still similar. In the center, the oxygen has more than one proton; it has a whole clump of particles. There are 8 protons and also 8 ***neutrons***. Neutrons are electrically ***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.

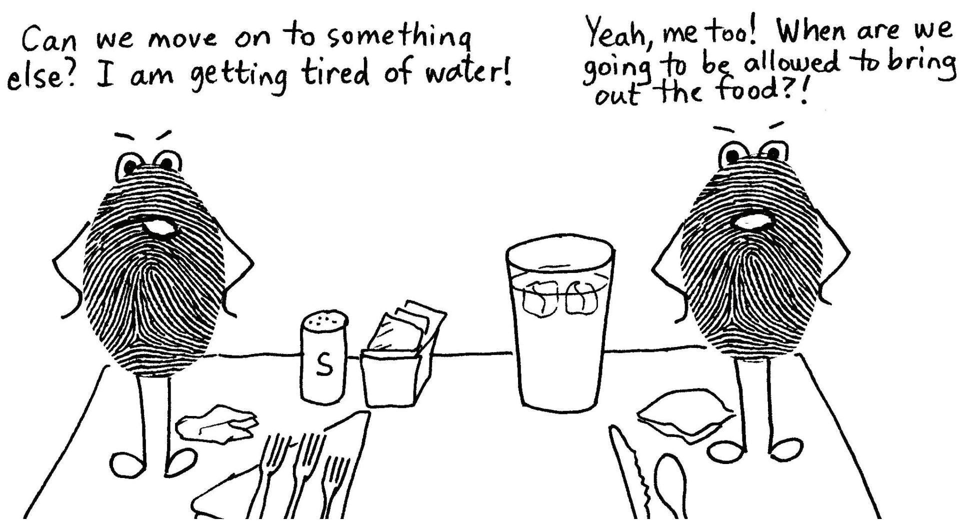
However, even though all three atoms are basically happy, this doesn't mean they are equal. The harsh reality for hydrogen is that it is puny in comparison to oxygen (or to any other atom, for that matter, since hydrogen is the smallest atom in the universe!). Hydrogen's one little proton is no match 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.





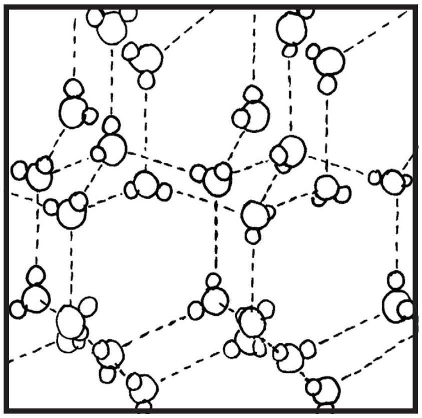
Being electrically lopsided, with a more positive side and a more negative side might seem like a bad thing, but actually it's a very good thing, and it's the reason you can take a bath or drink a glass of water. It's also the reason that plants can take up water through their roots. The negative side 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



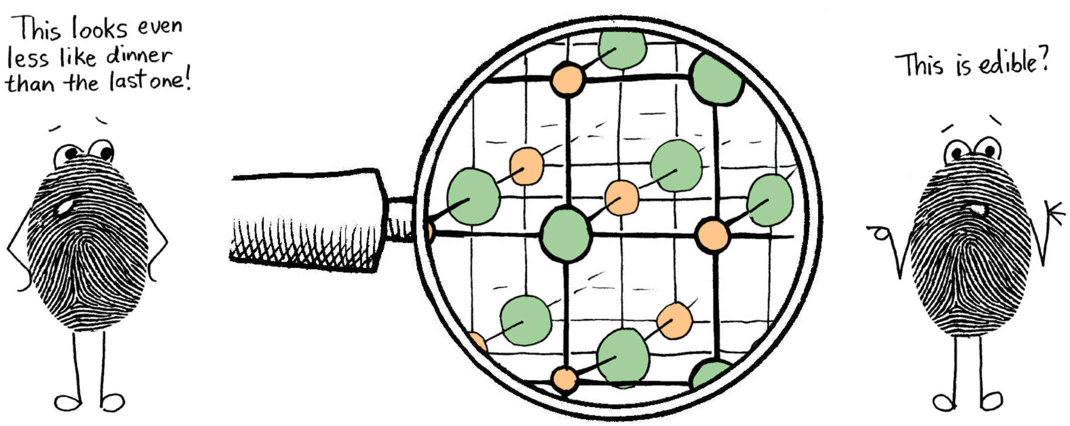
In this diagram, the dashed lines represent the electrical attraction (hydrogen bonds) holding the frozen water molecules together. These bonds (the lines) make a nice geometric pattern, and in the process they keep the water molecules farther apart than they would be if they were at room temperature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

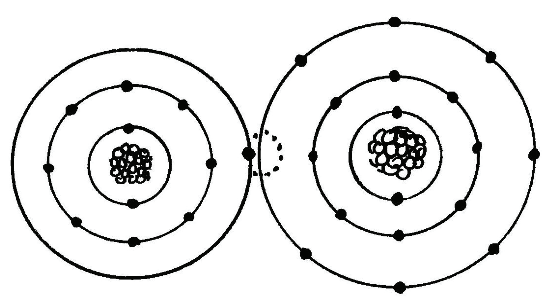
The scientific term for molecules being more or less tightly packed together is ***density***. Ice is less dense than liquid water because the molecules are more spread out, making fewer molecules per cubic measure. The densities of substances affect how they interact with other substances.

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.

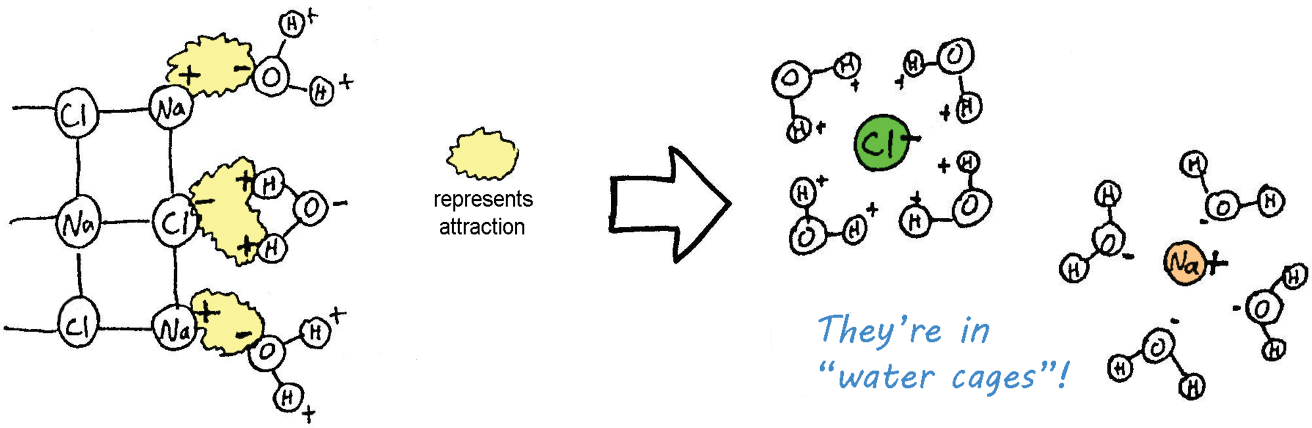


Sodium atom          Chlorine atom

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**.)



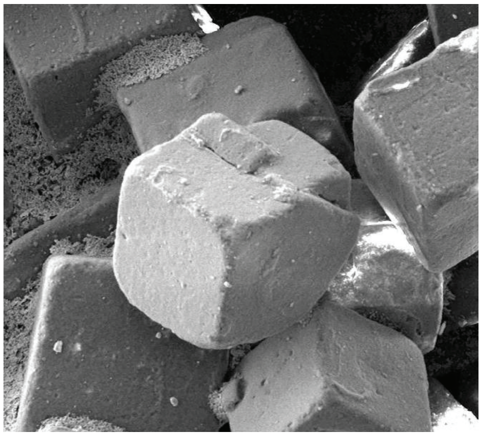

Look at the diagram on the right and notice how the water molecules surround the sodium and chlorine atoms. It almost looks like they have them imprisoned in little cages. The water molecules turn their positive sides inward to trap chlorine atoms, and they turn their negative sides inward to imprison 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!)

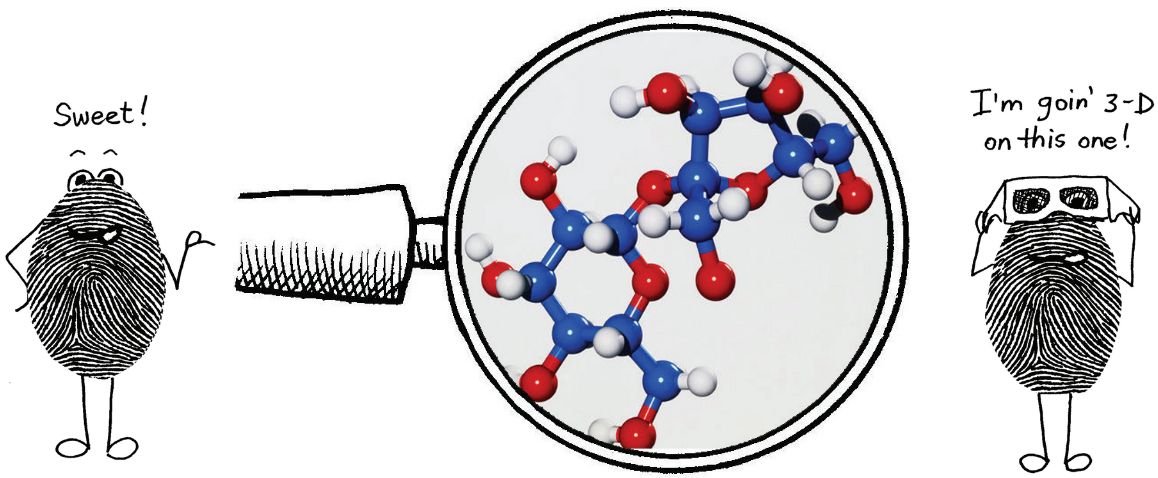
So what's left to dissect before the appetizers arrive? Let's open a packet of sugar. At first glance, it might look a lot like salt—little white crystals. But if we look at them under a magnifier (just an ordinary one this time, not our Sooper Dooper one) we can see a difference right away. The salt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

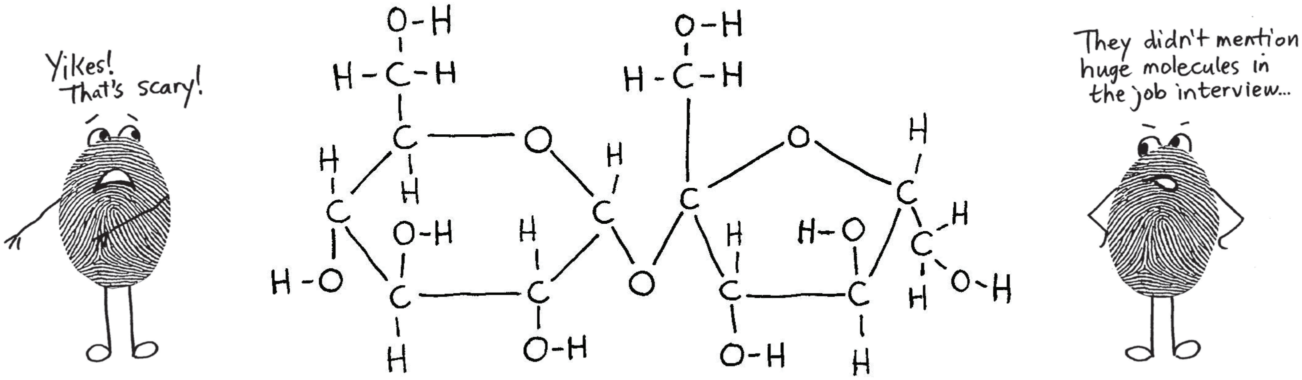
Now we'll switch to our amazing Sooper Dooper Magnifier and see what sugar molecules look like. But first, we'll toss the sugar crystals into our glass of water. Water has the same effect on sugar that it does on salt. (In fact, water has this effect in many substances. Water is sometimes called "the 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.

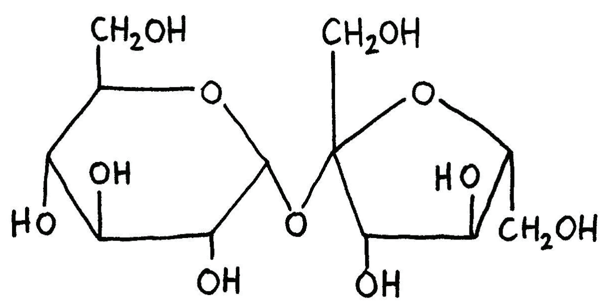
The picture in our magnifier shows the atoms as round balls. This kind of picture looks really nice, but you don't have a clue what those balls are, do you? For this reason, scientists have another way of representing molecules. They use letters, instead of circles or balls, to represent atoms. They 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:



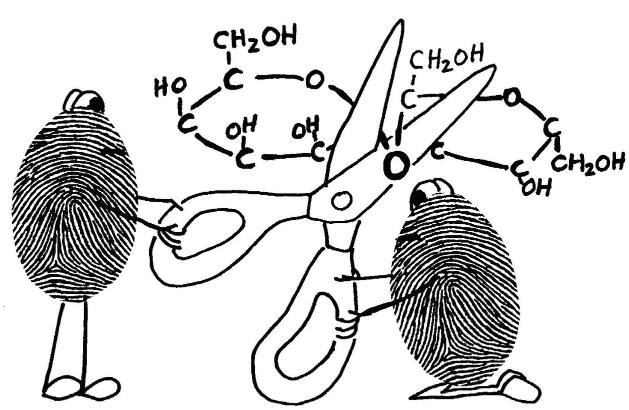

The biggest "plus" about this type of drawing is that you know exactly what type of atoms you are seeing. C is for carbon, O is for oxygen, and H is for hydrogen. These three elements are the main ingredients of most of what we eat. Another big "plus" is that it's much easier to draw or print a diagram 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.



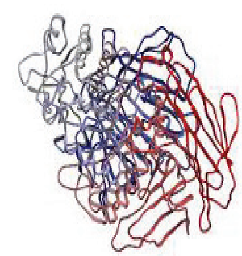
The correct name for this molecule is ***sucrose***. When we talk about putting "sugar" in a recipe, we are talking about "sucrose." In the world of science, the word "sugar" doesn't mean the stuff you bake with. "Sugar" is a more general word for a whole category of molecules that taste sweet. Sucrose 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.

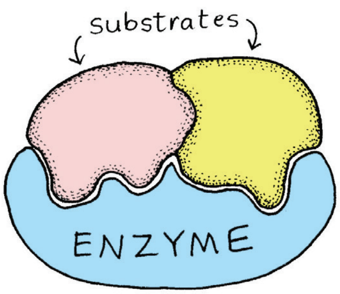


Wait a minute—SCISSORS?! Okay, okay, it works nicely in this picture and gets the point across. In real life, you need something called an ***enzyme*** to cut this molecule. An enzyme is a specialized protein molecule. Some enzymes act like scissors, but other enzymes act like staplers and fasten things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

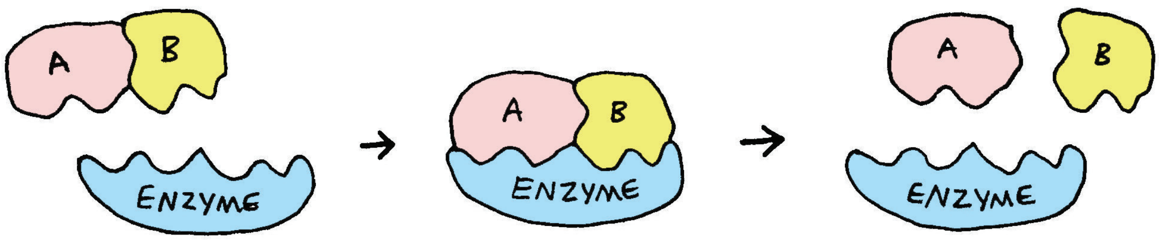


*sucrase*

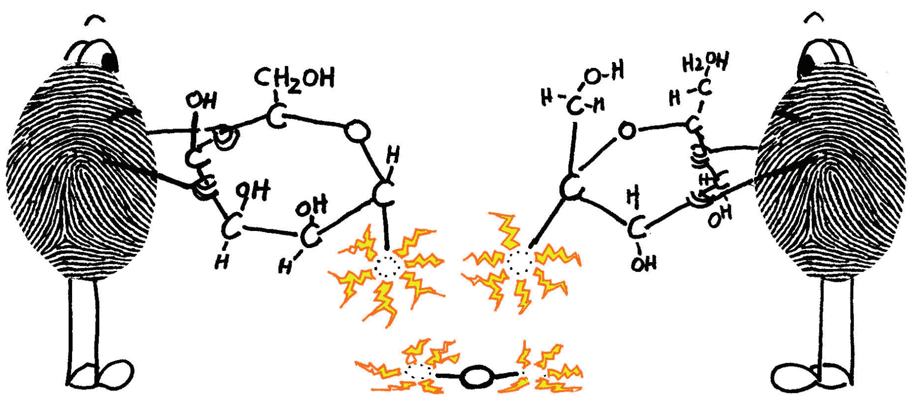



Here is the way enzymes are often look when you meet them in books. The artist makes the enzyme look like a large puzzle piece that attaches to two smaller puzzle pieces. The large piece is the enzyme and the smaller pieces are the things that the enzyme is putting together or taking apart. There's a 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.



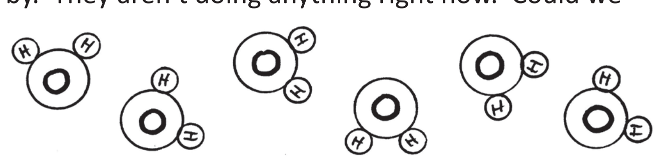

An enzyme is able to disassemble hundreds or thousands, or perhaps even millions, of substrates in its lifetime. You have sucrase enzymes in your intestines that work day and night to tear apart all the sucrose molecules you eat. Your digestive system contains many different kinds of enzymes, each one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

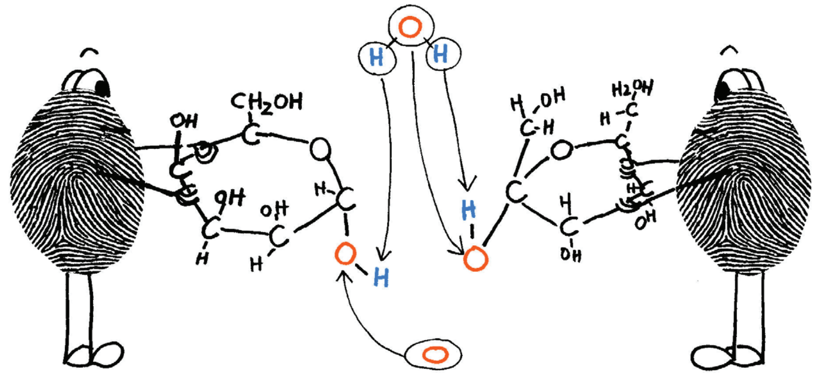
Here's what happening. Those sticks represent bonds between the atoms, right? But do you remember what a bond is? We looked at how hydrogens stick to an oxygen to make a water molecule. The "bond" was actually a place where the atoms shared an electron. It's the same with this molecule. That oxygen (O) 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?



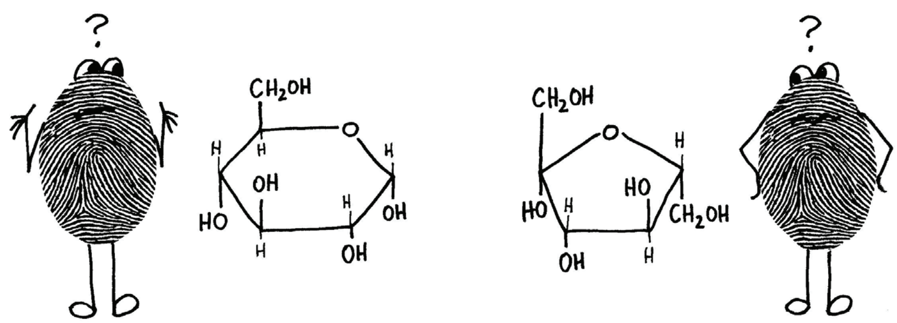
(Have you forgotten the word "substrate" yet?)

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.

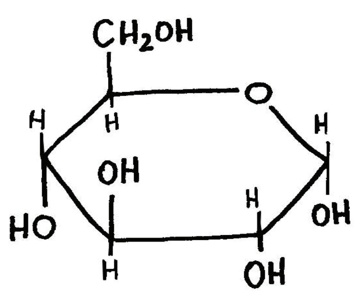


Let's try the same thing on the other side. Let's take the oxygen from water and put it onto the carbon. Then we'll patch the oxygen with the remaining hydrogen.

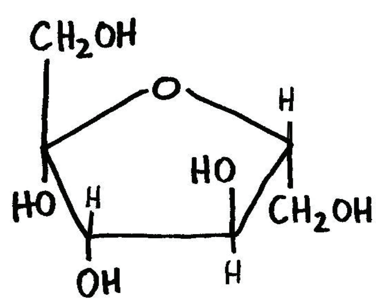
It looks like we've done it! We've separated the two rings and patched up all the bonds so that all the atoms are happy. What have we made? What are these rings?



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?

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## 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<br><br>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<br><br>2) Which do you think uses less water, a bath or a shower? |
| CHAPTER 1: WATER, SALT, SUGAR<br><br>3) 90% of the world's fresh water is located on which continent? | CHAPTER 1: WATER, SALT, SUGAR<br><br>4) What % of your body weight is water?<br><br>a) 1% b) 10% c) 60% d) 90% |
| CHAPTER 1: WATER, SALT, SUGAR<br><br>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)<br>a) 4 gallons b) 40 gallons<br>c) 400 gallons d) 4,000 gallons | CHAPTER 1: WATER, SALT, SUGAR<br><br>6) Can you guess which of these countries is NOT one of the top five producers of salt?<br><br>USA, Russia, China, India, Germany, Canada |
| CHAPTER 1: WATER, SALT, SUGAR<br><br>7) Can you guess which one of these foods doesn't rely on salt as a key ingredient?<br><br>cheese, yogurt, ketchup, mustard, soy sauce, olives, pickles | CHAPTER 1: WATER, SALT, SUGAR<br><br>8) Salt is often found underground in formations called salt domes. What other substance is usually found around or under the salt dome?<br><br>a) oil b) water c) iron d) magma |
| CHAPTER 1: WATER, SALT, SUGAR<br><br>9) Which type of outdoor water do you like best?<br>Ocean, lake, river, stream, puddles | CHAPTER 1: WATER, SALT, SUGAR<br><br>10) If you were required to give up either sugar or salt for one month, which would you choose? |
| CHAPTER 1: WATER, SALT, SUGAR<br><br>11) What is your favorite sweet food? | CHAPTER 1: WATER, SALT, SUGAR<br><br>12) What is your favorite salty food? |

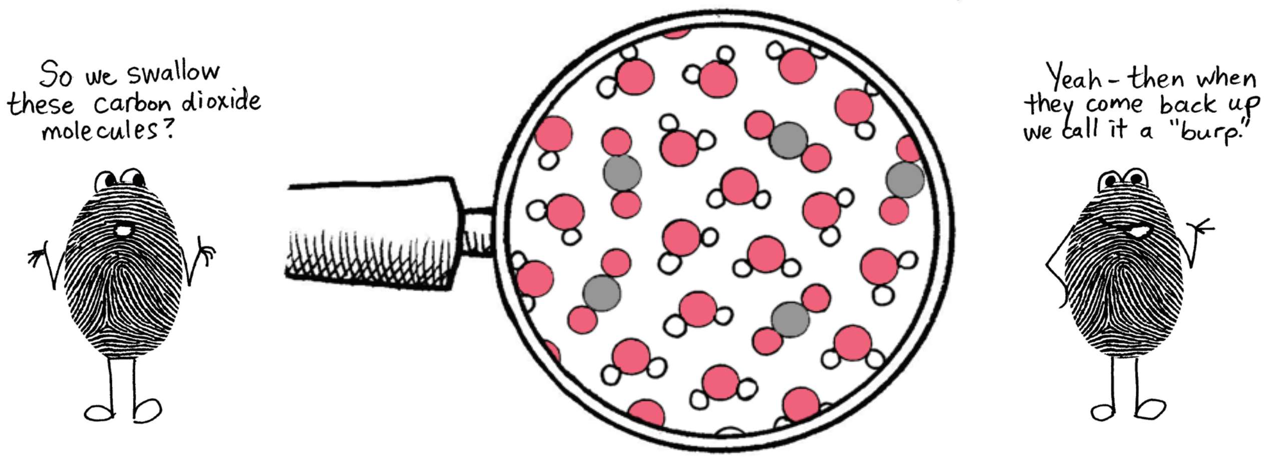
1) Probably not. Water is the only common substance found in all three states.
2) On average, a shower requires half as much water as a bath. 3) Antarctica
4) About 60% of your weight is water. On average, males have 60-65%, females 50-55%.
5) 4,000 gallons of water per day! 6) Russia
7) yogurt 8) oil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

# 2: Your Beverages Arrive

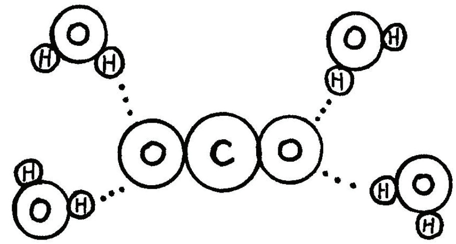
The waiters have brought your beverages. They have provided milk and a carbonated drink. You may have a special name for carbonated beverages, such as "soda," or "pop" or "coke." You can imagine this to be whatever kind you like. (If you don't drink carbonated beverages in real life, just play along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

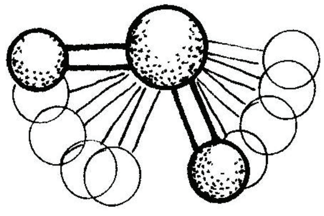
Carbon dioxide ($CO_2$) molecules can be dissolved into water the same way that sugar or salt can. $CO_2$ is the ***solute*** and water is the ***solvent***. Here's an interesting question: can you mix and match states of matter (solid, liquid, gas) to form solutions? For example, could you dissolve 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)

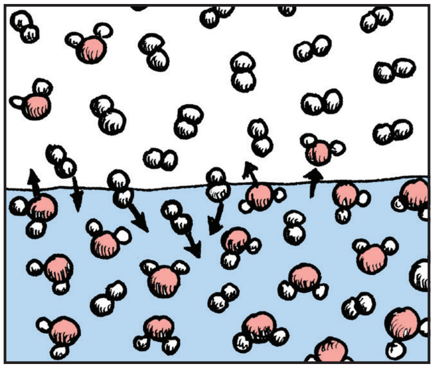
A **solid** dissolved into a **gas**: Smoke
A **solid** dissolved into a l**iquid**: Sugar water; salt water
A **solid** dissolved into a **solid**: Bronze (copper and tin); steel (carbon and iron)


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*

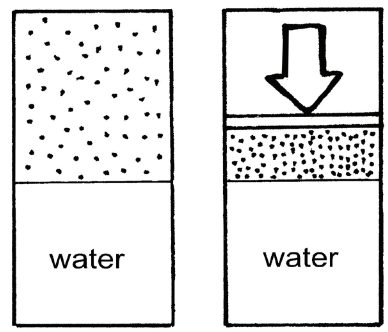
*Many molecules bumping and crashing*



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?

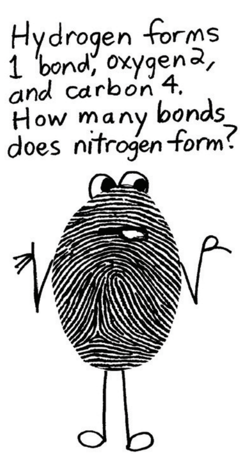


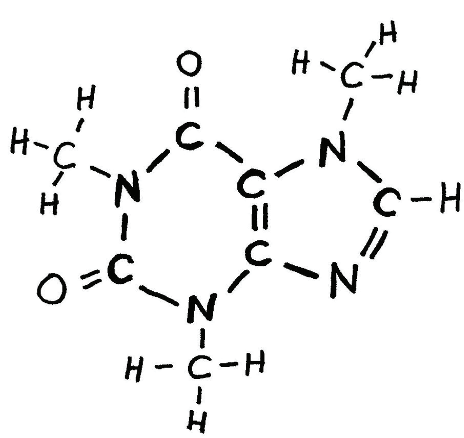

The last thing you can do to get more gas molecules into the water is to turn down the temperature. Cold water can hold more gas than hot water can. Why? Because heat is the same thing as molecular motion. The faster the molecules move, the more heat they have. The less they move, the less heat they 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.

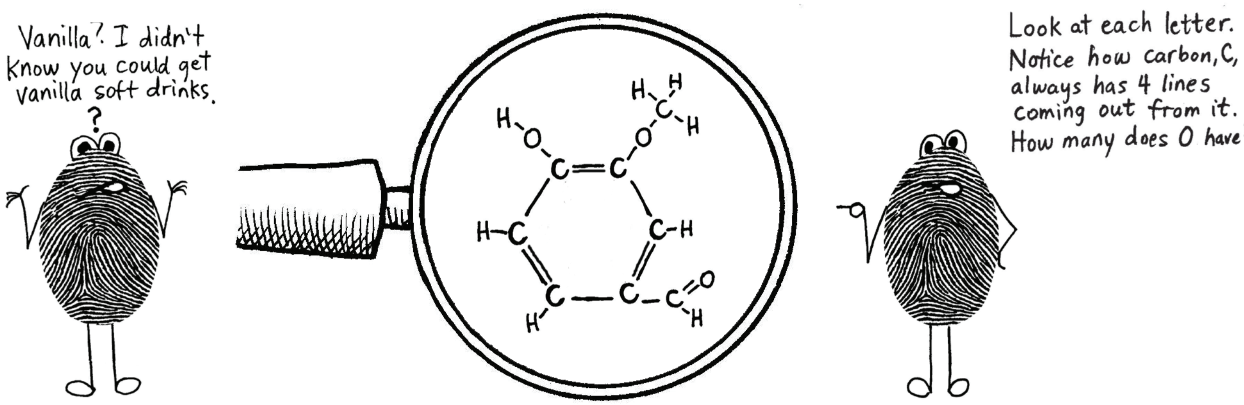


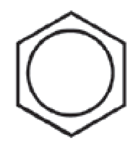
Caffeine has two rings: one pentagon and one hexagon. They might remind you of fructose and glucose. A big difference is that those rings include ***nitrogen*** atoms (N). Nitrogen molecules (as $N_2$) make up about 80% of the air we breathe. So what are they doing in a caffeine molecule? Just like carbon 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.

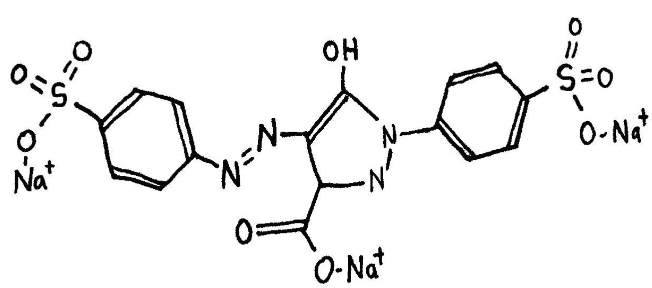


*Benzene rings are sometimes drawn like this. Chemists know there are carbons at the corners and 6 invisible hydrogens.*


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**.

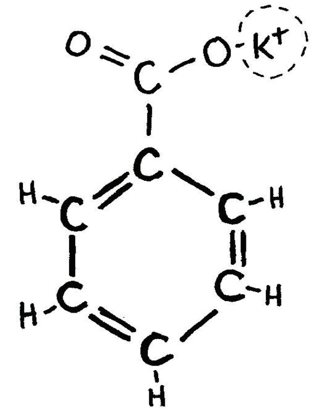
Your carbonated beverage might also have food coloring in it. Most consumers think clear liquids are boring. They are more likely to drink something bright orange or red or yellow. Most food coloring found in carbonated beverages is artificial, meaning scientists made the molecules in a lab. This doesn't 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.

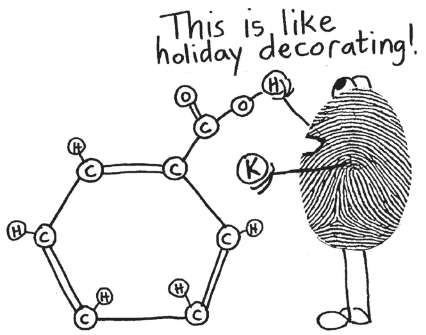


*This is "Yellow #5." Other options you can legally use are Yellow #6, Reds #3 and #40, Blues #1 and #2, and Green #3. That's it. Want orange? Mix yellow with one of the reds. Purple? Mix a blue and a red. Black? Use a lot of blue with some added red, yellow and green.*

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!



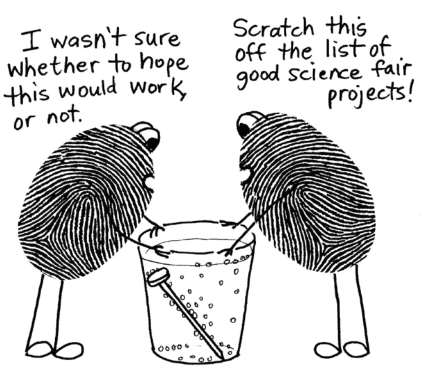

Benzoic acid doesn't affect humans the way it affects microorganisms, but there is a small potential danger to humans. If benzoic acid comes into contact with vitamin C, the vitamin C molecule strips off those extra atoms at the top (C, O and O), and thus turns benzoic acid into a benzene ring. However, 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.



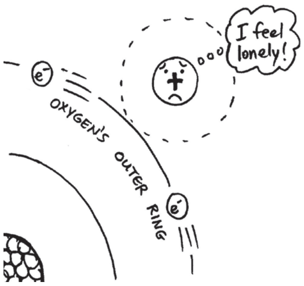

Phosphoric acid in carbonated beverages is just as controversial as potassium benzoate (or its "sister" molecule, sodium benzoate). Some people love to quote the fact that phosphoric acid can be used to remove rust from metal. One Internet rumor says that cola drinks will dissolve a nail in 4 days. That'll 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.

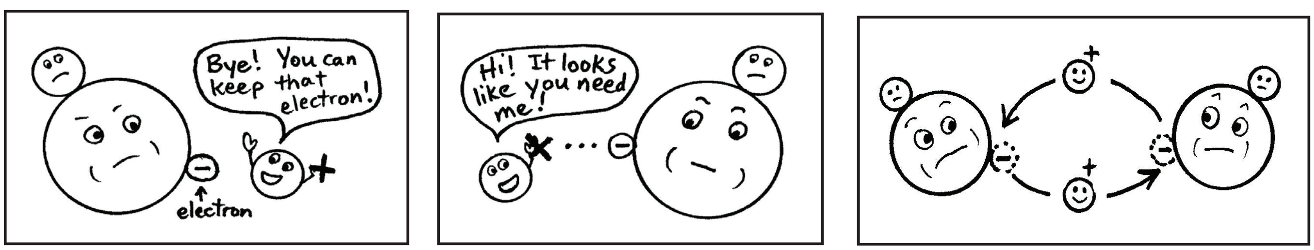
Now it's time to find out exactly what an acid is. To do this, we'll start by looking at water again.

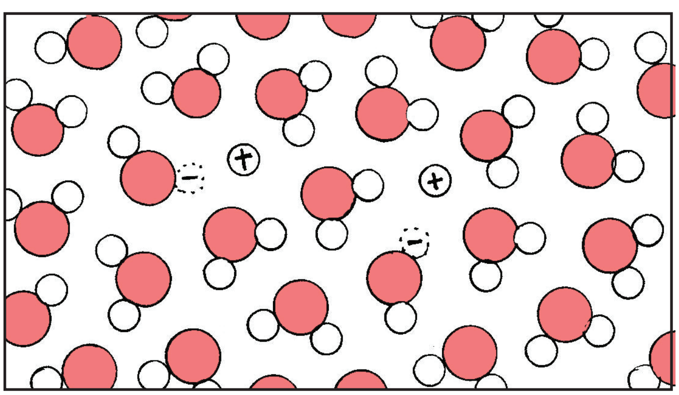
You'll remember that water molecules are made of two hydrogen atoms attached to an oxygen atom. Well, it turns out that those hydrogen atoms are not very faithful to their water molecules. They sometimes go wandering off, leaving $H_2O$ as $OH^-$.




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.

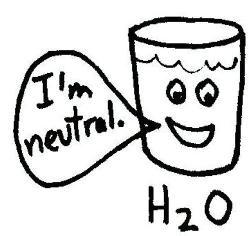


Imagine those hydrogen ions zooming around, pointlessly trading places with each other, when—SNAP! We take a picture. We have a split second of time frozen in a "photograph." Most of the water molecules are intact. But we've caught a few hydrogens mid-switch.

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?

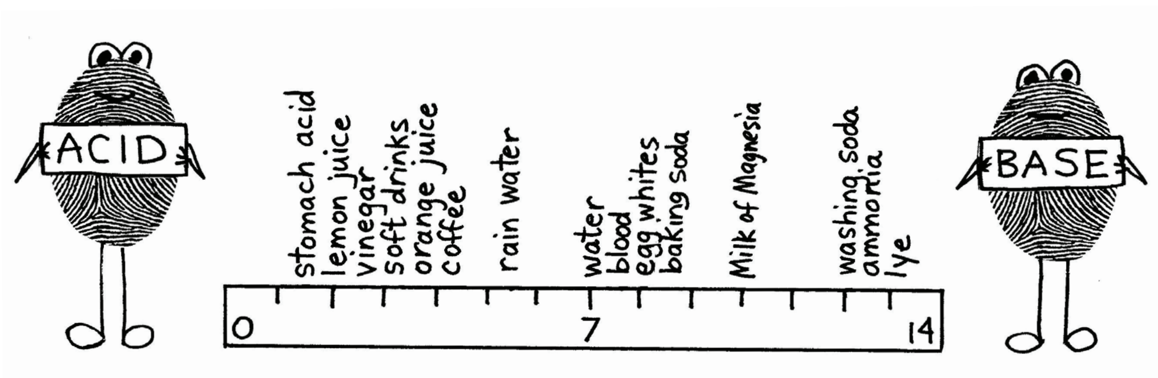
There are certain substances that release $H^+$ ions (protons) when they are dissolved in water. For example, if you put hydrochloric acid, HCl, into water, the ions $H^+$ and $Cl^-$ would separate. The $Cl^-$s would quickly be surrounded by water molecules, as we saw in the salt water. The $H^+$s would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

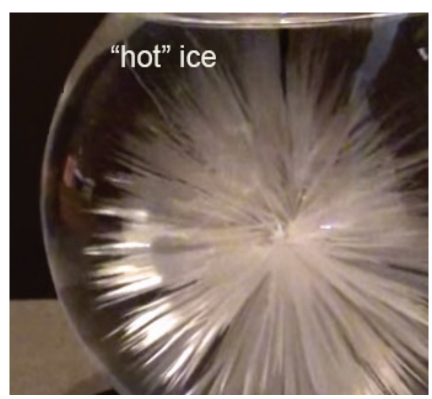
An increase in either the number of hydrogen ($H^+$) ions or hydroxide ($OH^-$) ions in a solution affects the chemistry of the solution, so this imbalance is important for chemists to measure. They use a scale called the ***pH scale***. The letters ***pH*** are most often interpreted as being an abbreviation 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.

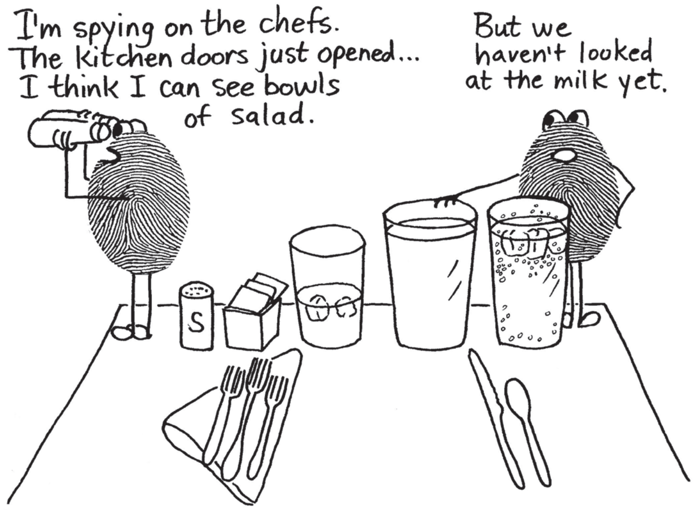



Here's a thought: If acidic substances have lots of hydrogen ions ($H^+$) and alkaline substances (bases) have lots of hydroxide ions ($OH^-$), what would happen if you mixed them together? Would all the hydrogen ions decide to attach to hydroxide ions? Yes, that's exactly what happens! And what do a 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***."

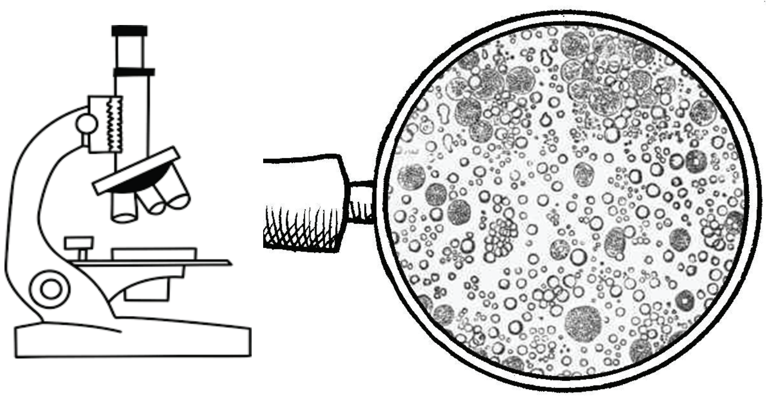



Many of us have mixed vinegar (an acid) with baking soda (a base) and witnessed the intense bubbling effect (carbon dioxide being given off). But most of us have never thought about the other product that is produced, a "salt" called ***sodium acetate***. You don't normally see this salt because it stays 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.



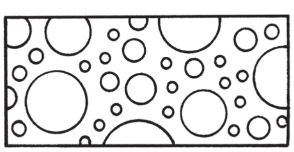

Let's take a look at your glass of milk before your salad arrives. We'll set our viewer's magnification on "regular microscope." If you could look at milk through a microscope in a biology lab, this is what you would see.



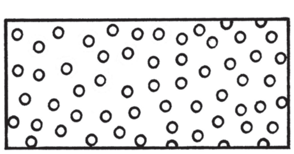
Those little round balls are blobs of fat. They're really small, about the size of a bacteria. And speaking of bacteria, if your milk had not been ***pasteurized*** (heated) at the dairy it came from, you would have seen bacteria floating amidst the fat blobs. Dairies that sell milk to the general public 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*



NOT HOMOGENIZED

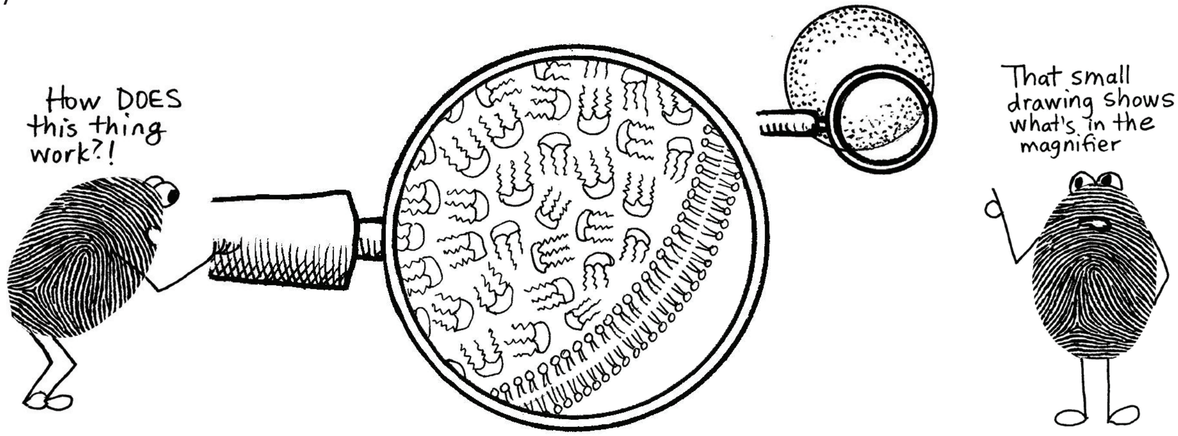


HOMOGENIZED

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.

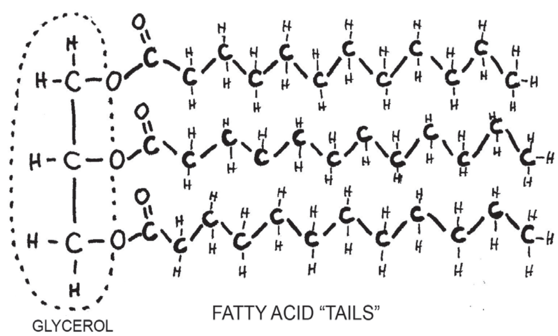
Another process can take some of the fat out of the milk, creating low-fat varieties of milk, such as 2%, 1%, or skim (no fat) milk. Some dairy scientists claim that "raw" (unprocessed) milk is better for your health, but others say store milk is just fine. If milk is not pasteurized, the dairy has to 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.

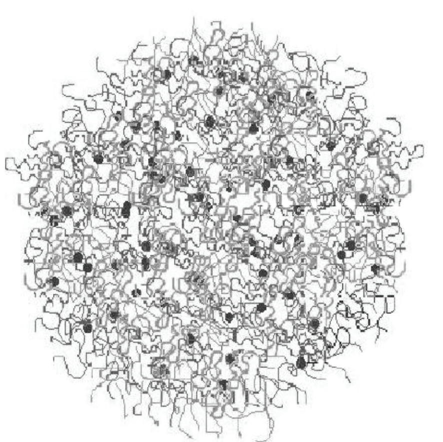
Let’s zoom in on one fat molecule. This type of fat molecule is called a ***triglyceride*** *(tri-GLISS-er-ide)*. The prefix “tri” means “three.” The ending “glyceride” refers to that 3-carbon structure inside the dotted line, ***glycerol*** *(GLISS-er-ol)*. Glycerol is like a handle that holds on to 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.




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.

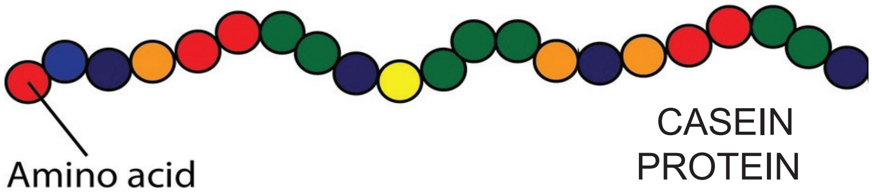
Let’s zoom in closer on the "spaghetti noodles."



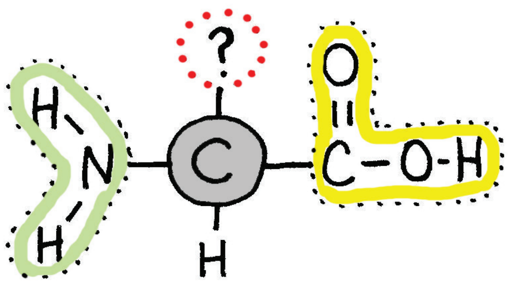
*Little clumps are called **micelles**. This word is used for other types of clumps, too.*

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.

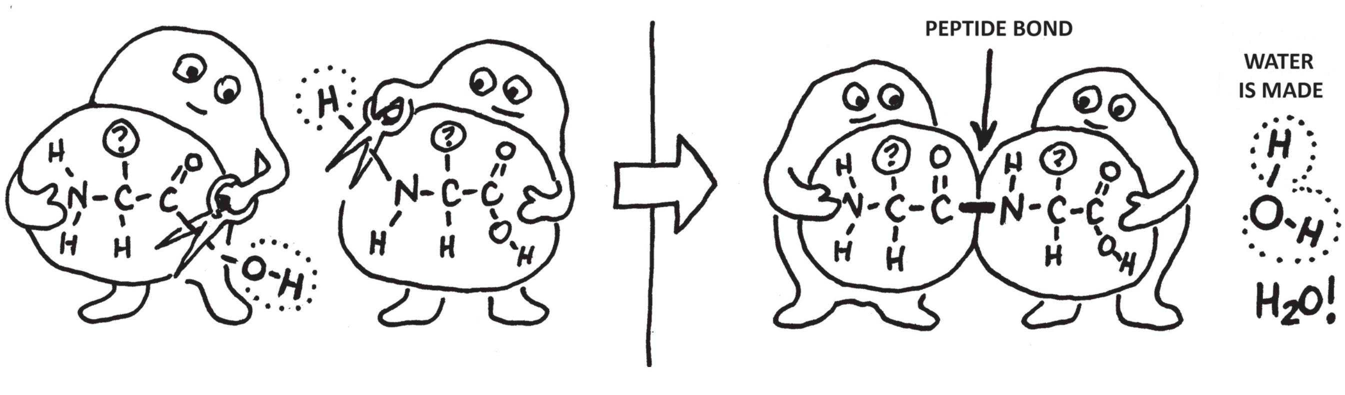


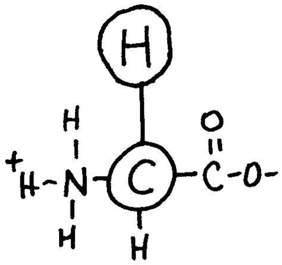
Let's use the highest power on our zoom lens and take a look at one amino acid. Since the word "acid" is in its name, we should expect to find at least one hydrogen, H, that will be able to leave the molecule in the form of a proton.

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.

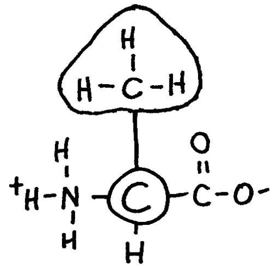
The alpha carbon's left arm is attached to a COOH. Notice the H on the end. It is sitting next to an electron-hogging oxygen atom. The oxygen atom has a strong pull on the hydrogen's only electron. From the hydrogen's point of view, its electron spends far too much time going around the oxygen atom, 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 on side and an H off another, producing an $H_2O$.

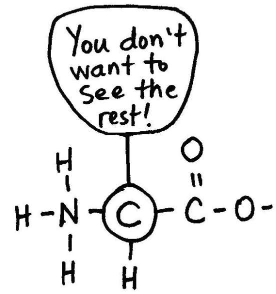




*glycine*



*alanine*

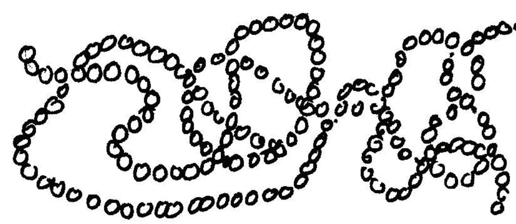




Now just a little bit of info about that "wild card" (?) at the top...

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.")

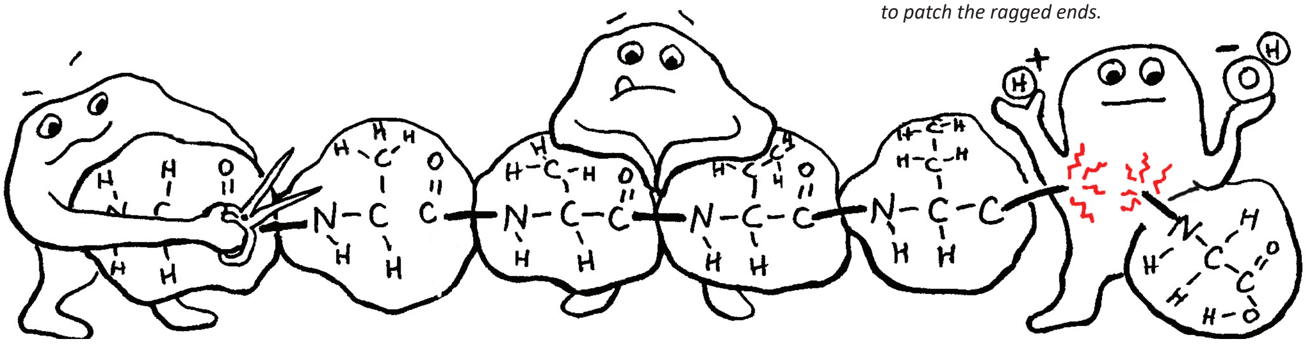


*If we made a model of casein protein using colored beads, we'd have to use 18 different colors!*

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 separater certain kinds of amino acids. Enzymes are highly specialized. As a general rule, enzymes are designed to do only one job.

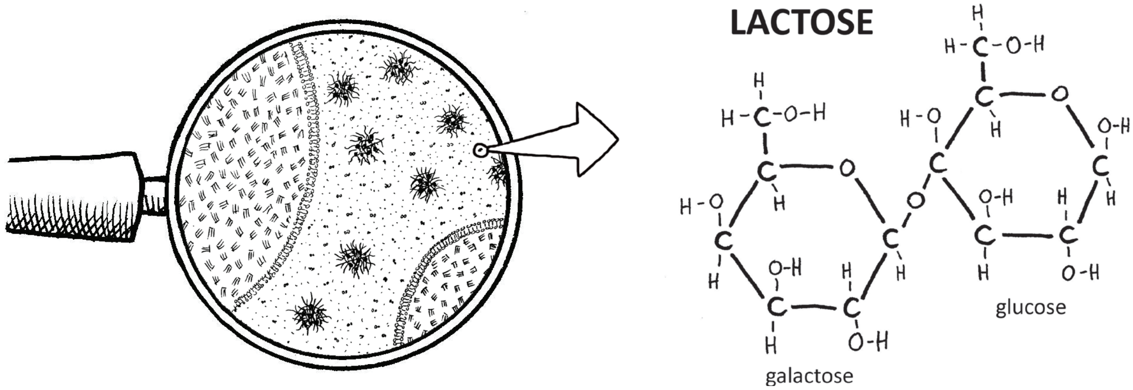
When peptidases break apart amino acids, they use water molecules to patch the unhappy broken bonds they leave behind, just like we saw in the case of sucrose being broken apart. A water molecule can be split into $H^+$ and $OH^-$, and each of these parts can be used as a "band aid" on one side of the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

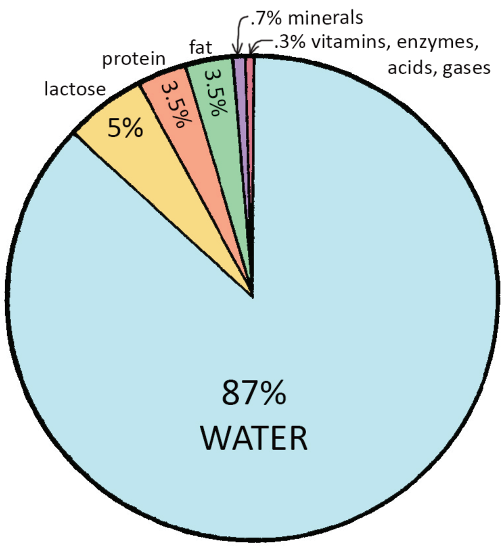
To tear apart the double-ring lactose molecule you need (no surprise) a special enzyme that can snip the bond between glucose and galactose. That enzyme is called ***lactase***. Babies of all mammals produce lactase in their digestive systems to that they can digest their mother's milk. In the vast majority 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 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 ___(16) ___ ___ ___ ___(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 ___ ___ ___ ___ ___ ___ ___.
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<br><br>1) The average cow can produce about how many glasses of milk each day? | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>2) In the U.S., which month is National Dairy month? |
| CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>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?<br>a) Black Garlic b) Onion<br>c) White Fungus d) Mustard | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>4) Until 1950, this carbonated drink contained lithium citrate, which is today used as a brain medicine:<br>a) Coke b) Pepsi c) 7-Up d) Dr Pepper |
| CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>5) About how many teaspoons of sugar are in a can of soda (pop/coke)? | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>6) Which of these frozen desserts does not contain milk?<br>a) sherbet (sherbert) b) sorbet<br>c) spumoni d) gelato |
| CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>7) The name of the orange-flavored soft drink "Fanta" is a German word for what?<br>a) imagination b) happiness<br>c) intelligence d) courage | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>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?<br>a) mice b) rats c) pigs d) rabbits |
| CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>9) Have you ever tasted goat milk or goat cheese? Would you recommend it? | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>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<br><br>11) What is your favorite carbonated beverage? | CHAPTER 2: CARBONATED BEVERAGES and MILK<br><br>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 |