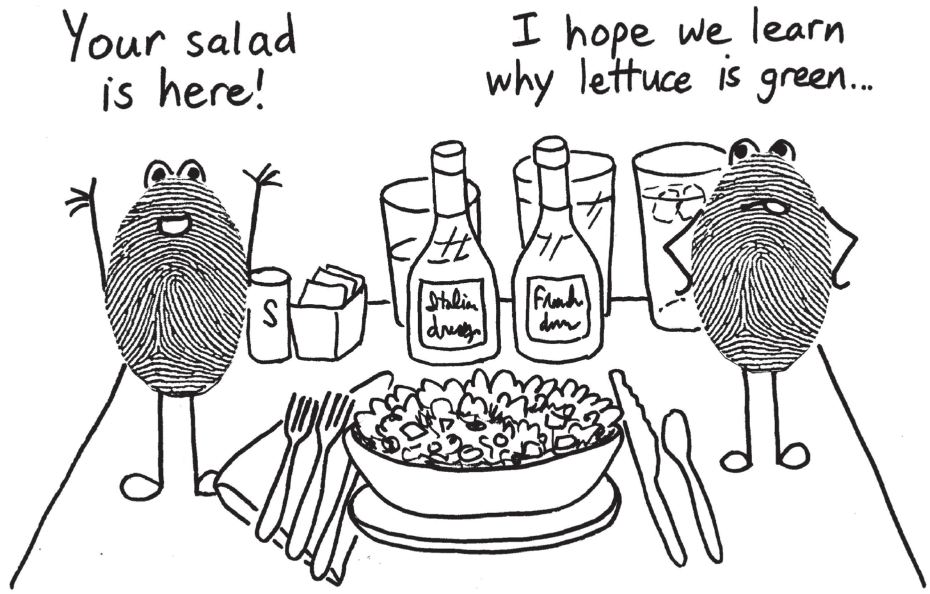
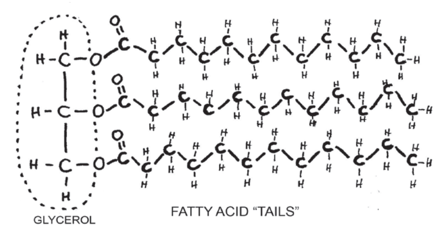
4: Salad

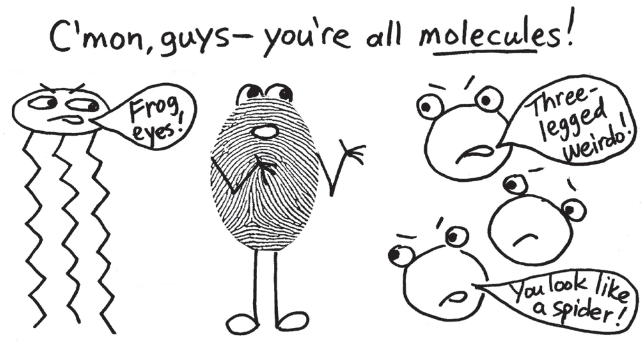


Wow! Where do we begin? You might be about to reach for one of those bottles of salad dressing. How about if we start with those? It looks like we have an Italian style dressing and a French dressing. They look very different (the Italian is fairly clear, the French is orange and opaque) but their basic chemistry is similar.

All salad dressings are a type of solution called an ***emulsion***. An emulsion is made of a polar liquid and a non-polar liquid held together by an ***emulsifier.*** Good thing we already know what a polar molecule is! In chapter one we learned why water is a polar: the electrons are shared unevenly. The poor hydrogens hardly ever get to see their electron because oxygen is such a bully. There are many other polar molecules, beside water. A simple way to test for polarity is to see if the substance will dissolve in water. If it does, it's polar. There are so many substances that dissolve in water, that water is often called "the universal solvent."

Non-polar substances won't mix with water. You can probably name some: cooking oil, the fat found in meat, butter, shortening, petroleum jelly, motor oil, etc. Anything greasy or oily is non-polar. At the molecular level, a non-polar substance usually contains strings of carbon atoms, like we saw on our triglycerides. The carbon and hydrogen atoms in a fat molecule are not at all interested in interacting with water molecules. In fact, we call them "hydrophobic." The word "hydro" is Greek for "water," and "phobic" is Greek for "fear or hate." Sometimes we say that non-polar substances "hate water." Molecules have no feelings, of course, so they can't love or hate anything, but it does make the chemistry more memorable.



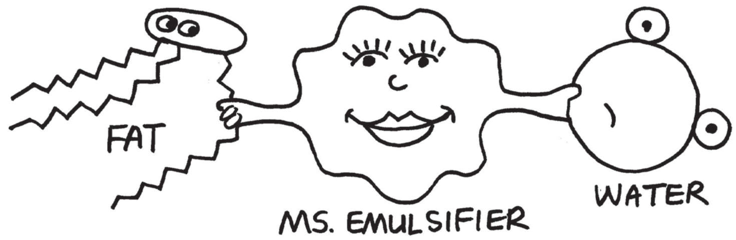


HYDROPHOBIC FAT

WATER MOLECULES

A salad dressing is an almost equal amount of a non-polar substance (like olive oil) mixed with a polar substance (like vinegar, lemon juice or water). How will this work? We are mixing two substances that "hate" each other. If you've never done this, try it at home. Mix some oil and water or vinegar, shake the bottle, then see what happens. The oil will float to the top and stay there, and the water or vinegar will happily rest on the bottom. They will stay like this until you shake the bottle again. Though salad dressings do need to be shaken, they stay mixed a little better than this. So, what's the secret ingredient?

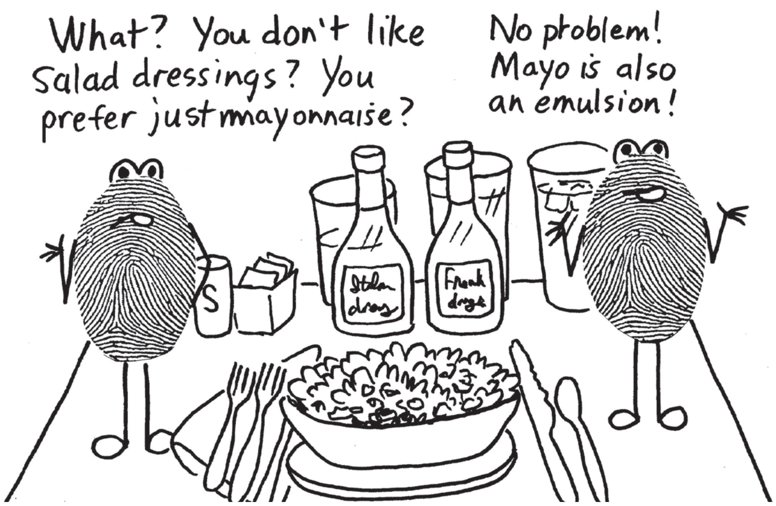
The secret ingredient is an ***emulsifier***. Common emulsifiers found in dressings are egg yolks, mayonnaise, mustard, and honey. These substances just happen to have the right chemistry.



Emulsifier molecules have a part that is polar and a part that is non-polar. This means they can interact with both water and oils (polar and non-polar). When enough emulsifier is mixed into the dressing, the oil and water don't separate nearly as much. Or at least not for a while. If you've ever gotten an old bottle of dressing out of the fridge, one that has been sitting for months, you may have noticed that the ingredients have settled out into layers.

The last essential ingredient in a dressing is something (or several things) to give it a particular flavor. Our Italian dressing probably has bits of dried herbs such as oregano, basil, thyme or rosemary, and garlic. Many dressings also have salt, pepper or sugar. Dressings that are thick and white may also use cream or sour cream.

With these four ingredients (oil, water or vinegar, an emulsifier, and spices) you can make your own dressing. The dressings you buy at the store often have preservative chemicals added, too, so that they won't go bad if they have to sit on the store shelf for many weeks or months. If you read the list of ingredients you can find out exactly what preservatives they've used, but you might be a bit disappointed to find that they don't list all the herbs and spices. It might just say "spices." They are allowed to keep some parts of their recipe a secret.

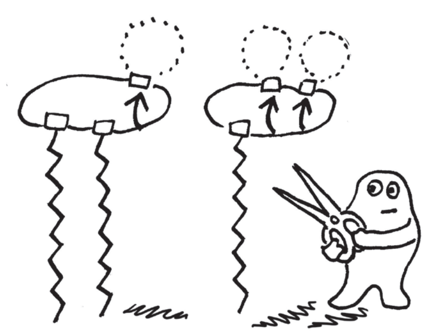


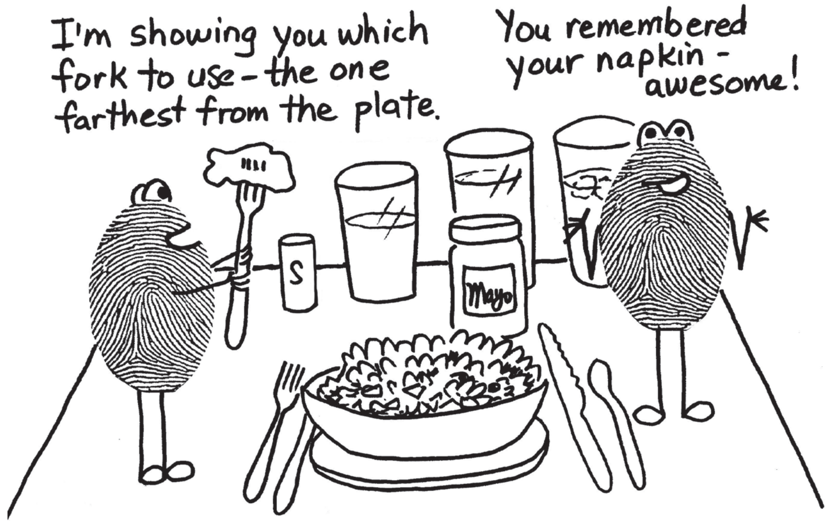
Sure, no problem. Mayonnaise is probably the most well known and widely used emulsion in many parts of the world. Emulsions don't have to be liquid like salad dressings; they can be soft solids like your mayonnaise. You can make your own mayonnaise from scratch using any type of vegetable oil, eggs, lemon juice or vinegar, and mustard as your emulsifier.

Of course, not everyone can eat eggs and mustard. Food scientists have discovered substitute emulsifiers that almost everyone can eat. For example, here is a widely used emulsifier that has a name that might look scary when you read it on a label: "Monoglycerides and diglycerides." Are they dangerous?

Jog your memory a bit and you will hopefully remember seeing a similar word: triglyceride. That's our jellyfish-looking fat molecule (shown as a funny cartoon at the top of this page). "Di" means "two," and "mono" means "one." If you chop one leg off a triglyceride, you get a diglyceride. Chop off another leg and you get a monoglyceride. The place where the leg came off can grab on to something else, often a polar molecule. The membranes around all your cells (and the membranes around the fat globules in milk) are made of diglycerides that are holding onto a polar phosphate molecule.

Monoglycerides and diglycerides are used in many food products including ice cream, chewing gum, bakery products, whipped toppings, and nut butters. They are particularly helpful in industrial bread baking, as they improve the volume and texture of the loaves.


Enzymes make monoglycerides and diglycerides



We are going to take a short break from chemistry and do some botany (the study of plants). Salad usually contains a number of plant parts: leaves, stems, roots, buds, fruits and seeds. You can probably name most of the parts in your salad. Lettuce and spinach are leaves, celery is a stem, carrot is a root, and broccoli crowns are buds. However, you might not identify the fruits: peppers, cucumbers and tomatoes. Scientists and chefs have different definitions of the words "fruit" and "vegetable."

To a scientist, anything with seeds is a fruit. Peppers, cucumbers and tomatoes all contain seeds, so a botanist would say they are fruits. The scientific definition for vegetable is the "vegetative" parts of a plant, meaning those parts that are not involved in reproduction—leaves, stems, and roots.

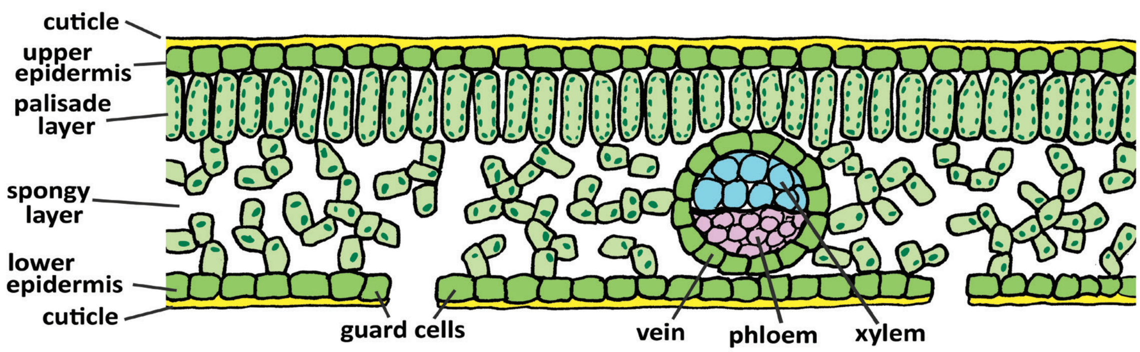
To a chef, the word "fruit" is restricted to the scientific fruits that are also sweet, and "vegetables" are non-fruits, no matter what part of the plant they come from. A chef's vegetables include roots, leaves, stems, fruits, and seeds. (Peas and corn are seeds.)

lettuce seed

We prefer to eat plants at various stages of their life and can easily forget that they all have the same structures. For example, we think of lettuce only in its leaf form, but lettuce plants produce flowers, fruits and seeds. In fact, hundreds of years ago, lettuce was used for its seeds, not its leaves; oil was pressed out of the seeds. It was only later that people decided to start eating the leaves. We are very used to seeing heads of broccoli with all those tiny green buds, but if you have ever grown broccoli in your garden, you will probably have seen some heads that were not picked early enough and started to bloom with tiny yellow flowers. Bean sprouts are tiny plants that we eat whole—stems, roots and leaves. In some cases, there is a good reason why we eat only one part of a plant. Tomato and potato stems and leaves are mildly toxic.

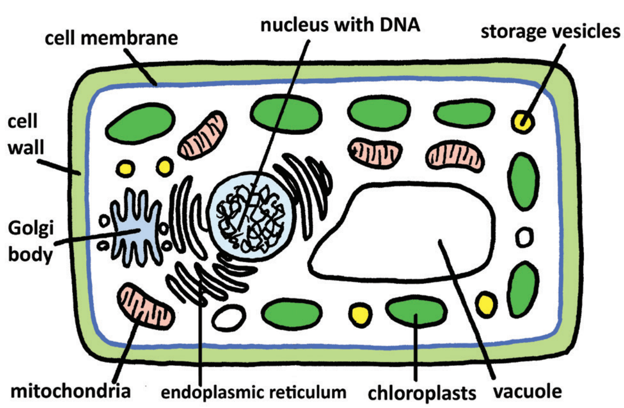
What do your lettuce and spinach leaves look like under the microscope? It depends on how we look at them. If we look straight down on a leaf, we will see a flat, green surface made of many long rectangles. The rectangles are the plant cells. If we look at the underside of a leaf, we will see the same rectangles, but we will also see tiny holes called ***stomata***. The holes are made of two ***guard cells*** that can open and close the hole, controlling the flow of air in and out of the leaf. They often close during the day when it is hot and dry, and open at night when it is cooler.

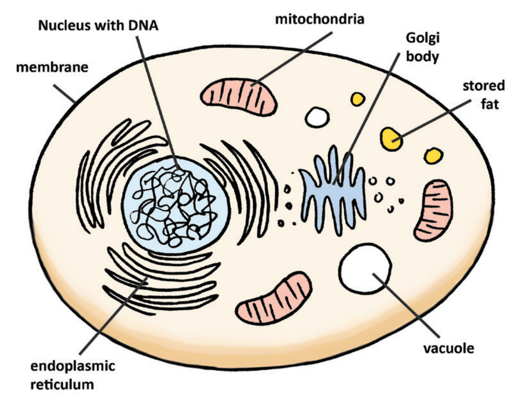
If we cut the leaf and look at the thin side we just cut, we will be able to see the leaf's internal structure. There are different types of cells on the top, middle and bottom.



The yellow cuticle *(kew-tick-uhl)* layers are made of a waxy, waterproof substance. They keep the leaf from drying out or getting too wet. The upper and lower epidermis layers form the large flat surfaces of the leaves. The palisade layer is the primary site for photosynthesis. Those tiny green dots are chloroplasts. It is inside the chloroplasts that sunlight, carbon dioxide and water and turned into glucose sugar molecules. The spongy layer has lots of air space. (The cells are not really floating—cross sections just look strange because we don't see those cells in a 3-dimensional context.) The spongy cells have a few chloroplasts, but not as many as the cells in the palisade layer. The circle is a vein that has been cut. The inside of the vein has two types of cells. Xylem *(zie-lem)* cells transport water, and phloem *(flow-em)* cells transport sugary sap along with some minerals. This is one of the smaller veins in the leaf. You would need a microscope to see it.

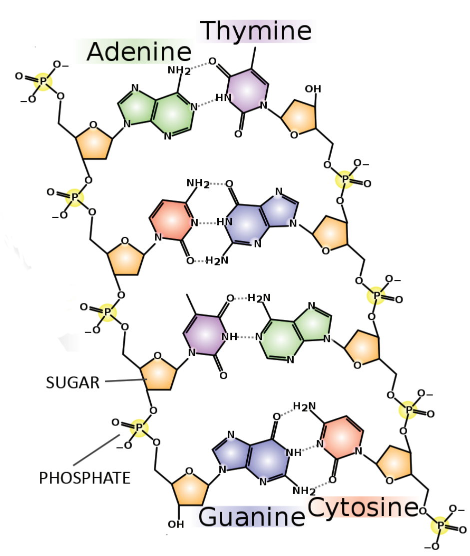
The drawing above does not show all the organelles inside the cells. Let's take a close-up look at one palisade cell and compare it to a yeast cell.





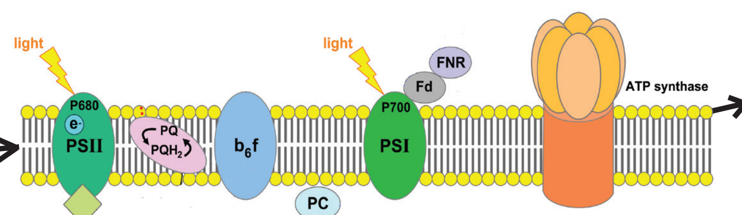
We don't have time to go into great detail about what all these organelles do. (If you want to know all the details, check out the book titled "Cells" by the same author.) Most of a cell's parts are made of things we've already learned about: proteins (strings of amino acids), fats, and sugars (usually in long strings). We'll learn more about the cell wall and the chloroplasts in a minute.

The fourth major ingredient is the cell's nucleic acids: DNA and RNA. The cell's DNA stays inside the nucleus, and RNA can be found both inside and outside the nucleus. DNA and RNA are made of three parts: a sugar, a phosphate and something called a base. There are only 5 different bases, and these bases are the same for all living organisms. The only difference between your DNA and a plant's DNA is how the bases are arranged. So as your body digests the plant cells in your salad, some of the lettuce and spinach DNA rungs could end up as part of the DNA in one of your own cells!



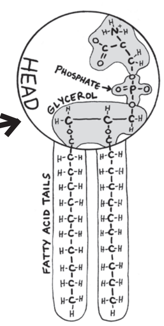
If we look inside a chloroplast, we find hundreds, or perhaps thousands, of things that look like stacks of green pancakes. The outside of these flat ***thylakoid*** discs is made of the same stuff as the cell's thin membrane just under the thick cell wall. (The yeast cell also has a membrane around it, but no cell wall. Only plant cells have walls.) Cell membranes are made of a double layer of molecules called ***phospholipids***, which look a lot like our two-legged diglycerides. These "legs," which are properly called "tails," are made of fatty acids—chains of carbon atoms with hydrogens attached. The round part (shown as yellow cirlces in the diagram below) isn't really round, but represents an area where the third glycerol "clip" is holding on to a water-loving phosphate molecule.

The purpose of these thylakoid membranes is to be a platform into which a lot of amazing little nano-machines can be embedded. Some of these "machines" function as pumps or shuttle buses, and one of them, called ATP synthase is a proton-driven motor that recharges little energy molecules. Most of these machines are made of protein (strings of amino acids). The DNA holds the code for how to string amino acids together so that the string will fold up into a useful gizmo that will perform a task.



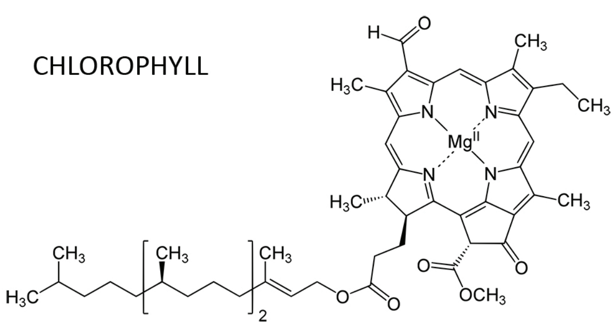
These colored shapes represent little "machines" that work to collect light, to pump protons, and to recharge little "batteries."

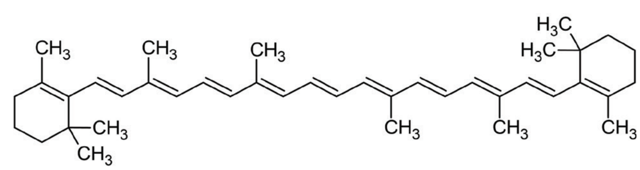
PHOSPHOLIPID



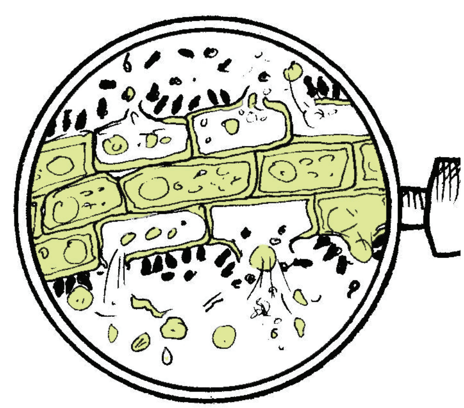
The green ovals represent a complicated light-collection system. One of the key molecules in these systems is ***chlorophyll***. Since chlorophyll reflects green light, leaves appear green. These "photosystems" contain a lesser amount of other light-collecting molecules such as ***beta-carotene*** (orange), ***xanthophyll*** (yellow) and ***anthocyanin*** (red). The green chlorophyll is so strong that it often masks over these other color molecules. If the chlorophyll is removed, you can then see these other colored pigment molecules. This is what happens in the autumn when green leaves turn red, orange or yellow.

CHLOROPHYLL





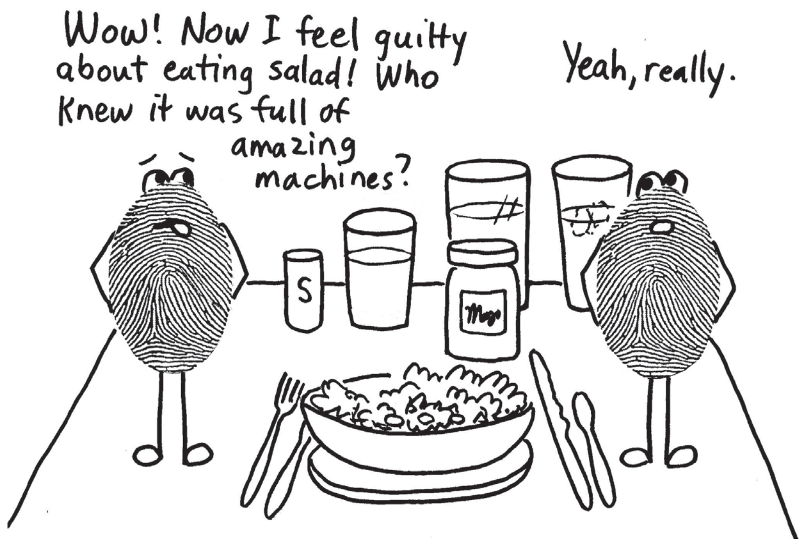
BETA-CAROTENE



organelles spilling out of cells

Because this is a food chemistry book, we are not going to take the time to learn how these fascinating cellular machines work. Instead, we are going to break them and tear them apart. When you chew, some of the plant cells will break open and the organelles will spill out. Digestive enzymes will then go to work and reduce them to piles of fats, amino acids, sugars and nucleic acids. (Yes, it does seem a shame to destroy all these fascinating little machines, but plants are always busy making new ones.) Amino acids are the same in all organisms, so your cells can use the digested amino acids taken from the plant cells to build their own cellular machines.

As we've already seen, ***beta-carotene*** molecules can be chopped in half and used in your eyes. The square-ish part of the chlorophyll molecule can be re-purposed by taking the magnesium (Mg) atom out of the center and replacing it with an iron atom, making it into ***heme (heem),*** the molecule in your red blood cells that carries oxygen. Other pigment molecules are used by our cells as natural sunscreens, or as chemicals that help our immune system to be more efficient.



Beta-carotene, chlorophyll and other pigments are part of very large group of molecules called ***phytonutrients*** *(fie-toe-nutrients)*. Phytonutrients are the fifth category in our list of types of nutrients found in plants. For the most part, phytonutrients are not proteins (not made of amino acids), and they are not classified as fats or sugars, though they might have some chains of carbon atoms (like a fatty acid) or rings of carbon (like glucose). They form a very large and diverse category, with some scientists claiming there are as many as 25,000 of them.

"Phyto" is Greek for "plant."

Phytonutrients, also known as ***phytochemicals***, are classified by their molecular shape and by what types of atoms they contain. Some are long and straight, like beta-carotene. Others have many hexagons or pentagons. Molecules containing sulfur have their own group. We'll look at just a few general categories. (If you want a lengthy list, check out the Wikipedia article titled "List of phytochemicals in food.")

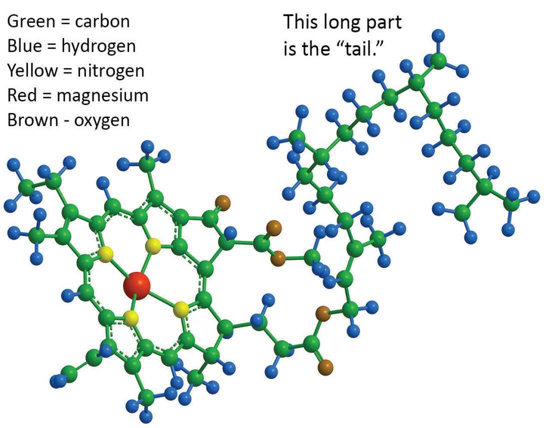
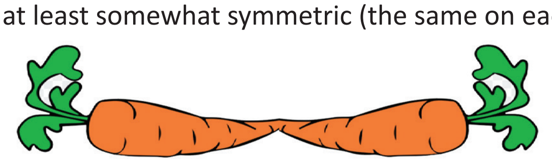


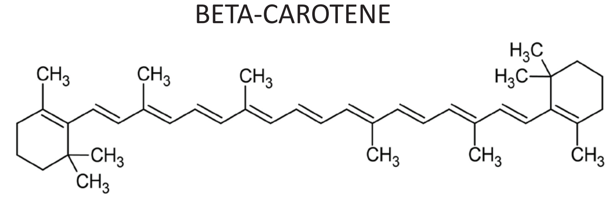
Image from Shutterstock, contributor Raimundo79

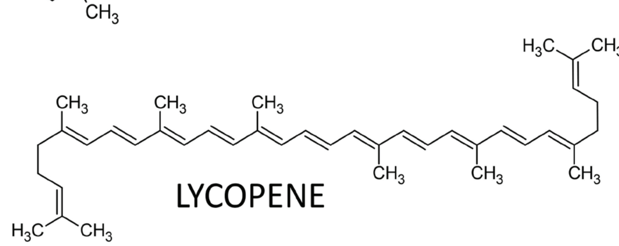
The ***chlorophylls*** have their own category. There's chlorophyll-A, chlorophyll-B, and others. They are all some shade of green, and their name comes from the Greek word for green: "chloro." ("Phyll" means "leaf.") Chlorophyll molecules have a square-ish part that has an "X" in the center, made of four nitrogen atoms and one magnesium atom. ("X marks the spot" where light energy is first captured for the process of photosynthesis.) There is also a long "tail" made of carbon and hydrogen atoms. Does it remind you of a fatty acid? The tail is fat-friendly and helps to hold the molecule in place in the membrane.

Beta-carotene belongs to a group of phytonutrients called ***carotenoids*** *(care-OT-in-oidz)*. All of these molecules are orange, yellow or red. Many of them have complicated names that we'll never remember, but here are two names that are fairly well-known: lycopene and lutein. These molecules are often included in mutli-vitamin pills. They are said to have anti-cancer properties as well as positive effects on the eyes and the immune system. The molecules in this group tend to be long and straight (like a carrot) and are often at least somewhat symmetric (the same on each side).



BETA-CAROTENE

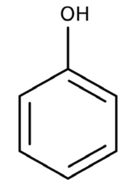




LYCOPENE

Carotenoids tend to be long and symmetric.

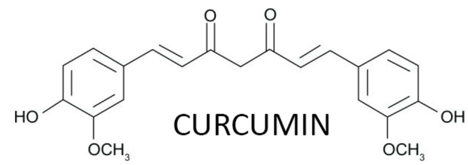
Polyphenols *(polly-FEE-nols)* form the largest category of phytonutrients. Subcategories include flavonoids, tannins, curcuminoids, and resveratrol. These names may sound difficult and strange, but in the world of food chemistry they are words that everyone knows. The word root "poly" means "many" and "phenol" is a hexagonal "ring" of carbon atoms with an -OH hanging off. So all the molecules in the polyphenol group have more than one of these carbon rings. Some of them have dozens of these rings.



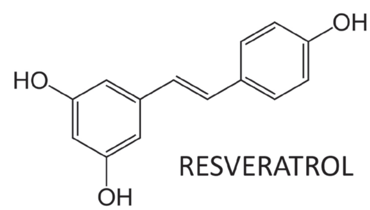
phenol

Flavonoids are found in many fruits and vegetables, and also in coffee, tea, and chocolate. ***Anthocyanin*** flavonoids are red, blue and purple and give those colors to the plants that contain them. Studies find that, on average, people who eat a lot of flavonoids experience better overall health than those who do not. Flavonoids help to slow the aging process in a number of ways, including reducing inflammation and helping to catch "free radicals" (dangerous broken molecules that can damage healthy body molecules).

Curcumin *(ker-KOO-min)* is a chemical found in ***turmeric***, a bright yellow spice found in many Indian recipes. Curcumin reduces inflammation, stops cancer cells from growing, and lowers the amount of cholesterol (a type of fat) in the blood.

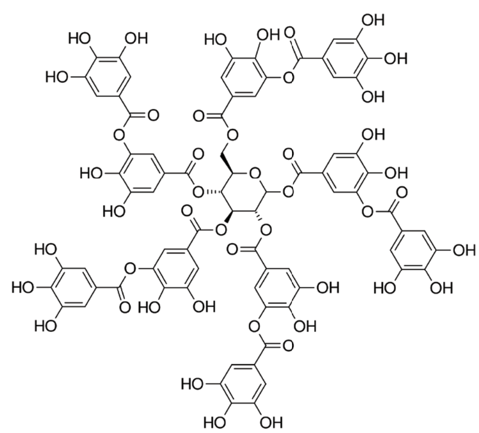


Resveratrol *(res-VARE-i-trol)* is most abundant in dark red or blue fruits such as grapes, blueberries and cranberries. It seems to have anti-inflammatory properties as well as the ability to help your body get rid of dangerous "free radical" molecules that have unpaired oxygen atoms. Oxygens that are either on their own or are left hanging on the edge of a broken molecule can wreak havoc on other molecules in their neighborhood. Substances that can capture these dangerous oxygen atoms are called ***antioxidants***.



Tannins get their name from the process of tanning leather. For many centuries, the bark of oak trees was the source of important chemicals for the tanning process, though no one really knew what they were until chemists in the 1800s were able to extract the various tannin chemicals, isolate them, and give them names.

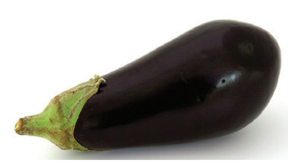
Tannins are found in great abundance in tea leaves, and are responsible for tea's "tangy" taste. Tannic acids are made by plants as pesticides—chemicals that are toxic or distasteful to organisms that want to eat the plants, such as insects or bacteria. Tannins, as well as many other phytochemicals, are part of a plant's defensive strategy to avoid being eaten.

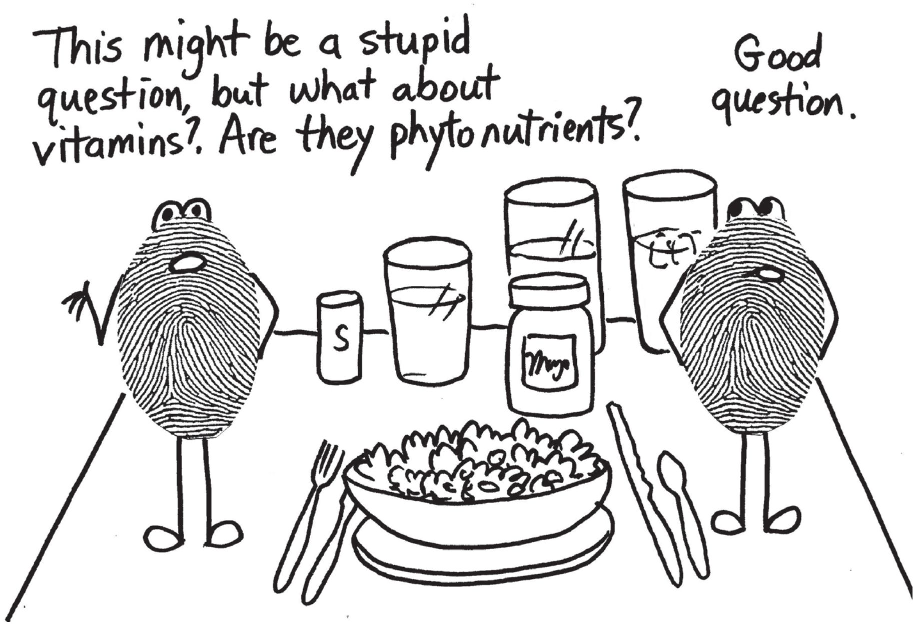


TANNIC ACID

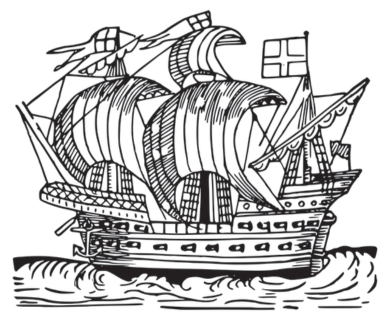




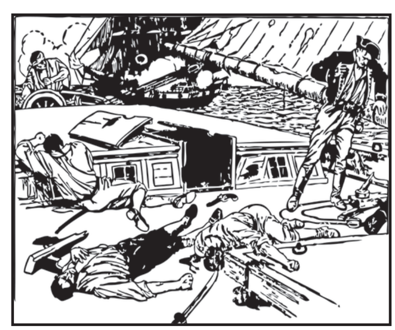




Many vitamins are similar to some phytonutrients. We've already seen the connection between vitamin A (retinol) and beta-carotene. Enzymes in our bodies can modify beta-carotene and turn it into vitamin A. Vitamins are sort of like phytonutrients we can't live without. We can survive without ingesting all the different types of polyphenols and tannins. But if we try to live without vitamins, we will eventually develop a deficiency disease. Diseases due to lack of vitamins are actually what led to their discovery. The story of vitamins starts out in the so-called "Age of Discovery," when European explorers began to make long voyages by ship.



Starting in the 1500s, Europeans set out to explore the world in wooden sailing ships. Often, their real mission was to discover where certain spices were grown, such as pepper, cloves, and cinnamon. These spices are so common now that is hard to imagine a world in which a teaspoon of cloves was worth hundreds of dollars. We shake pepper onto our food without a thought, not knowing that in past centuries battles were fought over this spice.



The voyages were often very long and the sailors spent months at sea. Fresh food only lasted a week or two and after that it was nothing but hard tack biscuits made of wheat flour and possibly some salted preserved meat. After several months at sea, the sailors would begin to get sick with a disease called ***scurvy***. Their gums would start to bleed, then they would get sores all over their body that would not heal. Eventually the sores would become infected and they would die. (At the time, they noted that it was rarely the officers on board that came down with scurvy, just the sailors. Hindsight allows us to solve this mystery. Only the officers were allowed to drink wine, which is made from grapes, a source of vitamin C.)

In 1747 a Scottish surgeon named James Lind put forth his theory about how to prevent scurvy. He recommended that citrus fruits such as lemons and limes be added to the food provisions. These fruits did not go bad quickly and could even be sliced and dried. Dr. Lind did not know about vitamin C, only that citrus fruits seemed to prevent scurvy. The British navy took his advice and the incidence of scurvy dropped dramatically.

Not everyone was convinced, however. Some very influential people held that good hygiene (staying clean), regular exercise and maintaining a positive attitude were the keys to keeping sailors healthy.

Other people thought scurvy might be caused by spoiled food. These ideas were put to the test in the 1800s when a number of Arctic expeditions decided to sail without bringing any citrus fruits along. The results were disastrous.

In 1881, a Russian scientist, Nickolai Lunin, did one of the first experiments to test the idea that disease could be caused by a lack of nutrients. (The reason that this idea was not being explored by more scientists was that germs had been discovered during this time period, and scientists had jumped to the conclusion that they now knew the root cause of ALL disease.) Dr. Lunin set up an experiment with mice where he controlled their diet, allowing some baby mice to drink milk, but feeding other baby mice a concoction he'd mixed up that had fats, sugars, and amino acids—all the nutrients they required, as far as he knew. Of course, the baby mice who drank this substitute milk died. Dr. Lunin concluded that milk contained other ingredients essential to life, besides fats, sugars and proteins—substances that had not yet been discovered. Many scientists disagreed with his conclusion, and thought the mice had died for another reason. It is important to remember that scientists don't always agree, and can often be resistant to new ideas.

Aren't these guys adorable? (Even if you don't like rodents, at least it's a break from chemistry!)

After this, other researchers began to design similar experiments, and finally the results were overwhelmingly in favor of the theory that foods contain substances other than protein, fats and sugars, that are essential to life.

In the early 1900s, many experiments were preformed on small animals to try to identify the "anti-scurvy" substance. The breakthrough came when experiments were done on guinea pigs instead of rats or mice. Guinea pigs and humans are the only mammals whose cells are unable to produce vitamin C—they must get it from their diet. Scientists were able to perform experiments on guinea pigs that they could never do on humans. Finally, in 1932, the discovery of the "anti-scurvy" substance was announced. It was named ***ascorbic acid***, with "a" meaning "against" and "scorbic" coming from the Latin term for scurvy: "scorbuticus." Only later was it called vitamin C.

The author of this book used to raise long-hair guinea pigs, like this one. They got plenty of foods with vit. C.

Meanwhile, research was also being done on other diseases that seemed to be caused by a lack of nutrients. During the late 1800s, a process for refining and polishing rice was invented. The brown hull around the rice was removed, leaving a beautiful white grain with a mild flavor. People in Eastern Asia gave up eating natural brown rice and began eating nothing but white rice. The Japanese Navy was especially hard hit, with many sailors dying of a condition they called "beriberi," which caused the heart, brain and nerves to malfunction. Just like in the British Navy, it was the low-ranking sailors who were most affected, not the officers. The officers were fed meals with a greater variety of foods, but at the time no one thought this was important.

In 1897, a Dutch physician used experiments on chickens to show the link between polished rice and beriberi, though at the time he was unable to determine the essential substance in the brown rice hulls. Eventually it was shown to be a chemical called thiamine, which later was named vitamin B1.

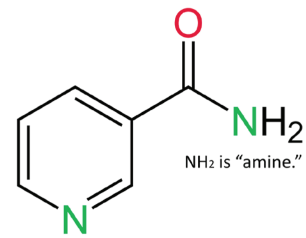
Chickens were used in the research that discovered thiamine, B1.

In the early 1900s, there was a race among researchers to be the first person to discover a new essential nutrient. Communication at this time was very slow. The telegraph was the only way to get news to other parts of the world quickly, but it was limited to short sentences, and wasn't a method of communication that worked well for scientists who wanted to explain their research. It was not uncommon for scientists to be completely unaware of research that people in other parts of the world were doing. Two researchers could make the same discovery simultaneously and not know it. This led to many controversies and arguments among the scientists of the world about who should be allowed to claim credit for the discoveries and possibly earn a Nobel Prize. If you do some in-depth reading about the history of vitamins, you'll come across many of these arguments. As we continue with our story of vitamins, we will not be able to mention all the scientists who devoted their lives to this area of research.

The Nobel Prize was established by Alfred Nobel, inventor of dynamite, who gave his fortune to this cause.

In 1912, a Polish researcher named Casimir Funk was also working on the problem of beriberi. He isolated a chemical he thought was the anti-scurvy cure, and named it "***vitamine***," meaning "vital amine." (Remember, "amine" is NH_2.) What he had actually discovered was later found to be niacin (vitamin **B3**), unrelated to beriberi, but his discovery was still important.

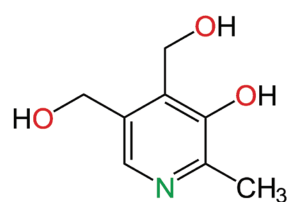
In 1913, a researcher at the University of Wisconsin, USA, announced his discovery that these essential "vitamines" were of two types: "fat-soluble type A," and "water-soluble type B." This was the beginning of the long list of "B vitamins." (B1 through B12)



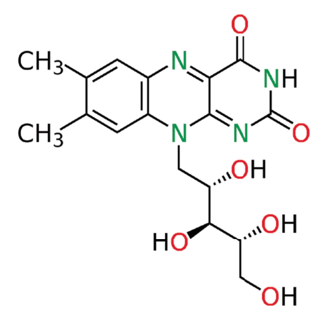
Nicotaminide, a form of B3.

By 1920, other "vitamines" had been found that did not have an "amine" group (NH_2), but by now the name "vitamine" had become so popular there was no changing it. A British scientist suggested that everyone should start spelling it "***vitamin***," without the final "e," as a way to acknowledge the fact that many vitamins were not "amines." It's been "vitamin" ever since.

Riboflavin was discovered in 1922 in Germany and was eventually named vitamin **B2**. The same group of scientists went on to discover pyridoxine (**B6**) in 1934. During this time, an American pharmaceutical research company, Merck, decided that vitamins might turn out to be something that could be manufactured and sold to the public. Their first product was thiamine tablets for the prevention of beriberi. Then they jumped into the vitamin discovery race and their researchers announced the discovery of pantothenic acid (**B5**) in 1940.



B6 PYRIDOXINE

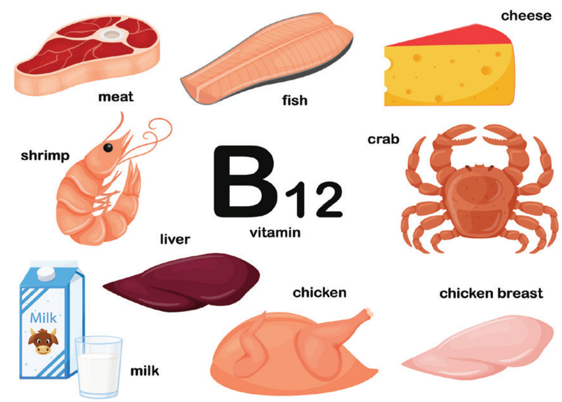


B2 RIBOFLAVIN

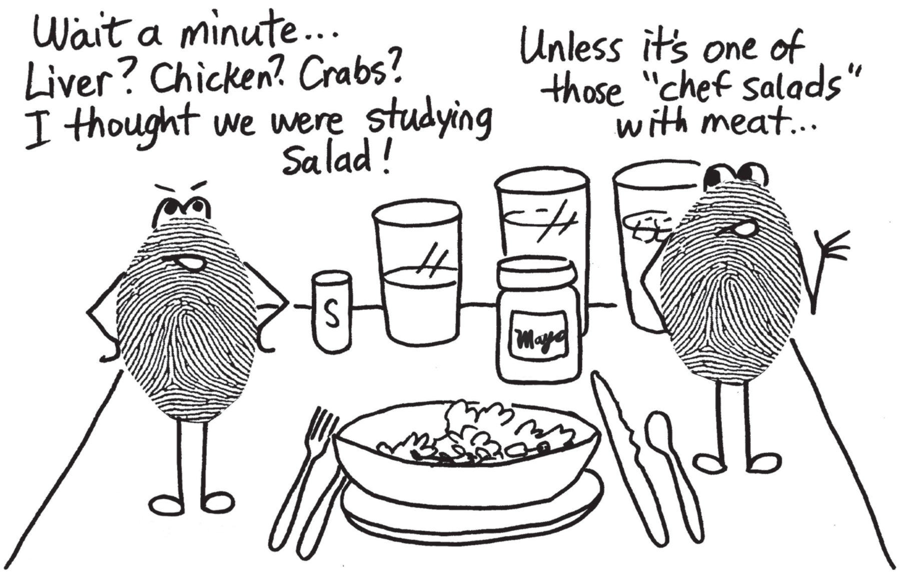
One of the last B vitamins to be discovered is cobalamin, **B12**. All during the 1800s and early 1900s, physicians were mystified about a rare diseased they called "pernicious *(per-NISH-us)* anemia." (Pernicious means "causing damage in a gradual way that is not easily seen." It is not a science word, and you might come across it in another context.) Patients with this illness would be tired and weak and short of breath. Blood tests revealed that too few red blood cells were being made, but the doctors did not know why. In 1926, scientists at Harvard University, USA, discovered that they could cure this disease by having patients eat half a pound of liver every day. Finding the critical substance in the liver was going to be difficult, however, because this type of anemia was never seen in animals. Without lab rats (or chickens or guinea pigs) to work with, researchers were limited in what they could do. Then, one day, an American microbiologist named Mary Shorb discovered a certain type of bacteria that seemed to react to liver chemicals the same way that human bodies did. Merck hired Shorb to assist their team of researchers who would attempt to isolate the curative agent in liver.

Fried liver and onions with potatoes

The liver chemicals that were most effective on the bacteria were pinkish in color, suggesting to the scientists that the mystery substance they were looking for was either pink or red. Sure enough, when they finally isolated this chemical, it came in the form of red crystals. They named it cobalamin, with the "cobal" part of the world coming from "cobalt," element number 27 on the Periodic Table, which was part of this vitamin's molecular structure. Finding cobalt in a vitamin was very surprising. Previously, cobalt was only known as a metal that was used to make magnets or to add blue (not red) color to glass. This illustration shows some other foods, besides liver, that contain significant amounts of B12.



Graphic by Valeriia Soloveva



Well, we were on the topic of B vitamins, so it was best finish that topic in this chapter even if plants are not a good source of vitamin B12. In fact, before vitamin B12 pills were available, being a vegetarian (vegan) put a person at risk for pernicious anemia. However, very few people were vegan back then. For those who were, nutritional yeast was used as the primary source of B12. Now vegans can simply walk into any grocery store and buy a bottle of B12 tablets.

Before we leave the topic of vitamins, let's do vitamin D, too, since its discovery was linked to vitamin A.

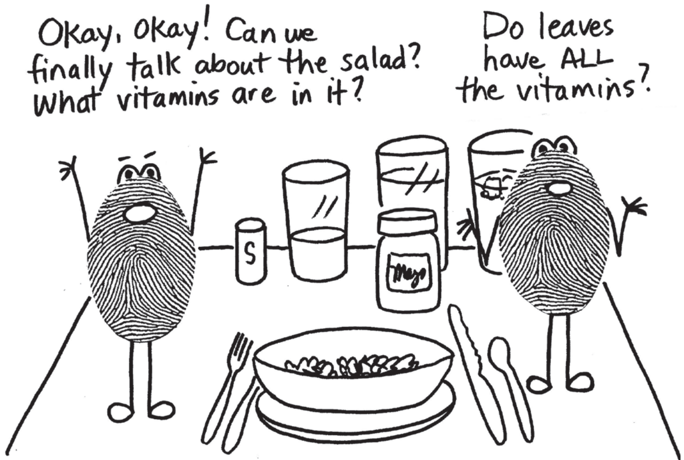
Vitamin D was discovered by the same research team that discovered vitamin A. They had discovered vitamin A in cod (fish) liver oil, and had also found this oil to be an effective treatment for a disease called ***rickets***. People with rickets often looked "bowed legged" (bent legs) because the disease affects the ability of bones to maintain their hard mineral content. The researchers attempted to find out exactly what it was in the cod liver oil that cured rickets. Their first guess was that it was vitamin A itself, so to test their theory they took the vitamin A out of the oil and tried it on dogs who had rickets. The dogs still got better, even without the vitamin A in the oil, so they knew it must be a new vitamin not yet discovered. Even though they did not know exactly what it was, they still gave it a name. The obvious choice was "vitamin D" because we already had A, B and C.

COD LIVERS (Yum, yum.)

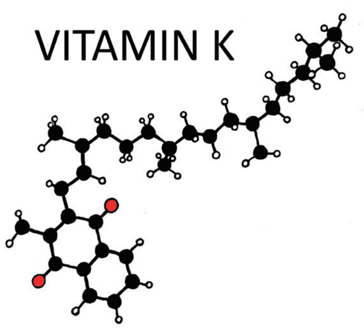
A few years later, other researchers discovered that vitamin D can be produced naturally by skin cells when they are exposed to ultra-violet light. In places of the world where people are out in the sun a lot, no one has rickets. Food chemists found that when they exposed food products such as milk, to UV light, the level of vitamin D went up. The use of UV light was an inexpensive and efficient way to fortify milk with vitamin D. Once this became common practice in the food industry, cases of rickets became extremely rare.

Vitamin E, discovered in 1922, is not a single molecule but a group of similar molecules. Plants make these molecules to catch dangerous "free radicles" (bits of broken molecules) that are created as UV light from the sun hits their leaves. Vitamin E molecules sit in the membranes we looked at on pagge 65 and protect those fancy little machines by catching and trapping free radicals.

By the mid-1900s, it had become obvious that these "vitamins" were absolutely essential to good health. Manufacturers of animal feed began putting vitamins into their products. Governments started telling companies that processed grains for human consumption that if their processes took out vitamins, they had to find a way to put them back in. When you see the word "fortified" on a product (often flour or cereals) this means that vitamins have been added in order to restore the original vitamin content of the grains.



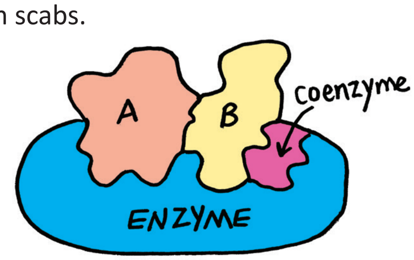
VITAMIN K



Before we compare vitamin contents of your salad greens, we need to mention a vitamin that most of these greens are high in: ***vitamin K***. This vitamin comes in two forms. The one found in your salad leaves is called ***phylloquinone***. You don't have to pronounce it or remember it. It's just interesting to see the proper names of these vitamins. See that long string of carbon atoms at the end? By now, you should easily recognize that this is what a fatty acid looks like, and you should be able to predict that this vitamin is in the "fat-soluble" category. That carbon tail will want to hang out with fatty acids which are also made of long strings of carbon atoms.

Your body uses this vitamin for several things, with the most well-known function being its participation in the blood clotting process. Vitamin K is necessary for making one of the proteins your body uses to make cuts and scrapes stop bleeding and form scabs.

Like vitamin K, many vitamins act as "cofactors" or "coenzymes" in body processes. Enzymes work on what they call the "lock and key" principle. The shape of the enzyme must match the shape of the substrates. There are a few enzymes whose natural shape isn't quite right, and they need another molecule (sometimes a vitamin) to fit into a gap, making the shape perfect. Vitamins are often the necessary "missing piece" needed to complete the shape and allow the enzyme to do its job.



Now... let's stage a contest between your salad greens. We did the research for you (you're welcome). Use this chart to compare the levels of vitamins and minerals in four types of greens commonly found in salads. Of course, there would be phytonutrients in the leaves as well, but it is next to impossible to find enough detailed information on this to include it in the chart. In general, the darker the leaf, the more phytonutrients it has. You might already know what "fiber" means, but we'll discuss it in molecular detail on the next page. We also included some minerals that you may be familiar with. (Minerals are elements that you can find on the Periodic Table.)

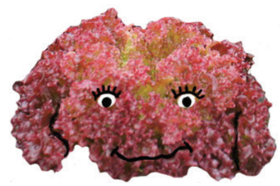
You might have a different name for these greens. For example, "iceberg" is the most common name in the U.S., but in other places it is called "crisphead."

Most of the numbers in the chart are listed as percentages of the ***Recommended Daily Allowance (RDA)***. You aim get at least 100% of every type of nutrient. So if one food gives you 5% of a vitamin, that means you still have to get the remaining 95% of that vitamin from the other food you eat that day.

ICEBERG **ENDIVE** **RED LEAF LETTUCE** **SPINACH**

NOTE: These numbers are for serving size of 100 grams (3.5 oz).





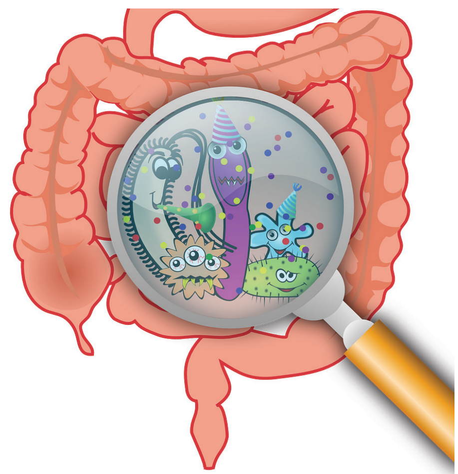

	ICEBERG	ENDIVE	RED LEAF LETTUCE	SPINACH
sugars	1.97 g	.45 g	.48 g	.4 g
fiber	.2 g	3.1 g	.9 g	2.2 g
vit. A	3%	72%	47%	59%
thiamine (B1)	2%	7%	6%	7%
riboflavin (B2)	2%	6%	6%	16%
pyridoxine (B6)	2%	1.5%	8%	15%
folate (B9)	7%	36%	9%	49%
vit. C	5%	8%	4%	34%
vit. K	20%	220%	134%	460%
calcium	2%	5%	3%	10%
iron	1%	6%	9%	21%
magnesium	2%	4%	3%	22%
phosphorus	3%	4%	4%	7%
sodium	1%	1.5%	2%	5%
zinc	1%	8%	2%	6%

And now, fiber...

Technically, ***fiber*** isn't really a nutrient. In fact, for the most part, it goes through your digestive system intact and undigested. Some people called it "roughage." Before the late 1900s, fiber was under-appreciated as a necessary part of a healthy diet. If you can't digest it, then what good is it, right? However, scientific studies began collecting data on people whose diets contained a lot of fiber and on those who had very little. The results of the studies showed that people who ate lots of fiber had healthier digestive systems as well as having fewer problems with other internal organs such as heart and liver. It became obvious that eating plants that you can't digest is actually good for you.

At first, scientists speculated that the fiber was causing the food to move along more quickly through the intestines, preventing the build-up of toxins along the way. They also guessed that perhaps the bulk of the fiber was somehow mechanically "cleaning" the inner walls of the intestines. Both of these theories are likely to be true, but there was a key element they had overlooked.

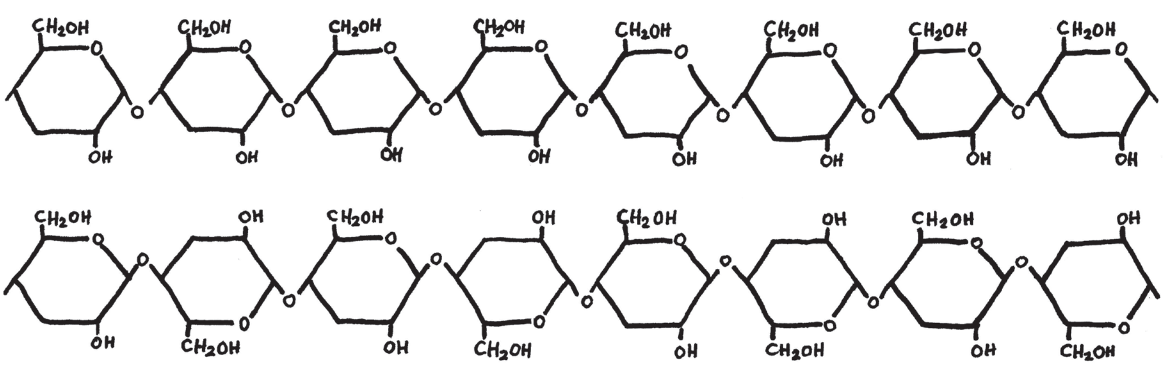
At the very end of the 1900s, a whole new branch of science began: the study of the ***microbiome***. "Micro" means "small," and "bio" means "life." Your microbiome consists of all the microscopic organisms that live inside of you. Most of them are beneficial, not harmful, and you really can't live without them. They keep "bad" bacteria out, they make helpful chemicals such as vitamins (B7 and B9) and fatty acids, and they even play a role in brain health. The number of bacterial cells in your body is ten times the number of your own cells! Much of your microbiome is found in your intestines, particularly the large intestine. Like all living things, these bacteria have to eat, and many of them love to eat the plant fibers that you can't digest. As a general rule, the species of bacteria that are the least helpful are the one who like to eat sugar and "junk food," and the species that are most helpful are the ones who like to eat healthy food such as vegetables and salad greens.



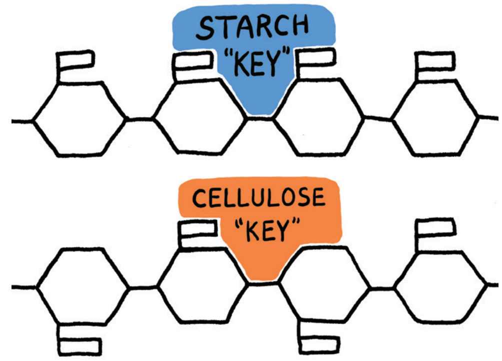
Fiber is made of long molecules called ***cellulose***. At first glance, cellulose molecules might look identical to starch. However, if you look carefully at the orientation of the glucose units, you will see the difference. In starch, all the glucose molecules are sitting the same way, with their "flags" (CH_2OH) at the top. In cellulose, every other glucose molecule has its "flag" pointing down: up, down, up, down, up, down, etc. This is a small difference, but it has a large effect. Our bodies can only tear apart glucose molecules that are all facing the same way.

STARCH

CELLULOSE



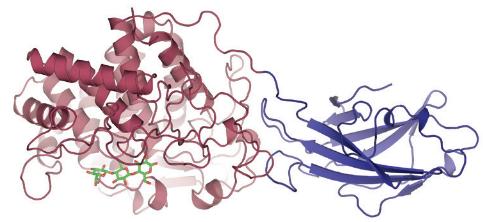
Enzymes, as we have mentioned previously, can only do one job. The enzyme that can disconnect the glucose molecules found in starch has a shape that fits exactly into the space between the glucose units. In this illustration, we've drawn this enzyme as a blue shape that acts like a key. (The real enzyme doesn't look anything like this, but the blue shape will help us to understand the function of the enzyme.) The enzyme that is needed to disconnect the glucose units in cellulose is shown in orange. You can see that the keys have different shapes.



Our bodies don't make those cellulose keys; we only make starch keys. Bacteria, however, do make the cellulose keys, so they are able to tear apart cellulose and use the glucose molecules.

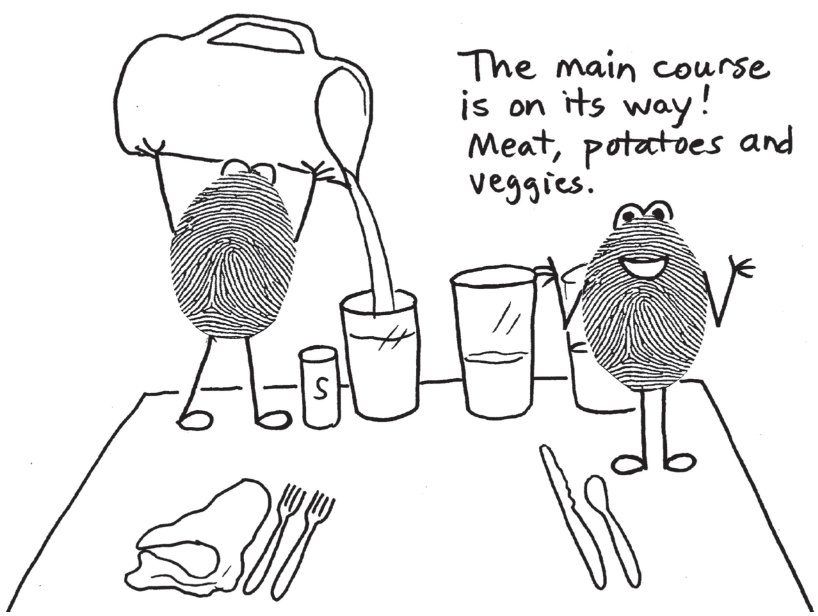
The correct name for the cellulose enzyme key is ***cellulase***. It's not just humans who can't manufacture cellulase—not a single mammal can. Grazing animals like cows and sheep can live on nothing but grass because their digestive tracts house massive numbers of bacteria. Cows have a collection bag where all the grass goes, and in this bag are not only bacteria but also some one-celled protozoans. These microorganisms feast on all the grass the cow has swallowed. The semi-digested grass, and many dead bacteria, then go into a regular stomach where digestive enzymes finish the job and prepare the nutrients to be absorbed in the intestines.

CELLULASE



By B.T.Riley - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=46569786 rid=46569786

Let's end by summarizing our salad. What is salad made of? Over 90 percent of it is water. If you dehydrated your salad it would shrivel down to almost nothing. The next most abundant ingredient is cellulose, which makes the thick cell walls around all the cells. In third place we'd have a tie for sugar (in the form of either starch or free floating glucose molecules) and protein (which would include all those fancy little machines that do photosynthesis). The remaining small percentage would be nucleic acids (DNA and RNA), fats, vitamins, minerals, pigment molecules (green chlorophylls in lettuce, orange beta-carotenes in carrots, and red anthocyanins in tomato) and other phytonutrients.



(Don't forget to check out the videos that go with this chapter at YouTube.com/TheBasemenetWorkshop.)

Comprehension self-check

1) Water is polar because the ____________ are shared unevenly.

2) An emulsion is made of a polar substance and a non-polar substance held together by an _______________.

3) Which of these is NOT used as an emulsifier in dressings? a) egg yolks b) salt c) mayonnaise d) mustard

4) How many fatty acid chains are on a diglyceride molecule?____ A monoglyceride? _____ A triglyceride? ____

5) To a scientist, a fruit is anything with ________. Which of these would a scientist NOT classify as a fruit?
a) cucumber b) green pepper c) sweet potato d) tomato

6) The tiny holes in leaves are called _____________, which are made of two ____________ cells.

7) Which layer in a leaf contains the greatest number of chloroplasts?

8) TRUE or FALSE? Plant DNA is fundamentally different from human DNA.

9) The membrane around a cell, or around a thylakoid disc, is made of "2-legged" molecules called:

10) Which pigment molecule has an "X" in the middle of a square shape?

11) Which pigment molecule gets chopped in half to make vitamin A for your eyes?

12) The square part of chlorophyll is very similar to this molecule in your blood that carries oxygen:

13) What is the atom at the very center of (the square part of) the chlorophyll molecule?

14) Lycopene and lutein belong to what category of phytonutrients?

15) What flavonoid molecule is responsible for red, blue and purple coloration in plants?

16) This bright yellow polyphenol phytonutrient is used in Indian recipes:

17) Substances that can capture dangerous "broken" molecules and single oxygen atoms are called:

18) Tea leaves contain this tangy phytochemical:

19) From a plant's point of view, what are phytochemicals for?

20) What disease is caused by a lack of vitamin C? ___________ Vitamin B1? _____________

21) What does the "-amin" ending mean, in the word vitamin?
a) It is an acid. b) It is a base. c) It has a COOH group. d) It has an NH_2 group.

22) Which one of these is NOT a B vitamin? a) resveratrol b) thiamine c) pyridoxine d) riboflavin e) cobalamin

23) Which one of these is NOT a good source of vitamin B12? a) chicken b) liver c) spinach d) fish e) cheese

24) Name the two vitamins that were discovered in cod liver oil:

25) Which vitamin can be made by your skin cells when exposed to ultraviolet light?

26) Which vitamin is needed for the blood clotting process?

27) What do you call a small molecule that is needed by an enzyme to complete its shape?

28) Fiber is made of c_____________. The enzyme needed to tear it apart is called c______________.

29) Can any animals digest fiber?

30) Why do you need to eat fiber?

These question use the chart on page 73.

31) Which type of salad green has the greatest amount of vitamin K?

32) Which type of salad green has the greatest amount of natural sugars?

33) Which type of salad green has the highest level of iron?

34) Which type of salad green as the most fiber?

35) Like humans, guinea pigs cannot make vitamin C and must get all of it from their diet. Which type of salad green would be the best to feed to your guinea pig?

36) Which type of salad green has the most magnesium?

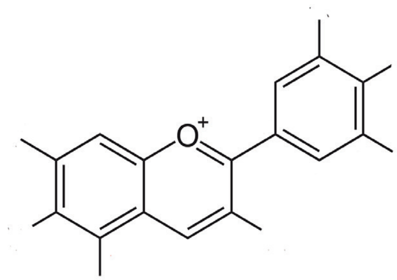
37) People who take medication to prevent blood clots are often told not to consume a lot of vitamin K. Which salad green would you recommend that they eat?

38) Which type of salad green has the least amount of B vitamins?

39) Many people like to be careful not to consume too much salt, which includes sodium. Would these people have to limit their intake of salad greens?

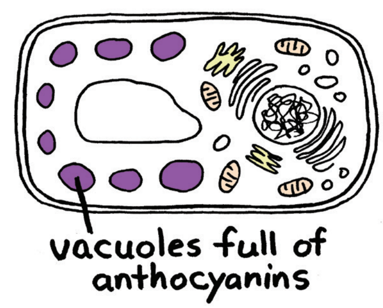
40) Which salad green contains the greatest amount of vitamin A?

ACTIVITY 4.1 BONUS INFORMATION: Anthocyanin— the amazing color-changing molecule!



Anthocyanins are a family of pigment molecules that share the basic structure shown here. They are in the polyphenol group and are manufactured by plant cells using the amino acids phenylalanine and tyrosine. After the molecules are made, they are put into a storage vacuole. Cells in any part of a plant can make anthocyanins: roots, stems, leaves, and fruit.

When anthocyanin molecules are in an acidic environment, the acid causes the molecule to reflect only red light. As the pH rises and the environment becomes less acidic, the molecule will change shape just enough that it no longer reflects red light but reflects blue instead. If the environment is neutral (7 on the pH scale) the anthocyanin will reflect dark purple light. We see these dark purples in eggplants and black beans. If the pH starts to become alkaline (higher than 7 on the pH scale) the molecule will stop reflecting purple light and begin to reflect green. In a very alkaline environment, the molecule reflects yellow light. The picture of the test tubes shows these color changes.

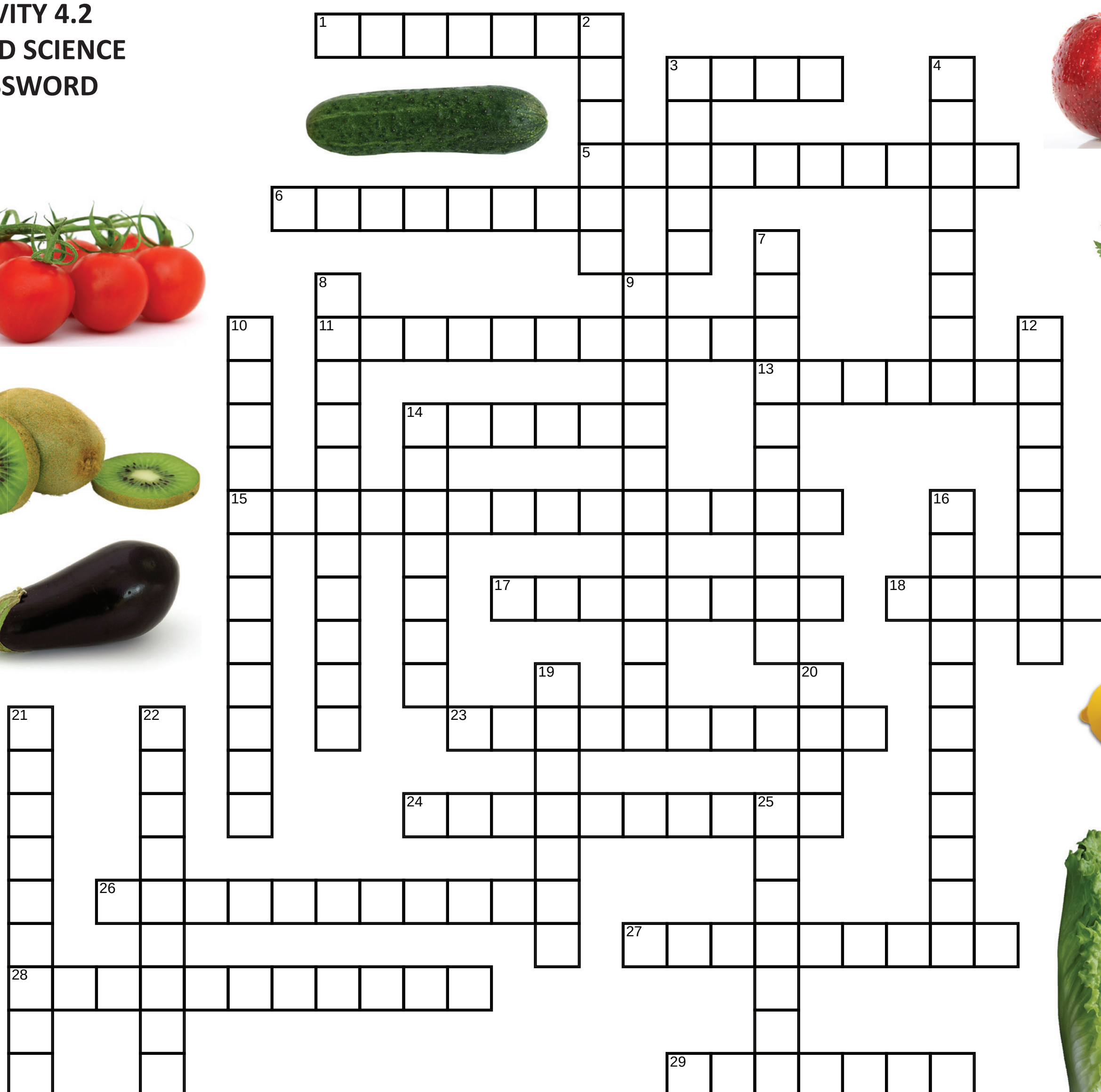


This ability of anthocyanins to change color explains why many berries, including raspberries and blueberries, are red when they are unripe, but blue or purple when ripe. Have you ever tasted an unripe berry? Wow, are they sour! When something tastes sour, it is acidic. As the berry ripens, the chemistry changes and the berry becomes sweeter and much less tart. The ripe berry tastes less sour because it is less acidic. This change in pH as the berry ripens affects both taste and color.

There's another chemical that can make plants red, called ***betalain***. Plants that produce betalain don't make anthocyanins. Betalain is found in beets, Swiss chard, and many cactus flowers. Betalain doesn't change color; it stays red regardless of the pH around it.

By Indikator-Blaukraut.JPG: Supermartlderivative work: Haltopub (talk) - Indikator-Blaukraut.JPG, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=7741760

ACTIVITY 4.2
SALAD SCIENCE CROSSWORD



ACROSS:
1) This group of polyphenols gives tea its tangy taste.
3) The scientist that gave us the word "vitamin."
5) The scientific name for vitamin B2
6) This yellow spice contains the polyphenol curcumin.
11) This word means "water fearing/hating."
13) This condition is caused by lack of vitamin D.
14) The __________ layer in a leaf has many air spaces.
15) The process of turning sunlight, water and carbon dioxide into glucose (plus oxygen and water).
17) A small molecule that completes the shape of an enzyme.
18) Anything with a seed is technically a _____.
23) A substance that can hold both polar and non-polar molecules.
24) The scientific name for vitamin B6
26) This polyphenol is found dark red or blue fruits and has anti-inflammatory properties.
27) This very long molecule is a primary building material plants use to make their cell walls.
28) Any molecule or substance that can catch and trap dangerous molecules, such as lone oxygen atoms.
29) The empty "bubble" in the middle of a plant cell.

DOWN:
2) A string of glucose molecules that can be broken apart by the enzyme amylase.
3) The general word describing any substance that goes through our intestines undigested.
4) The scientific name for vitamin B1
7) The term used to describe all the bacteria that live in and on you.
8) The organelle in a plant cell where you find chlorophyll molecules
9) Phytonutrients that have in their molecular structure at least one hexagonal ring of carbon atoms with an OH attached.
10) The name of the molecule that forms membranes
12) Vitamin C is also called ________ acid.
14) The microscopic holes in a leaf
16) Phytochemicals that reflect orange light
19) The waxy surface layer of a leaf
20) The molecule in our blood cells that carries oxygen molecule (similar structure to chlorophyll)
21) The enzyme that can break apart cellulose
22) The atom at the very center of the chlorophyll molecule, where photons of light are captured
25) DNA and RNA are _______ acids.

ACTIVITY 4.3 Fourth 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 4: SALAD 1) Name a plant that you like to eat if it is cooked, but you don't like if it is raw. Then name one you like raw but not cooked.	CHAPTER 4: SALAD 2) Guess what percentage of the population in America admits that they almost never eat vegetables.
CHAPTER 4: SALAD 3) Guess which root vegetable is reportedly the most hated (according to a U.S. survey)? a) beet b) turnip c) rutabaga d) radish	CHAPTER 4: SALAD 4) All of these vegetables have purple varieties except one. Which one is never purple? a) carrot b) cabbage c) potato d) cucumber d) cauliflower 3) pepper
CHAPTER 4: SALAD 5) Guess which of these scores higher on the favorite vegetables list (according to a U.S. survey): Green beans or green peas?	CHAPTER 4: SALAD 6) Guess which U.S. state holds the record for growing the largest vegetables. a) Alaska b) Hawaii c) Texas d) Florida
CHAPTER 4: SALAD 7) Four of these vegetables belong to the same family of plants, commonly called the "nightshades." Can you guess which one is not related to the others? a) potato b) pepper c) eggplant d) avocado e) tomato	CHAPTER 4: SALAD 8) STRANGE FACT: The Vegetable Orchestra, based in Austria, makes all their instruments from fresh vegetables. They assemble the edible instruments before each performance, then serve vegetable soup to the audience afterwards.
CHAPTER 4: SALAD 9) How many salad greens or vegetables can you name that are <u>always</u> eaten raw and never cooked?	CHAPTER 4: SALAD 10) INTERESTING FACTS ABOUT CUCUMBERS: 1) The skin of a cucumber can erase pen marks. 2) A slice of cucumber can be used as a breath freshener. 3) Cucumber juice has been used for waterproofing.
CHAPTER 4: SALAD 11) Go around the table and have each person try to name five foods they have eaten today or yesterday that contain some kind of phytonutrient. (You don't have to name the phytonutrients.)	CHAPTER 4: SALAD 12) If you had to take a job working with lab animals, which one would you choose? a) mice b) rats c) guinea pigs d) chickens

2) 25%
3) b) turnip
4) d) cucumber
5) Green beans
6) Alaska, because in the summer they get up to 20 hours of sunlight each day.
7) d) avocado (Yes, the potato and tomato are related!)
9) cucumber, lettuce (though lettuce is cooked in some parts of the world), radish, perhaphs you know another