Core Knowledge® SCIENCE

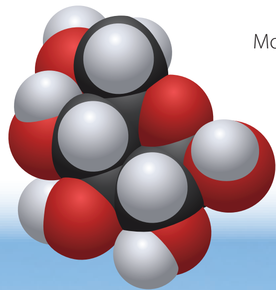
Chemical Reactions and Matter:

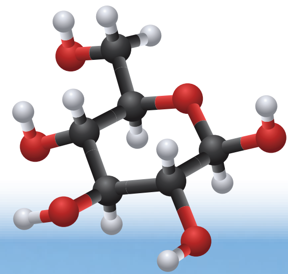
How can we make something new that was not there before?

Science Literacy Student Reader

Science Literacy

Products and reactants





Models

Iron + oxygen + water → rust

THIS BOOK IS THE PROPERTY OF:

STATE ____________________

PROVINCE ____________________

COUNTY ____________________

PARISH ____________________

SCHOOL DISTRICT____________________

OTHER ____________________

Book No. __________

Enter information in spaces to the left as instructed.

ISSUED TO	Year Used	CONDITION	
		ISSUED	*RETURNED*

PUPILS to whom this textbook is issued must not write on any page or mark any part of it in any way, consumable textbooks excepted.

1. Teachers should see that the pupil's name is clearly written in ink in the spaces above in every book issued.
2. The following terms should be used in recording the condition of the book:
   New; Good; Fair; Poor; Bad.

Chemical Reactions and Matter

Science Literacy Student Reader

Core Knowledge®

ISBN: 978-1-68380-803-9

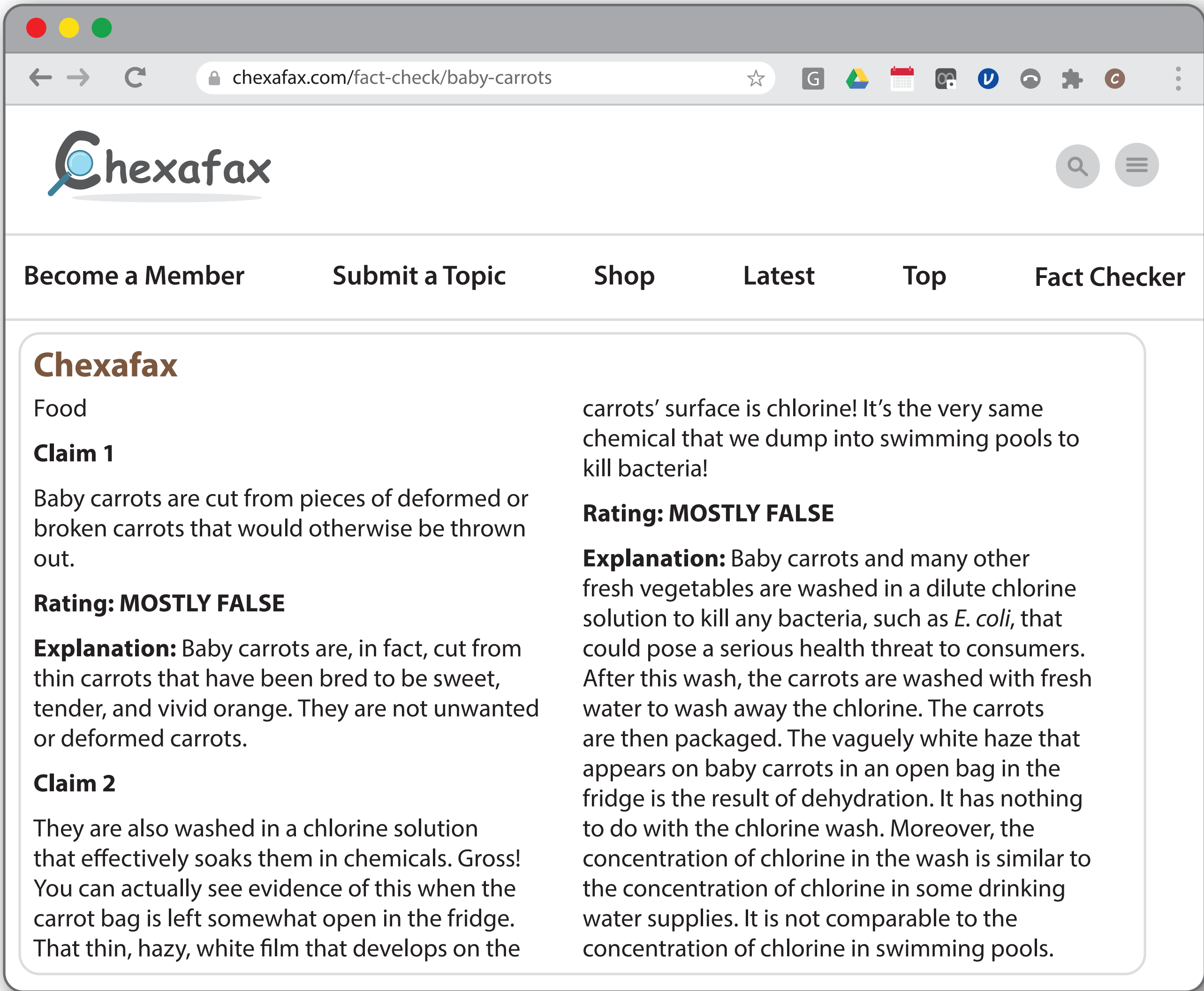
Chemical Reactions and Matter

Table of Contents

Put Yourself in This Scene

You're browsing a social media platform when you come upon this post.

You think this post seems both fishy and old, like maybe this isn't the first time you've seen it. You go to a website that is known for debunking falsehoods, myths, and conspiracy theories.



chexafax.com/fact-check/baby-carrots

Chexafax

Become a Member | Submit a Topic | Shop | Latest | Top | Fact Checker

Chexafax

Food

Claim 1

Baby carrots are cut from pieces of deformed or broken carrots that would otherwise be thrown out.

Rating: MOSTLY FALSE

Explanation: Baby carrots are, in fact, cut from thin carrots that have been bred to be sweet, tender, and vivid orange. They are not unwanted or deformed carrots.

Claim 2

They are also washed in a chlorine solution that effectively soaks them in chemicals. Gross! You can actually see evidence of this when the carrot bag is left somewhat open in the fridge. That thin, hazy, white film that develops on the carrots' surface is chlorine! It's the very same chemical that we dump into swimming pools to kill bacteria!

Rating: MOSTLY FALSE

Explanation: Baby carrots and many other fresh vegetables are washed in a dilute chlorine solution to kill any bacteria, such as *E. coli*, that could pose a serious health threat to consumers. After this wash, the carrots are washed with fresh water to wash away the chlorine. The carrots are then packaged. The vaguely white haze that appears on baby carrots in an open bag in the fridge is the result of dehydration. It has nothing to do with the chlorine wash. Moreover, the concentration of chlorine in the wash is similar to the concentration of chlorine in some drinking water supplies. It is not comparable to the concentration of chlorine in swimming pools.

You feel pretty sure that the website has debunked the baby carrot story, and you make a mental note to make sure that your friends and family get the true facts if they ever post this story on your timeline.

That's what this book is about—scientific literacy, which means knowing how to think about science topics that you read or hear about. Our world has 24-7 news, social media, and too many websites to count. The amount of information we have to sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism.

We will make our way back to the topic of what it means for something to be "chemical" by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is really important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

Variety of Bubbles

Bubbles come into existence in a variety of ways. Generally, bubbles are pockets of gas contained in a solid, in a liquid, or even in another a gas. In a gaseous environment, a thin liquid membrane separates the gas inside a bubble from the gas outside. Some bubbles form from ways that materials physically interact. Other bubbles emerge from chemical changes.

Suds from soap, shampoo, and other bath products are groups of bubbles. Sticky tension, called cohesion, between molecules of the liquid allows spherical bubbles to form around pockets of air. These bubbles tend to form on the surface of liquids, where the pressure around them is not very high and molecules from the liquid get involved in bubble formation.

Wave action churns the ocean in the surf zone, bringing pockets of air into the water, making it cloudy with bubbles. This can make a surf zone highly oxygenated, as the bubbles break down and molecules of oxygen dissolve into the water.

Photosynthesis in plants and algae results in the production of oxygen. Bubbles of oxygen can appear on the surfaces of aquatic organisms when the amount of oxygen produced is greater than the amount the organism needs. This is how aquatic photosynthetic organisms help oxygenate bodies of water.

On land, oxygen gas is released from the leaves of plants directly into the atmosphere. This oxygen does not form bubbles, though, unless leaves are coated with water or some other liquid to trap the oxygen gas.

When a carbonated beverage bottle is opened, the release of pressure allows tiny bubbles of carbon dioxide gas in the liquid to expand, giving the beverage a distinct fizziness. Water gets this carbon dioxide via a blast of pressurized gas. This is how a carbonated beverage is made fizzy. If the liquid is trapped under pressure in a sealed container, the carbon dioxide remains dissolved as a gas until the container is opened.

Along with lava, sulfurous gases can erupt from a volcano. As gases are superheated, they quickly expand. A rapidly expanding lava bubble can burst, splashing lava that made up the bubble's surface out across the landscape. This can be very dangerous to any nearby organisms.

When some types of lava cool, they harden into a rock called pumice. Bubbles of volcanic gas that were in the lava become trapped. This gives pumice a lightweight, partially hollow structure. "Rafts" of pumice float on the sea after undersea volcanoes have erupted. These rocks can drift on the ocean for thousands of miles. They are coincidentally useful for scrubbing.

At the Strokkur geyser in Iceland, water boiled by heat from magma deep in the ground explodes into the air at the surface. The bubbles rise so suddenly that a dome of water and gas forms for a brief instant. This geyser erupts every five to ten minutes, thanks to steady supplies of water and heat in the ground.

When scuba divers breathe air underwater, both their bodies and the air they breathe are under pressure. Nitrogen is a gas that does not dissolve in blood under normal pressure, but under higher pressure it does dissolve. If a diver goes to the surface too quickly after a long dive in deep water, the dissolved nitrogen is under less pressure, and it can expand and accumulate into bubbles of nitrogen gas in the blood. This is like bubbles of carbon dioxide appearing in a freshly opened bottle of a carbonated beverage. These nitrogen bubbles can cause serious injury, even death, as they travel through the bloodstream. Divers

suffering from decompression sickness, as it is called, can be treated by spending time in a decompression chamber and breathing air that does not contain nitrogen. Gradually, the pressure on the divers is reduced while nitrogen is emitted from their lungs.

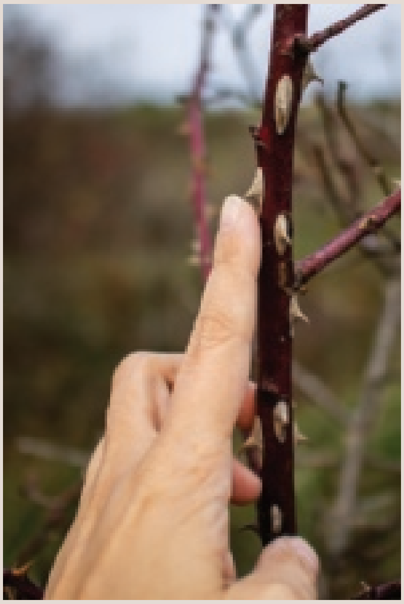
Humpback whales sometimes feed by exhaling underwater while swimming in a circle. This produces a curtain of bubbles around a school of prey, such as herring. The prey is briefly trapped as if in a net. Then the whale lunges upward through the school with its mouth open.

Sensing States of Matter

The human body is skilled at sensing states of matter. Dip your feet into a stream. Thermoreceptors in your skin and interpretation by your brain will tell you if the water is cool or warm. Pressure receptors will enable you further to tell that the water is a moving liquid. The same sensory organs will tell you when the stream is frozen solid. When pressing against a solid such as ice, the pressure sensors in your skin perceive the force on your body. Likewise, if you dip your feet into a pool of mud, the thickness of the fluid will be perceptible, and you can contrast it with the feeling of liquid water, which is less **viscous**.

Can you feel gases with your skin? Yes, if they're moving. Wind is the movement of air. And when the atmospheric pressure changes, you might be able to feel that, too. At sea level and under normal temperatures, the air is applying 14 pounds of pressure on every square inch of your body. Because your body is used to this amount of pressure, you don't really feel it at all. Only a change in pressure is likely to be noticeable.

Some people have a rare condition called congenital insensitivity to pain, or CIP. People with CIP do not experience pain, whether it's from a paper cut or a life-threatening stab wound. The condition appears to be connected to a specific gene involved in nerve pathways. People with CIP often must learn to avoid activities, not because they hurt but because other people have told them that they are dangerous. Studying CIP patients is helping the pain-medication industry to develop treatments for people who suffer from chronic pain.



A sudden change in atmospheric pressure occurs if you move up or down in elevation and can cause your ears to "pop." This is your body's way of equalizing the pressure on your eardrums.

Likewise, you're unlikely to notice the pressure of the ground against your feet much as you stand still unless you are riding an elevator. When the elevator drops, you might feel a release of pressure on the soles of your feet and a momentary feeling of lightness. When the elevator rises, you might feel slightly heavier for an instant as the elevator floor pushes up against your feet.

Our sense of sight can also help us perceive states of matter, but it's not completely reliable. Can you observe air and tell it apart from a vacuum by sight? Not unless the air contains visible vapor or particles of other matter. Some solids can look like liquids and vice versa. Sight is mostly useful in identifying solids, liquids, and gases once you have already learned to recognize them. For example, a balloon that is on the ground and does not shift with the wind is probably filled with water, while a balloon that appears to be trying to float away but is kept near the ground by a tethered string is probably filled with helium gas. But you would only know that from past experience or prior knowledge.

Your sense of smell can detect gases as well as small particles of solids and liquids that are suspended in air. Smoke is an example of particulate matter that your nose can detect.

You've learned about solids, liquids, and gases, but you might not be familiar with a fourth state of matter called plasma. While plasma is somewhat rare on Earth, it composes about 99 percent of the known universe. Plasma is superheated gas that is conducting electricity or being affected by some other electromagnetic field or energy. On Earth, lightning is an example of a plasma. Beyond Earth, stars are examples of plasma. We can perceive plasma with our eyes, but perceiving it with our sense of touch is not a good idea!

This plasma ball is full of gases at low pressure that are receiving a high-voltage electrical charge. Lightning and stars also consist of plasma.

Word to Know

A *state* is a particular condition that something is in at a specific time.

Vocabulary

viscous, adj. how thick, sticky, and semifluid a substance is

Chemicals in Nature

The word *chemical* can spook people. We hear about chemicals in food, water, shampoo, sunblock, clothing, and pretty much everything else. And the context is often an unsettling story about harmful substances that might get into our bodies. But *chemical*, both the noun and the adjective, does not necessarily mean bad, unnatural, or unhealthy. Water is a chemical. It also happens to be a chemical we need a lot of.

A chemical is a substance made of a particular set of atoms arranged in a particular way. The chemical formula for water is H_2O. This means the smallest unit of water contains two atoms of hydrogen combined with one atom of oxygen. Add another oxygen atom and the chemical changes. H_2O_2 is the formula for hydrogen peroxide, which is a very different substance (and much more dangerous) than water despite being different by just one additional oxygen atom. Because they are different chemicals, water and hydrogen peroxide interact with other chemicals in different ways.

For something to be chemical in nature, it simply means it is made of matter. An asteroid traveling through space has a chemical makeup. So does a stick of bubblegum. In a different sense, the word *chemical* might mean a substance manufactured by people through chemical processes and for specific purposes.

So, does it mean much if someone warns that the shampoo is made of chemicals? Not really. You'd need to know more about those chemicals to make a judgment. Are they artificial or synthetic chemicals, meaning substances that are not found in nature but have been manufactured? Do they mean harmful chemicals? Are they harmless to your skin but dangerous if discarded into a lake? If so, harmfulness is not judged by a simple yes/no analysis.

The aloe vera plant, for example, is used to make beverages. Extract from the aloe vera plant also happens to be on California's "Prop 65" list. The list features chemicals that are known to cause cancer, birth defects, or reproductive harm so that consumers can be aware of them, especially in sources of drinking water. Specifically, experiments with aloe vera in the drinking water given to lab rats showed a relatively high incidence of intestinal cancers. Does this mean aloe vera extract should not be in drinks sold for human consumption? Or in skin care products? So far, no, it does not mean that. But California's Proposition 65 law requires that potential consumers of aloe vera be given a warning on any products containing it.

Words to Know

A *substance* is a particular kind of matter with uniform properties. For example, sugar is a substance. So is water. Lemonade is a *mixture* of those two substances plus lemon juice.

Chemicals: Matter and Energy in Systems

You have probably learned about different systems on Earth, including the geosphere, hydrosphere, and atmosphere. In biology, scientists study localized systems of interconnected organisms and environmental factors. These are called ecosystems. Ecosystems are open systems because they require sources of energy and, usually, sources of matter to keep the system going. For example, a coastal wetland ecosystem needs energy in the form of sunlight, and it also depends on the flow of nutrients, oxygen, salt water, and other forms of matter.

Ecosystems vary. The coastal wetland ecosystem might be the focus of a marine ecologist. A coral reef expert will focus on a coral reef ecosystem. But someone who is studying an entire coastline might zoom out and study the wider ecosystem, defining it as an entire region of a specific sea. Zoom out further, and the whole Earth is a system.

How many systems are in this image? There's the coral reef ecosystem and a tropical island land ecosystem. Scientists could study them separately or together. There's also the atmosphere, which is an Earth system. These systems are open. Matter and energy flow among them, with most of the energy originating from the sun.

To really understand a system such as a coral reef or a rain forest, scientists keep tabs on the amount and types of matter that are within the system and flowing into and out of the system. And energy can travel into or out of a system as heat or light without requiring movement of matter. Sunlight travels to Earth through a vacuum. There's a lot of energy in sunlight, but no matter is moving from sun to Earth in the form of sunlight.

However, energy can also move in and out of a system within matter. For example, if a warm mass of seawater drifts into a coastal habitat, matter is involved. Energy can also be stored and transmitted in chemical form. When a right whale dies at the surface of the sea and eventually sinks to the bottom, many tons of chemical energy are taken to the dark, cold depths, where energy can otherwise be scarce. That energy eventually gets taken up by the organisms that consume and break down the whale carcass until nothing is left. Nutrients that were in the whale can eventually flow back toward the surface. Those nutrients can be absorbed by plankton at the base of the marine food chain and eventually end up in another whale.

The whale carcass represents a bounty of energy and matter for organisms of the ocean floor. Some of that energy and matter will eventually cycle back up toward the surface because of the way chemicals flow in an ecosystem.

Word to Know

A *nutrient* is a substance that provides nourishment essential for an organism's life, including its growth. For example, calcium is an important nutrient for bone development.

The Periodic Table

and Properties of Some Elements

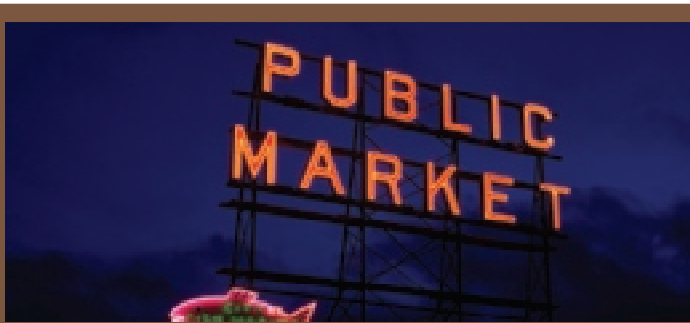
Oxygen, carbon, nitrogen, gold, silver, lead, and helium are all examples of elements. An element is matter made entirely of atoms of one kind. A pure piece of the element calcium is made of billions of atoms, all calcium atoms. Each element has its own distinct properties. Study of these properties has led chemists to organize them into a periodic table. The periodic table organizes elements in groups according to their properties.

1 H								
3 Li	4 Be							
11 Na	12 Mg							
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co
37 Rb	38 Sr					43 Tc	44 Ru	45 Rh
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm

11 Na

Sodium (Na) is a soft, silvery substance. At room temperature, sodium is a solid. At 98°C, it melts, or becomes a liquid. At 883°C, it boils, or becomes a gas.

One property of an element, for example, is the mass of one of its atoms. Another is the temperature at which it changes state. The structure of an element's atoms determine how they interact with other elements. Some elements react very easily with others, and some do not react at all. Some elements are excellent conductors of heat and electricity and others are not.



Neon (N) has melting and boiling points so low that it is almost impossible to find it in any state other than a gas. It is in a group of elements called noble gases, which do not react with other elements under natural conditions. Neon glows red when trapped in a vacuum discharge tube that is electrified. Other "neon" signs tend to use additional gases to give them other colors, but these other gases are not reacting with neon.

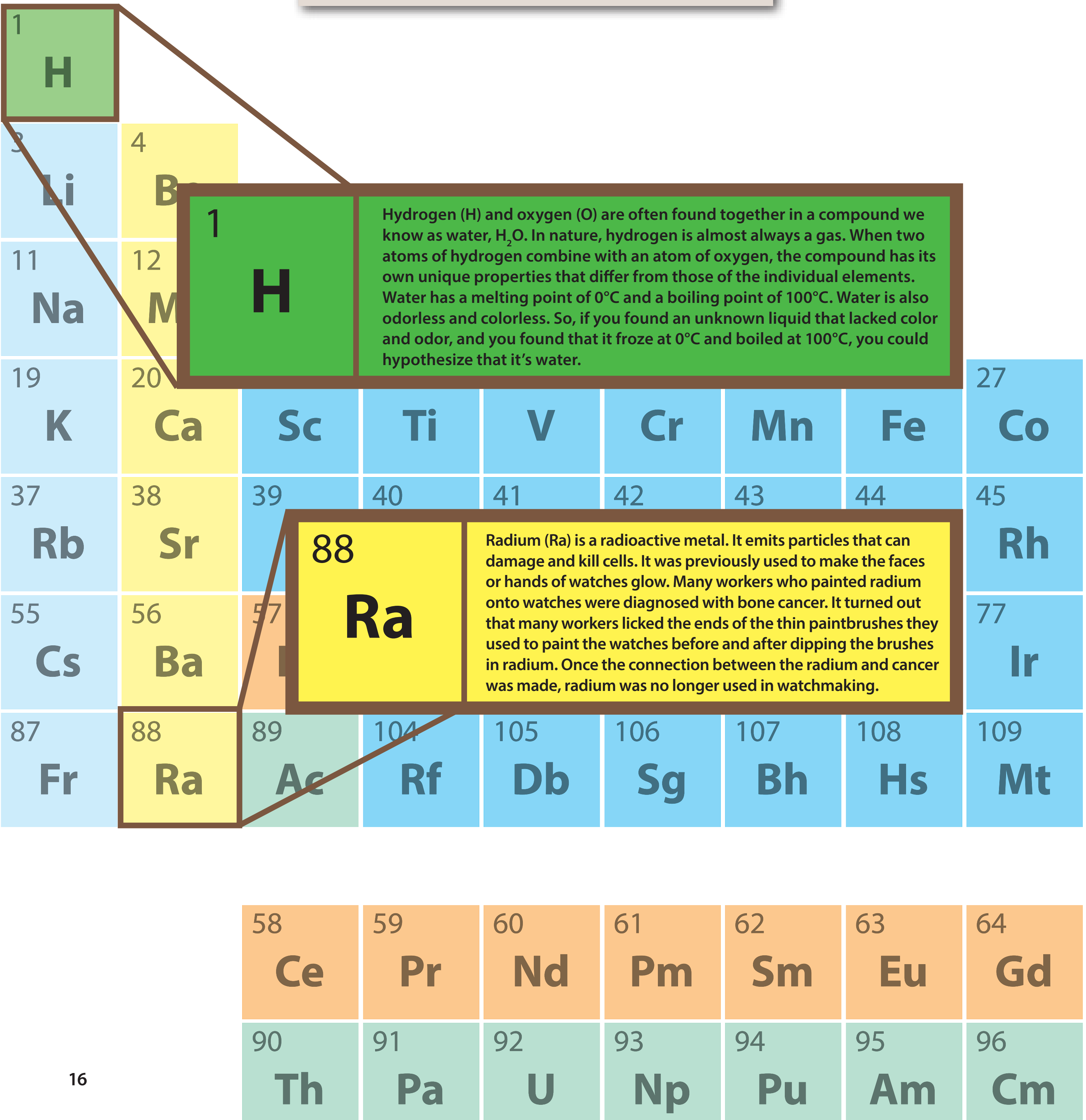
10
Ne

47
Ag

Silver (Ag) is a metal. It is solid until it reaches 962°C, then liquid until it reaches 2162°C. As a metal, it conducts electricity and heat very well. It is also relatively soft, making it a favorite for shaping into jewelry.

Words to Know

The words *elemental* and *elementary* refer to things that are basic or primary—the most simplified versions or parts of things. *Element* is the root of those words.



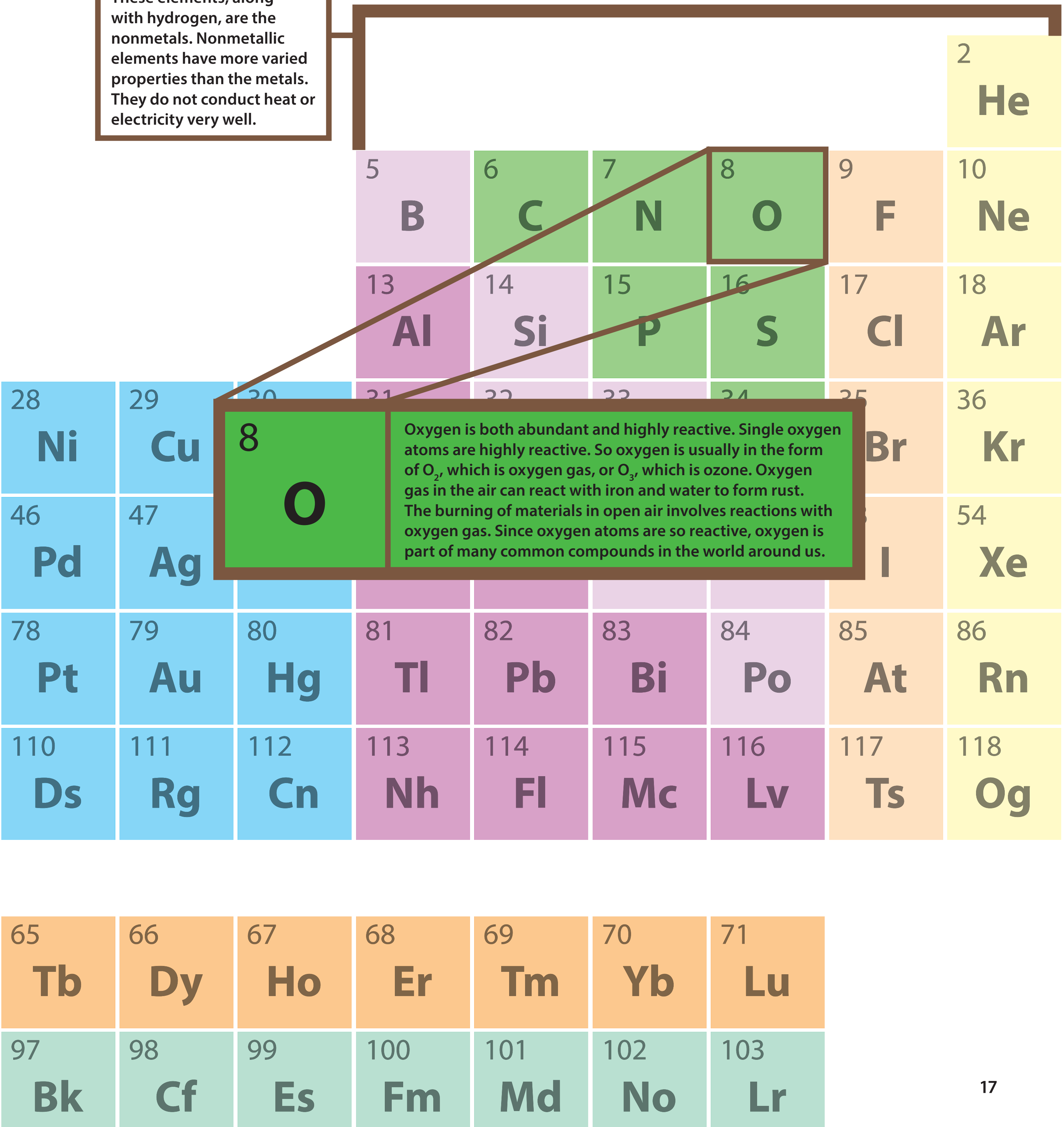
1 H

Hydrogen (H) and oxygen (O) are often found together in a compound we know as water, H_2O. In nature, hydrogen is almost always a gas. When two atoms of hydrogen combine with an atom of oxygen, the compound has its own unique properties that differ from those of the individual elements. Water has a melting point of 0°C and a boiling point of 100°C. Water is also odorless and colorless. So, if you found an unknown liquid that lacked color and odor, and you found that it froze at 0°C and boiled at 100°C, you could hypothesize that it's water.

88 Ra

Radium (Ra) is a radioactive metal. It emits particles that can damage and kill cells. It was previously used to make the faces or hands of watches glow. Many workers who painted radium onto watches were diagnosed with bone cancer. It turned out that many workers licked the ends of the thin paintbrushes they used to paint the watches before and after dipping the brushes in radium. Once the connection between the radium and cancer was made, radium was no longer used in watchmaking.

These elements, along with hydrogen, are the nonmetals. Nonmetallic elements have more varied properties than the metals. They do not conduct heat or electricity very well.



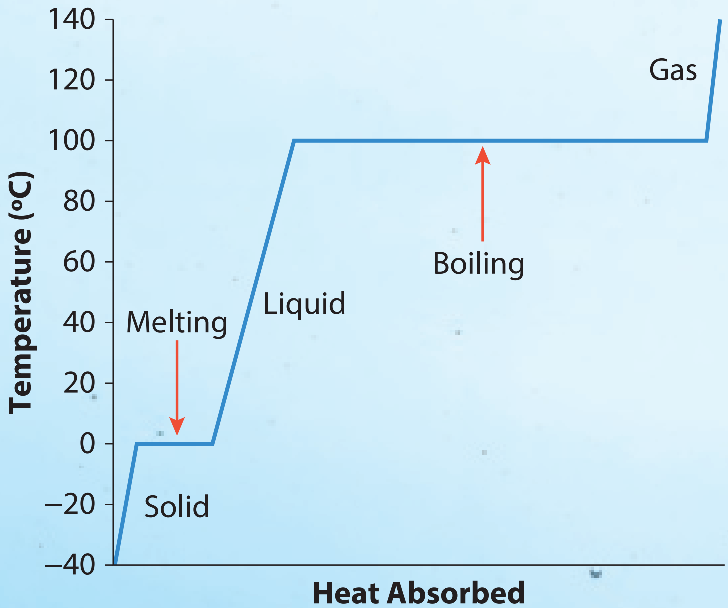
A Closer Look at Water

Before we take a closer look at some properties of water, let's pause and refresh our memories about **temperature** and states of matter. Whether a substance is in a solid, liquid, or gaseous state depends on the kinetic energy, or energy of motion, of its particles. Less kinetic energy means the particles get closer together. More kinetic energy increases the likelihood that particles moving apart may move around rather than merely vibrate in place.

When a substance is in a solid state and its temperature is rising, the particles gain more kinetic energy but do not yet break free of each other and form a liquid. At the melting point, the increasing kinetic energy goes into moving the particles apart—melting the solid into liquid—and the temperature will not increase further until the solid is fully melted.

Then, if energy is still being applied to the substance and the particles are getting even more kinetic energy, the temperature will rise again until the boiling point is reached. Once more, the temperature plateaus for a bit of time as added kinetic energy all goes into turning the liquid into a gas instead of raising the material's temperature. Beyond the boiling-point plateau, the temperature of the gas can then increase if the substance continues to acquire more energy.

The melting point of a substance can also be called its freezing point.



Now, on to temperature, states of matter, and water. If a teaspoon of water is chilled, once its temperature drops to 0°C it will begin to solidify. As energy leaves the freezing water, the molecules move less and rearrange into a solid crystal. The temperature of the water will not get any lower until all the water has frozen. If the surroundings continue to be very cold, the ice then can get colder than 0°C.

Water has a high specific heat. This means it takes a relatively large amount of energy to increase water's temperature. It takes 4.18 joules of energy to heat one gram of liquid water by 1°C. Iron, on the other hand, has a specific heat of just 0.46 joules per gram-degree. In real-world terms, this means that a piece of iron is going to get warm much faster on a sunny day than a similar mass of liquid water that is exposed to the same sunlight. Put another way, the iron gets much warmer than the water in an amount of time.

Specific Heats of Common Substances

Substance	Specific heat (J/(g•°C))
Liquid water	4.18
Ice	2.1
Aluminum	0.90
Iron	0.46
Silver	0.24

The high specific heat of water has a big effect on Earth. The ocean, which covers about 70 percent of Earth's surface, absorbs tremendous amounts of solar energy. Water's high specific heat means the ocean can absorb and store tremendous amounts of heat, even though the ocean is just a thin layer of water relative to Earth's overall mass. The heat-absorbing nature of water allows the ocean to soak up heat from the atmosphere over coastal areas. This is why central and southern California's coastal cities are not notably hot, even in summer. The high specific heat of water also means that bodies of water are slow to cool, and a large body of warm water can radiate heat to a coastal area even when the air temperature is cold and there's much less sunlight. Overall, the ocean makes coastal climates more moderate than those in inland areas. The ocean also prevents Earth from being as warm as it would be if it were not so watery. (Incidentally, water-filled organisms—including humans—are also less vulnerable to drastic changes in temperature than less hydrated life-forms.)

Water is known as "the universal solvent," because so many substances can **dissolve** in liquid water. In general, the **solubility** of a substance increases with temperature. Table salt, for example, dissolves more quickly in hot water than in cold water. The ability of water to carry many other substances makes it especially useful in organisms. A plant that draws up water from soil is also absorbing dissolved nutrients, such as phosphorus and calcium, carried in the water.

Connection

All the interesting characteristics of water described here are *physical* properties. None of them involve the fundamental change to the identity of the substance that occurs with a *chemical* reaction.

Vocabulary

dissolve, v. to become or cause to become incorporated into a liquid

solubility, n. how much a substance can dissolve into another

temperature, n. the average kinetic energy of the particles in an object or substance

Kitchen Chemistry

Cooks may not think of themselves as chemists, but they are. Cooking involves physical and chemical changes, adjusting acidity, breaking down molecules, using enzymes, and making ample use of water's unique properties. The transformations of ingredients into tasty dishes is all about skillfully using properties and processes to transform the ingredients.

Water, Solutions, and Mixtures

One of the most basic steps in cooking is making solutions, with water as the solvent. Making a broth? Boiling water increases the kinetic energy of the water molecules and makes it more likely that other substances added to the water will dissolve into solutes. Some things in the pot are not solutes because they do not dissolve. For example, shrimp in a chowder does not fully break down. Shrimp, potatoes, onion, and other things form a mixture with the broth. Only the substances that can dissolve are considered parts of the solution. If you leave a broth on a hot stove burner until all the water boils off, the dry substances left behind are the solutes. Remove the solvent, and the solutes remain. To rehydrate or reconstitute the original substance, add warm water. This is the basis for many canned or boxed foods, such as ramen noodles and condensed soups.

Proteins

Crack open a shell and drop an egg into a hot pan. The transparent egg "white" turns white, and the yellow yolk gets denser. If you remove the egg and eat it "runny," the yolk is still viscous, not solid. If you cook it longer, the yolk becomes dense and tastes different. Why can eggs produce different flavors, consistencies, and dishes? Eggs are loaded with proteins. When proteins are physically or chemically altered, they denature. This means their long, coiled molecules get stretched out and uncoiled and can bond in new ways with each other. In general, this means proteins get stiffer the more they are cooked.

Other techniques, such as whipping egg whites into fluffy meringue, work by blending bubbles of air among the proteins. Heating the mixture makes the proteins with the airy structure intact. If the trapped air escapes before the proteins solidify, the meringue will deflate, or "fall."

Emulsions

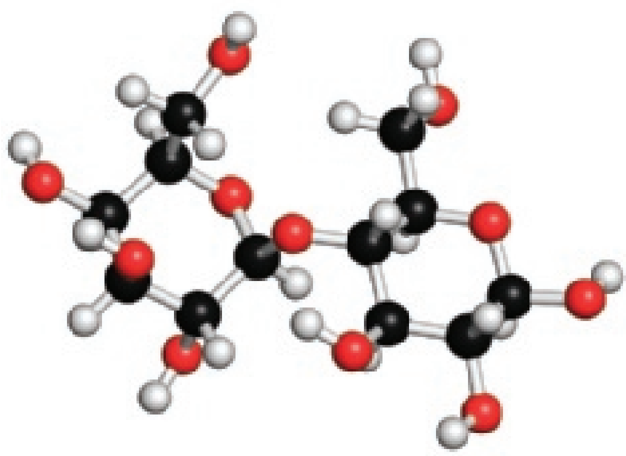
A basic salad dressing usually consists of vinegar, oil, a bit of water, and some other substances for taste, such as mustard, garlic, salt, and herbs. Oil provides a pleasing, fatty texture while vinegar provides a weak acid tang. Oil and vinegar do not easily mix. Because oil is less dense, it tends to float to the top of vinegar. A salad dressing needs to be an emulsion—a mixture of different liquids that is stable so the liquids don't separate. To emulsify an oil-and-vinegar dressing and make the emulsion more permanent, the dressing is heavily blended to distribute tiny droplets of oil in the watery vinegar solution. Mustard, mayonnaise, egg yolk, and other ingredients in the mixture can help surround droplets of oil and prevent them from gathering and rising to the top.

Soaps and other detergents are emulsifiers that help come cleanup time. They break greasy substances up and disperse them among water molecules, allowing them to be rinsed away more easily.

Enzymes

Enzymes are substances that help chemical reactions happen. In scientific terms, an enzyme catalyzes a reaction. Where food is concerned, enzymes can aid in cooking and in digestion. For example, lactose is a protein found in dairy products. Some people do not produce enough of the enzyme lactase that breaks down lactose. The result can be indigestion. Those lactose-intolerant people can either consume dairy products that have had the lactose removed, or they can swallow a tablet containing lactase prior to ingesting lactose-heavy foods such as milk, ice cream, and cheese.

Other enzymes can be used to prepare food. Pepsin is an enzyme that helps break down proteins, such as those found in steak. Sprinkling pepsin on beef before it is cooked breaks down some of the tough proteins, tenderizing the meat and making it easier to both chew and digest. Pepsin is one of several digestive enzymes in the human body, but pepsin can also be taken in tablet form to aid with digestion.



Lactose protein contains carbon atoms (black), oxygen atoms (red), and hydrogen atoms (white).

Cheese

Cheese making begins by heating milk in the presence of bacteria. The bacteria separate the solids in the milk from the liquid. The solids, called curds, are separated from the liquid, called whey. The curds are moved to a container and treated to another mix of bacteria, depending on the desired cheese. Temperature is increased to suit the bacteria, and the container is sealed to limit the amount of oxygen that can react with the other ingredients. In the absence of oxygen, the bacteria cause the lactose in the curds to ferment into lactic acid.

Fermentation is a kind of chemical reaction that occurs in the absence of oxygen. The lactic acid produced in cheese making lowers the pH of the mixture, meaning it gets more acidic. The combination of the increased acidity of the mixture and the activity of the bacteria turns the relatively soft curds into a smoother, more rubbery substance. If a hard cheese is being made, rennet is added. Rennet is a substance harvested from cow stomachs that has enzymes that help further separate the cheese's solids from the whey.

The pH is again controlled to determine the type of cheese that will be made. Gouda and cheddar need a pH of 6.55 when the rennet is added. Mozzarella and Brie need a pH of 6.45. Later on, when the cheeses are pressed and more moisture is drained from them, Gouda should have a pH of 6.5 while mozzarella should be at 5.25. Some cheeses are then aged, which allows bacteria and mold to continue to alter the chemistry and properties of the cheese. Authentic Parmesan, Parmigiano-Reggiano, is aged for at least two years. The aging process makes the cheese sharper and adds a flavor known as *umami*.

pH

Acids can help break down ingredients and even "cook" proteins such as fish and shrimp. A shrimp ceviche, for example, involves an acidic lime juice solution in which raw shrimp are bathed. A ten-minute marinade infuses the shrimp with lime flavor while slightly cooking the outside with acidity, not heat. A longer marinade can fully cook the shrimp in terms of altering the proteins. It is important to know, though, that this process differs from cooking with heat in that it does not destroy bacteria or parasites that may be in the food the way that heat does.

Umami

The human sense of taste has been divided into four categories: sweet, sour, salty, and bitter. Sweet signals the presence of carbohydrates. Salty is all about sodium chloride, NaCl, which our bodies need. Sour detects salt as well as acid. It is thought that this taste signals potentially harmful foods, but mildly sour things are enjoyable. Bitter often signals that something is basic and potentially harmful, but some bitter foods and drinks are enjoyed by some people. Tastes can change with age. Whether a food has a particular taste can also vary with how it is cooked, how old it is, and other factors. The Japanese word *umami* has been used to name a fifth taste that can also be called "savory." Umami is found in meat, cheese, soy sauce, and some types of fish. It signals the presence of protein.

Words to Know

An *acid* is a substance that has a pH less than 7.0. Vinegars and citrus juices are acids. A *base* is a substance that has a pH greater than 7.0. Baking soda is an example. A *catalyst* is something that helps a chemical reaction occur.

Burning and Charring

Some foods taste very different when they are cooked, especially if they have been browned or charred. Browning meat means cooking it on high heat until the exterior has changed color to a light to medium brown. This is a complex chemical process called the Maillard reaction. It involves interactions of sugar and amino acids, which are components of proteins. The overall effect is often described as sweet. Charring takes things further, causing carbohydrates and proteins to burn, leaving blackened areas that consist of carbon. This is a combustion reaction, one of the main types of chemical reactions. A toasted marshmallow is an example of combustion.

Table sugar can be heated into another substance called caramel. Caramelization is the process by which sugars are heated and changed into slightly different compounds, usually ones that are darker in color and nuttier in flavor. Caramelization can also introduce hints of bitterness or creaminess to a flavor. Caramelization can make some foods, such as onions, taste likely completely different things. Some recipes call for foods to be torched with a direct flame shortly before being served. Because substances are being burned, care must be taken when browning, charring, and toasting.

Science Fair Project: Modeling a Convection Current

By Seamus Foreman, Cyrus Howard, and Taylor Baskin

Mrs. Greer's Grade 10 Earth Science Class, Concord H.S.

Introduction

Convection currents drive the distribution of heat in Earth's spheres.

- In the hydrosphere, ocean currents wrap around the globe in a system called the global conveyor belt.
- In the atmosphere, convection currents consist of warm or cool air masses that rise, fall, and shift sideways because of differences in pressure and density. These movements, powered by the sun, produce wind, which helps power the water cycle.
- In the geosphere, warm rock of the mantle, heated by Earth's core, rises toward Earth's crust as cooler rock sinks. The top part of this convection cycle drags continents and other tectonic plates, causing continental drift.

Our goal was to develop a model using basic household materials to visualize how convection currents transport both thermal energy and matter.

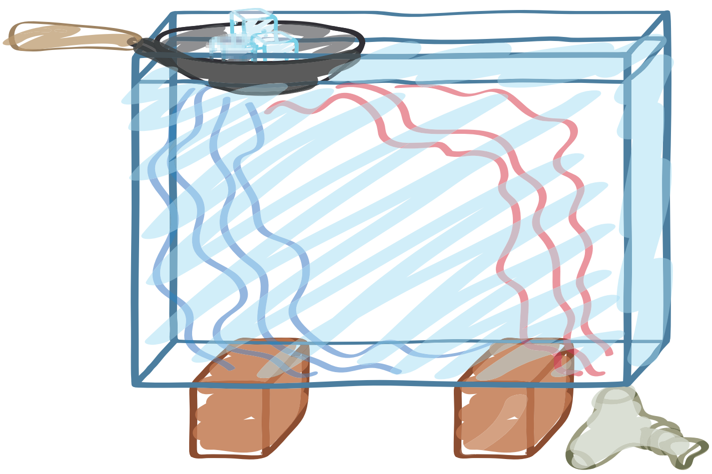
Materials We Used

- 10-gallon aquarium tank
- two large blocks
- red and blue food coloring
- tube sock full of rice, heated in microwave for 1 minute
- turkey baster
- 6-inch strainer, fine mesh
- ice to fill strainer, liquid water to fill tank

Our Method

Our model consisted of a 10-gallon aquarium tank sitting on top of two large blocks. The tank was filled with water of room temperature. We heated a sock full of rice and stuffed it under the right end of the tank. The hot rice modeled a source of heat, like a sun-warmed area of Earth's surface. We propped a metal mesh strainer full of ice so that the ice dipped below the surface of the water on the left side of the tank. Ice water from the strainer modeled a source of cooling, such as cold runoff from Greenland's melting ice cap. Then, we added a tablespoon of blue coloring to the cool water and used a turkey baster to add a tablespoon of red food coloring to the warmer water in the bottom of the aquarium directly above the heat source. We observed the convection current that developed. It was made visible by the movement of the cool, dense water being colored blue and the warm, less-dense water being colored red.

Our Results



Our model worked well for approximately three cycles of the convection current. The chilled blue water was denser, so it sank toward the bottom. It also flowed to the right along the floor of the aquarium to fill the void left by the rising, less-dense red water. The red water flowed leftward along the surface and merged with the cold water. After three cycles, the colors had melded into a purple color. The counterclockwise flow continued, but the mixed colors made it more difficult to tell apart the warm water from cold.

Vocabulary

density, n. the amount of matter in a volume of a substance or object, often measured in grams per milliliter or kilograms per cubic meter

Connection

Primary modes of heat transfer are radiation, conduction, and convection. Convection occurs in the movement of fluids. A fluid is not necessarily a liquid. Gas, such as the atmosphere, is also fluid. The rock of Earth's mantle is solid, yet it is fluid because of the intense heat and pressure it is under. In the model described here, heat from the hot rice pack conducts through the floor of the tank into the water.

Matter on the Move

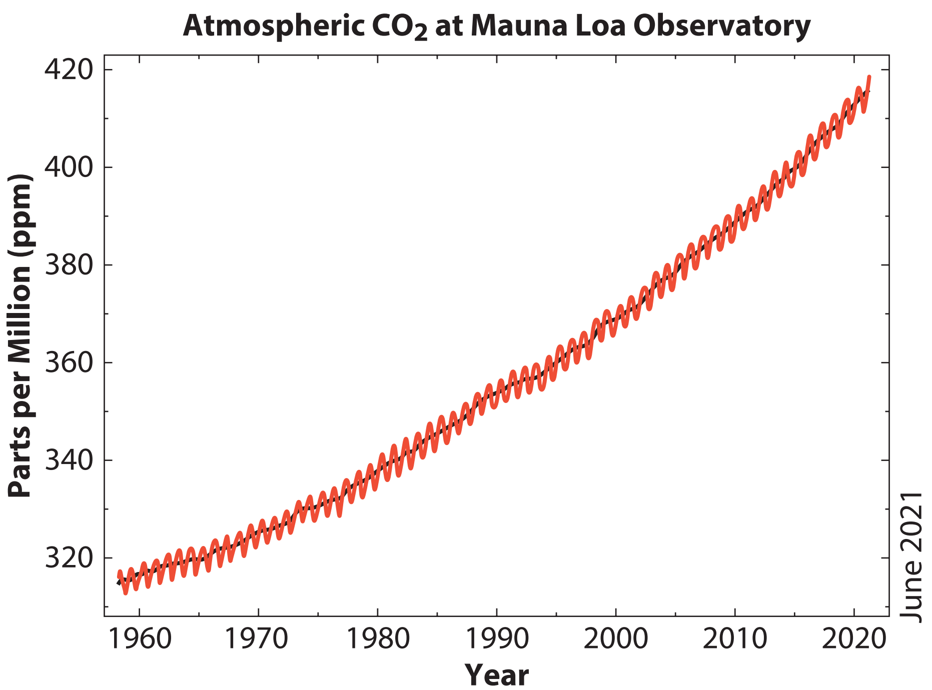
A lot of matter on Earth is on the move, into and out of natural systems. Some movements that occur over years, centuries, or millennia are hard to perceive on a short time scale. Others occur more quickly before our eyes.

Water is on the move. In one day, a large rainstorm can dump several inches of rain in a place, such as a forest ecosystem. That can add up to hundreds of thousands of tons of water falling on one system. Currents and tides mean very little seawater sits still on any given day. Rivers are constantly moving large volumes of water, especially in spring when they tend to flood. Snowfall is another form of water transport in the water cycle. When snow falls and accumulates in winter and continues to do so over time, it can form an ice cap that has so much weight that it causes Earth's crust to sit lower, like an overloaded boat. If the ice cap eventually melts away, the weight on the crust is reduced, and the crust can rebound upward, like a small boat whose passengers have leapt overboard.

Years of low precipitation in California caused the underlying crust to rise up because there was so much less water weight sitting on the continent.

Even the ground below us is on the move. A phenomenon that can cause an area of Earth's crust to rise is a prolonged drought. Just as the melting of ice removes mass from a landmass, the steady flow of water downhill from a landmass and the absence of precipitation to replace the lost water can cause a similar rebound. This occurred in California and much of the western United States over the course of a multi-year drought, from approximately 2003 to 2016. Measurements of the relative heights of different points of Earth's surface in the region, including mountaintops, showed that those locations had risen over the course of those years, as billions of tons of water were used and ultimately drained away from the continent without being replaced by rain or snowfall.

Another large-scale movement of matter is the movement of carbon out of Earth's crust and into the atmosphere and hydrosphere. Humans have removed large amounts of coal from the ground and pumped large volumes of oil and natural gas from vast "fields" of these fossil fuels that were in the ground for millions of years. These fuels have been burned, which converts them into carbon dioxide gas and water vapor. Carbon dioxide has accumulated in the atmosphere at a high rate. It has also dissolved into the ocean.



Since 1960, the concentration of carbon dioxide in the atmosphere has gone from just over 300 parts per million (ppm) to nearly 420 ppm. This is largely due to burning fossil fuels, which has moved carbon from the geosphere to the atmosphere.

The Smokeless O_2 Stove

Product Review—A few weeks ago, my friends and I were gathered around a campfire by the lake, enjoying the warm glow of the flames and the nostalgia-inducing aroma of the smoke—until the wind kicked up and started blowing smoke into our faces. The fire was built by a former Eagle Scout in our group, and we were using dry, seasoned oak logs, so it should have been smokeless. It was a fun night, but the next day we all reeked of smoke and our eyes were irritated. My lungs also felt congested and tired.

By some strange coincidence, the next day I saw an ad pop up for an outdoor fireplace called the O_2 Stove, which promised to be smokeless. "Sounds great!" I thought, so I clicked on the ad and learned more about it. At $199, it seemed pricey, so before I impulsively ordered it, I discussed it with my wife. She's frugal, but she loved the idea of an outdoor fireplace with a lower carbon footprint—we don't want to make climate change worse. She also prefers having a husband who doesn't smell like campfire smoke. We ordered an O_2 Stove, and it arrived within two days.

There was very little setup required. The whole thing is a stainless-steel cylinder about two feet wide. A series of holes at the base allows the fire to draw up air from above the ground. Logs sit on a raised grate, which is also stainless steel. It is a simple design, but it works so well because it is all about making combustion as efficient as possible. What does that mean?

Vocabulary

flammable, adj. the capacity to be easily set on fire

Combustion is a chemical reaction. Oxygen is one of the reactants, along with a second, flammable reactant that's usually wood, which is a chemical compound of carbon and hydrogen (also known as a hydrocarbon). What makes campfires and poorly designed outdoor fireplaces so smoky is the inefficient combustion reaction, often due to a lack of oxygen. Think of a rib smoker at a BBQ joint. It limits the amount of air that gets inside, which means the fuel burns slowly and gives off a ton of smoke. This is an inefficient, "incomplete" combustion reaction. Instead of the oxygen and carbon-based fuel burning completely, producing just carbon dioxide and water vapor while releasing heat and light, it also produces black carbon, or soot, and carbon monoxide. These are the products that add up to cough-inducing smoke.

The O_2 Stove is named for its ability to maximize the amount of oxygen (O_2) that combines with the fuel. It's able to achieve a much more complete combustion reaction. This stove produces a ton of heat and light and very little smoke. The next day, there is very little ash to remove from the bottom of the stove, no cinders, and very little soot on the sides. Even if it's breezy out, the O_2 Stove burns so well that the wind won't ruin the party.

Spot the BS

Heads up! There's some **b**ad **s**cience on this page. Can you detect what is wrong about the suggestion that the O_2 Stove could have a lower carbon footprint?

Consider the Source

This "article" is an advertisement. This type of ad, called an advertorial, has gotten more common as print publications are less able to make money from traditional advertisements. The advertorial is designed and written as though it is a review or testimonial by a customer or editor, but a closer look at fine print often reveals that the publication was paid by the product maker to feature the product.

Everyday Reactions

Chemical reactions occur all around you. Some reactions are initiated by human-made technologies or processes. Others occur at the cellular level in organisms, or in mixing bowls in kitchens.

Cellular respiration is a series of chemical reactions that converts oxygen and a sugar into carbon dioxide and water. The reaction releases the energy of chemical bonds and reestablishes them into new chemical bonds that power all of a cell's activities. Respiration is really a complicated sequence of reactions. One kind of cellular respiration needs oxygen. This is aerobic respiration. If oxygen is scarce, anaerobic respiration occurs. In this case, less energy is released. One of the products of anaerobic respiration is lactic acid, $C_3H_6O_3$. The muscle cells of an athlete who is exerting herself so much that her body's demand for oxygen can't be met are likely going through anaerobic respiration. This can cause a perceptible buildup of lactic acid in muscles and a burning sensation.

The balanced chemical equation for aerobic respiration is:

$$C_6H_{12}O_6 + 6O_2 \Rightarrow 6H_2O + 6CO_2$$

If the ratio of oxygen molecules to glucose molecules is less than six to one as shown in the equation, then respiration can shift from being aerobic to anaerobic. The equation then looks like this:

$$C_6H_{12}O_6 \Rightarrow 2C_3H_6O_3$$

Fermentation is an anaerobic process that breaks down glucose into other products. We rely on this process to make easily stored products such as kimchi, sauerkraut, yogurt, alcohol, and breads. The bacteria digest the sugars in the dough, producing lactic acid. This gives sourdough bread its slightly sour taste and its name. The bubbles that form in bread dough that help give bread its airy texture are from carbon dioxide that is produced as yeasts break down the sugars into carbon dioxide and alcohol. Different yeasts and bacteria are used to produce many different food and beverage products.

Methanogenesis is a type of anaerobic respiration that produces methane, which is a hydrocarbon that can be burned to produce heat. It is extracted from the ground and delivered to stoves, furnaces, and electric power plants as "natural gas," but it is also produced in the digestive tracts of some animals, particularly dairy cows. These animals' stomachs harbor methanogenic bacteria that make use of carbon dioxide and water that become available as the cow's food begins to digest. The methanogens convert the CO_2 and H_2O to methane. Because methane is a more powerful greenhouse gas than carbon dioxide, there is concern that the large numbers of cows emitting methane are a driver of climate change. Some scientists and dairy farmers are working on altering the diet of dairy cows so they emit less methane.

Photosynthesis is the opposite of respiration in terms of products and reactants. (The steps of the chemical reactions are quite different, though.) Energy from sunlight powers the conversion of carbon dioxide and water to oxygen and sugar. This occurs in plants and algae, allowing them to produce the sugar glucose, $C_6H_{12}O_6$, for themselves

Photosynthesis involves a series of chemical reactions resulting in the molecule glucose. The energy in the bonds of the glucose molecule provides plants with most of what they need to live.

$$6H_2O + 6CO_2 \Rightarrow C_6H_{12}O_6 + 6O_2$$

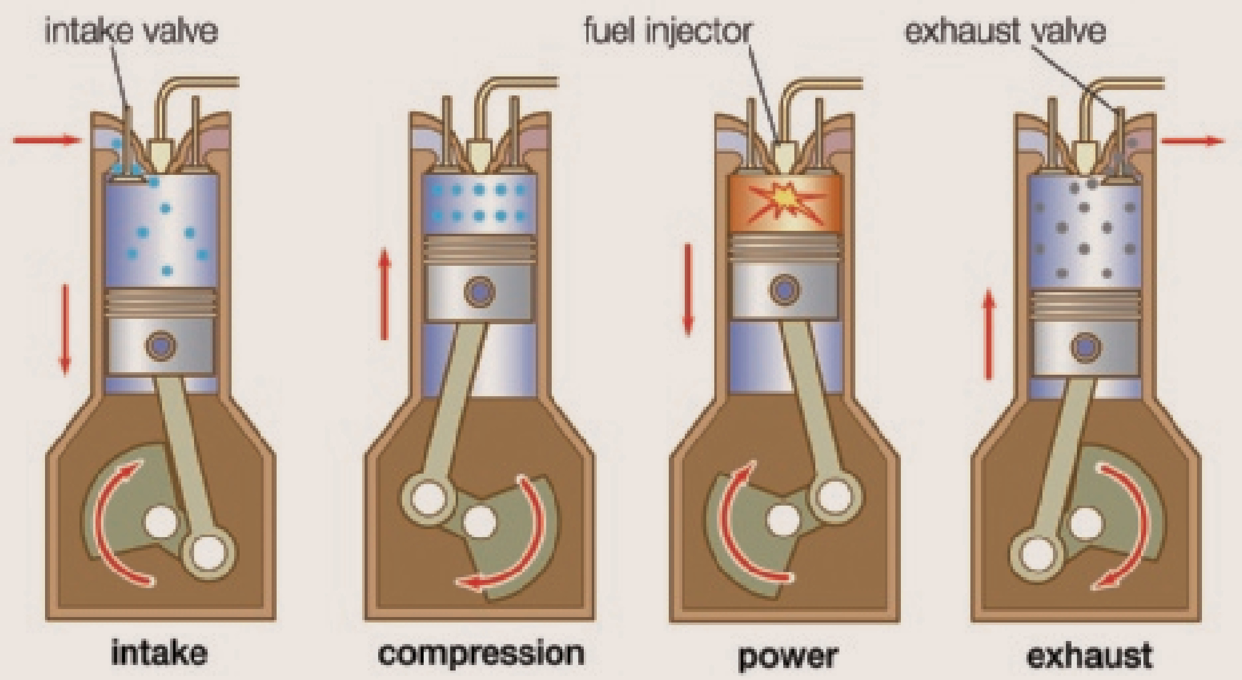
Combustion is the burning of oxygen and another compound, often one containing carbon. The products are usually water and carbon dioxide. The burning of methane in a Bunsen burner is classified as combustion. It occurs quickly and at high temperatures. The high temperatures of combustion reactions are useful for when high heat is needed. That heat can either be the desired product, or it can be converted to mechanical energy. For example, in a car's combustion engine, a mix of air and gasoline is ignited by a spark. The rapid heating and expansion of these products cause the piston to move. The piston is connected to a shaft. The shaft is connected by gears to a set of wheels.

Octane, C_8H_{18}, is a compound in gasoline. The equation for combustion of octane in a gasoline-fueled engine is:

$$2C_8H_{18} + 25O_2 \Rightarrow 16CO_2 + 18H_2O$$

The chemical energy in the fuel and oxygen becomes mechanical energy that moves the car. The products, carbon dioxide and water, are exhausted from the car via the exhaust pipe.

Unlike cellular respiration, true combustion cannot work without oxygen.



Other types of reactions can be classified by how the reactants and products form. In a combination reaction, two elements or compounds combine to make a single product. For example, two atoms of sodium and a two-atom molecule of chlorine, called chloride, can combine to form sodium chloride, or table salt. This occurs because sodium and chloride are ions, meaning they are charged, and in this case their opposite charges attract each other. Carbon, if ignited, can combine with oxygen to form carbon dioxide.

The opposite of a combination reaction is decomposition: a single compound is broken down into two products. This usually occurs thanks to energy applied to the compound. For example, when electricity is passed through water, the water molecules can decompose into hydrogen and oxygen.

In a single-replacement reaction, one element replaces another. An example is silver tarnish. This can occur when a silver object comes into contact with hydrogen sulfide gas, which is given off by decaying organisms. The silver replaces the hydrogen, resulting in silver sulfide and hydrogen gas. The tarnish has a different color than the pure silver, which is a sign that a chemical reaction has occurred.

A double-replacement reaction occurs in a water-based solution of ionic compounds. The positively charged and negatively charged ions swap partners. For example, if a solution of hydrochloric acid is combined with a sodium hydroxide solution, the sodium and hydrogen trade places, forming sodium chloride (salt) solution and water:

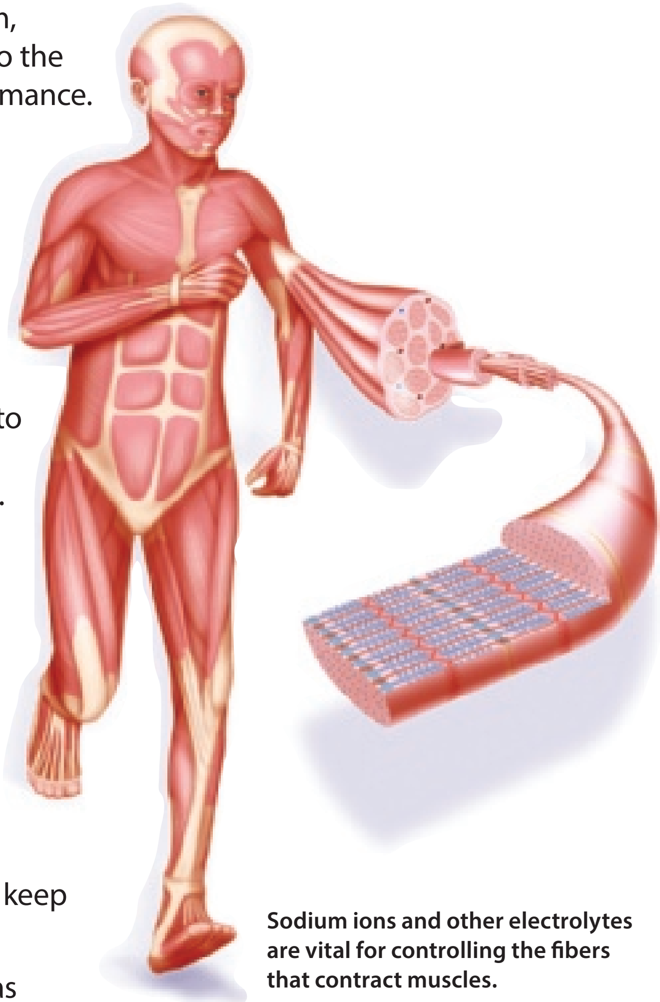
$$HCl + NaOH \Rightarrow NaCl + H_2O$$

Electrolytes and Sports

Browse the coolers in a convenience store, and you'll find a rainbow of bottled drinks. Many target athletes and promise improved performance. These drinks offer **electrolytes**. Several electrolytes—such as sodium, potassium, calcium, and magnesium salts—are important to the human body and, yes, to optimal athletic performance. Electrolytes are so named because when they dissolve in water, they form a solution that conducts electricity. Nerves and muscles are controlled by electrical signals, and electrolytes, are the means of control.

When the nervous system signals to a muscle fiber to contract, a sodium ion—a sodium atom with a positive electrical charge—flows into the muscle cells of the fiber, and potassium ions flow out. To relax the muscle, the reverse occurs.

Sodium is also important as a regulator of fluid levels in the body. Sweating releases water as well as sodium chloride (NaCl), which is why sweat tastes salty. Without replacing lost fluid and sodium, your body can struggle to provide water to tissues. Muscles are more likely to cramp and simply not work. Even your brain will have trouble processing information. Severe dehydration can be life-threatening, let alone a problem for an athlete who wants to keep performing.



Sodium ions and other electrolytes are vital for controlling the fibers that contract muscles.

Drinks that have some sugar for energy as well as electrolytes can be better than water to help an athlete recover and keep going. However, at a certain point the body has more than enough energy and electrolytes. Organs such as the kidneys will send excess electrolytes out of the body. Excess sugar will be converted to fat. So, one or two electrolyte drinks might be a good idea before or during exercise or competition, but there is no reason to drink them as a full-time replacement of water.

Vocabulary

electrolyte, n. a mineral that becomes an electrically conductive ion when dissolved in a solution

Winner-ade

was scientifically formulated by a team of chemists, team physicians, coaches, and athletes at Whitman University in 1984. Winner-ade helped Whitman teams win three national titles and eight conference championships in the ’80s, before Winner-ade went international and became the #1 sports drink on the market. Winner-ade provides vital electrolytes and sugars to keep your muscles firing without cramping. A 30-ounce bottle of Winner-ade provides 380 mg of sodium and 110 mg of potassium. These electrolytes are as important as oxygen to your muscles. Sugars add 48 grams of pure energy, for when your body has burned through your recent meals yet your muscles need energy ASAP. If you’re not looking to load up on water weight, Winner-ade 10X is a gel packed with the same electrolytes and energy as a 30-ounce bottle but in a 3-ounce pouch that you can pull from your pocket while running a marathon.

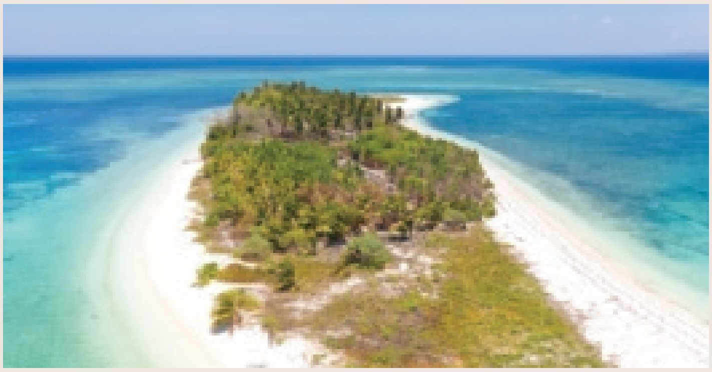
Spot the BS

There’s some bad (or at least questionable) science on this page. How is the ad playing fast and loose with the truth about electrolytes?

Potable Water in a Pinch

Humans are made of—and need—lots of water. Water is the solvent through which nutrients and dissolved compounds can be delivered to cells. What can you do if you are stuck somewhere without a source of clean, potable water? In this feature, we'll describe some scenarios involving poor supplies of safe drinking water and how to survive them.

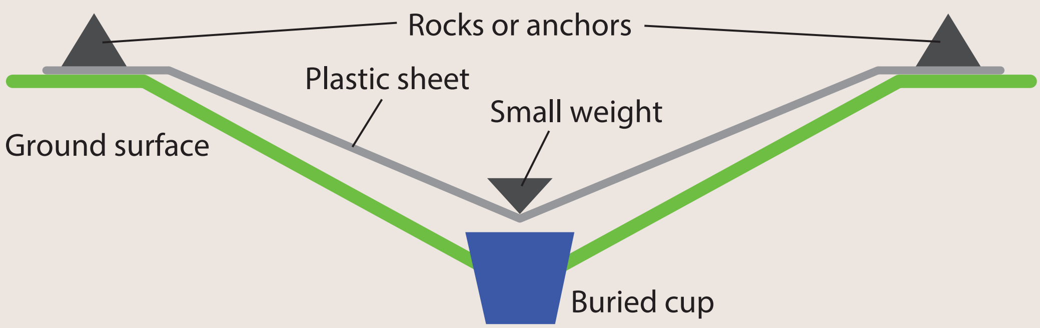
Shipwrecked on Desert Island



Imagine you are stranded on an island with no standing fresh water. Coconut water is delicious, but if there aren't many trees or if you can't scale the trees to gather the nuts, you might be in trouble. Meanwhile, as a resident of an island surrounded by the sea, you'd soon paraphrase Coleridge's ancient mariner: "water, water, everywhere, but not a drop to drink." Seawater is too salty to safely consume. If you have materials in which to gather rainwater, that might save you. But what if weeks pass without rain?

This is when you'd need to set up a solar still, which is really a miniature version of the water cycle. For this mission, you'd need a transparent, flat material, such as a sheet of plastic, to make a kind of tent over a shallow pool of seawater. You basically want a greenhouse in which the sun's energy evaporates the salt-free water out of the seawater while trapping the vapor so it can condense on the plastic. Angling the plastic makes droplets trickle down to drip into a collection cup. When the pool of salt water dries up, just add more seawater.

A still can be built in the damp sand with nothing more than a sheet of plastic and a cup. There are also packable solar still kits that can be tethered to a life raft or anchored in shallow water and left alone to operate with minimal oversight.



Stuck in a Swamp

Let’s say you’re stuck in a swampy environment. There is plenty of water, but it’s full of microscopic parasites and other things that will make you dangerously ill if you drink it. Meanwhile, you don’t have any sheet material with which to make a solar still. But you do have a source of fire, a vessel to contain water, and the clothes on your back. Step 1: Use a cotton T-shirt as a strainer to filter water into the vessel. This will remove some of the undissolved things like suspended bits of mud and some of the organisms. Step 2: Build a small fire, and boil the filtered water. This will kill organisms that are still in the water. Why? Boiling water is just a way to make it very hot. Nothing about the boiling action kills, but the intense heat denatures proteins and breaks down cell walls of organisms. Don’t boil it too long, though, as you’ll then lose a lot of the water to evaporation. Let the water cool, then drink away.

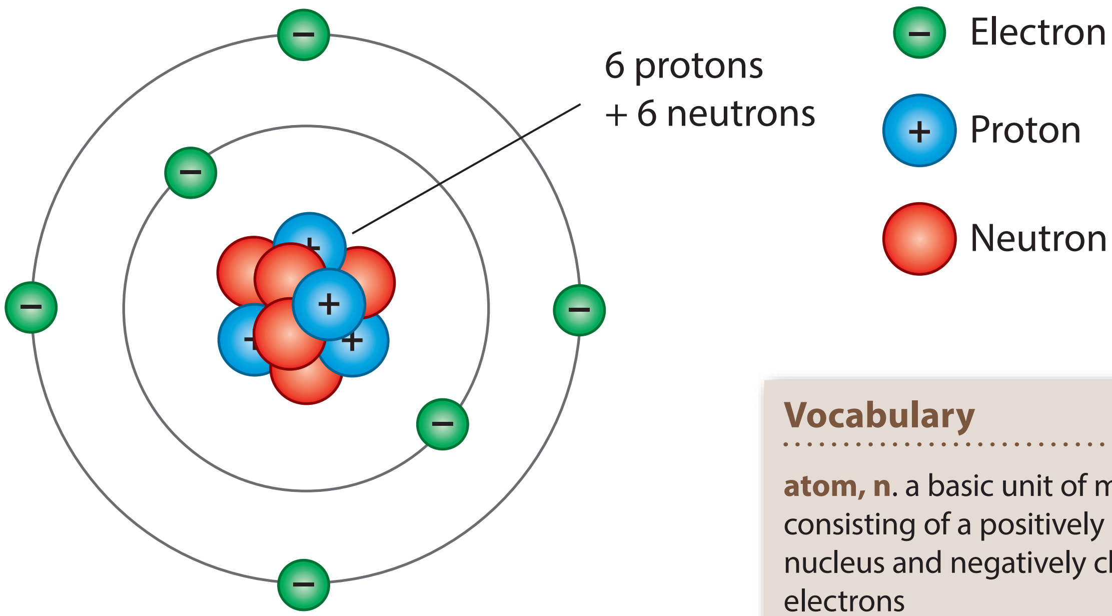
Plenty of Water, No Way to Boil

Suppose your plane crash-lands in the tundra of Iceland. There are small pools of murky water here and there. You have matches but no metal vessel in which to boil water. You do have a plastic one-liter bottle and some luck. You find some water purification tablets in the plane’s emergency kit. How do the tablets work? Unlike filtering or distillation, which separates solutes from the solvent, purification uses chemicals to kill or deactivate solutes. The main ingredient is often chlorine dioxide, which is the same thing used to kill germs in swimming pools and some municipal water supplies. Once this compound is added to water, it dissolves into chlorine ions and oxygen. The chlorine ions damage proteins and cell structures of organisms such as bacteria in the water. Because this requires contact between the ions and the target organisms, you should allow chlorine to work its chemical magic for at least ten minutes before you drink the treated water. It’s also very important to follow instructions on the tablet packaging to avoid putting too much chlorine in the water, which can make you sick. If it’s possible to filter the water before chemical treatment, this is also advisable.

Atomic Theory

All common matter is made of **atoms**. But atoms themselves are full of empty space. The center of an atom, called the nucleus, takes up a small fraction of the overall volume of an atom. The rest of the volume is determined by the electrons, which are much smaller particles that are found moving around the nucleus. Most drawings of atoms are very simplistic and are based on the Bohr concept of the atom.

An atomic model with particles drawn to scale would be more accurate, but it would be impossible to see. Here's a way to think about it—if a golf ball held in your hand represented a proton in the nucleus, the electrons would need to be a mile away. That's how much empty space there is within atoms. So, for practical purposes, models of atoms need to leave out most of that empty space.



Carbon Atom

The Bohr model, named for Niels Bohr, the physicist who helped develop the atomic theory, is good for visualizing the parts of atoms, but it is not drawn to scale. It also suggests that electrons are on fixed tracks, which is not accurate.

Vocabulary

atom, n. a basic unit of matter consisting of a positively charged nucleus and negatively charged electrons

molecule, n. an arrangement of two or more atoms that share electrons

compound, n. a distinct substance formed by the chemical union of two or more ingredients

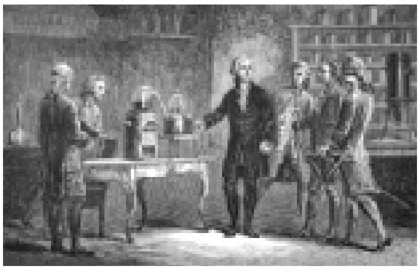
Ideas about Atoms

The idea of atoms being the fundamental building blocks of matter dates back 2,500 years, but for most of that time, science as we know it did not exist. Scientists did not have the tools to confirm the existence of atoms or their components.

500 BCE Greek philosophers theorize that everything in the universe consists of four elements: fire, air, earth, and water.

430 BCE Democritus develops a theory that all matter is composed of solid, indivisible things called atoms, which come in an infinite variety of shapes and sizes.

1789 CE Chemist Antoine Lavoisier determines that mass is neither created nor destroyed in chemical reactions. Among his many accomplishments was determining the chemical composition of air.

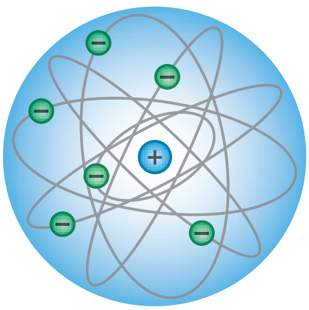


1803 John Dalton determines the relative weights of atoms, which he thinks are tiny, indestructible particles. He observes that elements can be combined in different compounds.

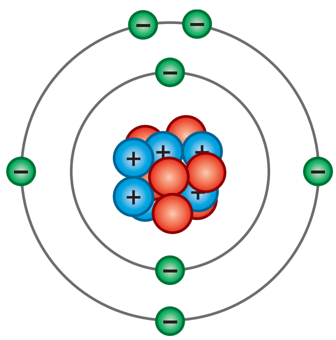
1897 J. J. Thomson discovers electrons, which he thinks are embedded in a sphere of positive electrical charge.

1904 Hantaro Nagaoka theorizes that electrons are moving in orbits around a central nucleus.

1911 Ernest Rutherford finds the nucleus and its positive charge and determines that electrons are orbiting the nucleus from a considerable distance.



1913 Niels Bohr's atomic model builds upon Rutherford's by showing how electrons can move from one orbit to another, depending on their energies.

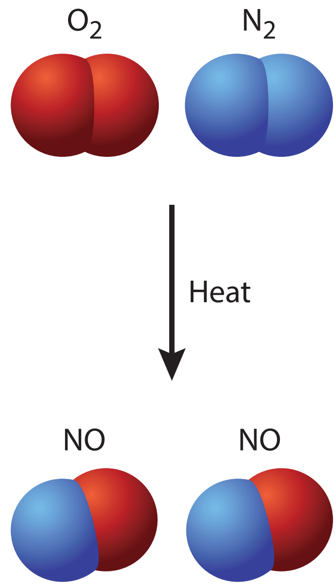


1926 Erwin Schrödinger develops the quantum mechanical model, in which electrons are not on neat tracks. This model describes the probability of finding electrons in clouds of certain shapes.

1932 James Chadwick confirms that an atomic nucleus contains neutrally charged particles, called neutrons, in addition to positively charged protons.

Molecules and Compounds

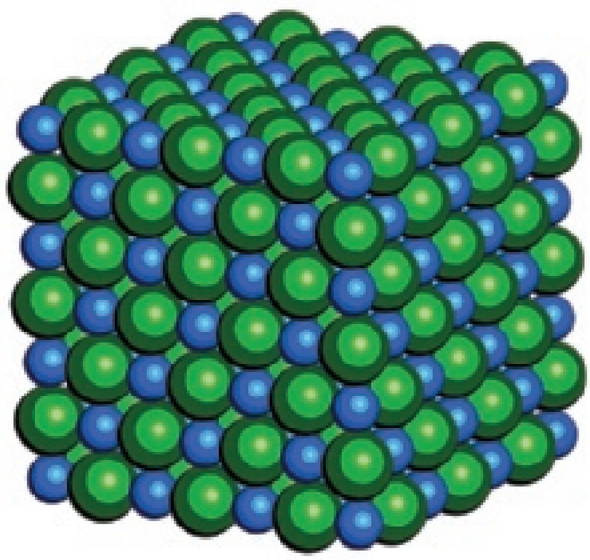
Atoms are often found bound together. This is due to some atoms having outermost electron clouds that are less stable when they are incomplete. So, if two atoms meet and both can become more complete by sharing some of their electrons, that's what they will do. These clusters of cooperating atoms are **molecules**.



A molecule can consist of two atoms of the same element. For example, nitrogen in its gaseous form is often found in a two-atom molecule, N_2. The same is true of oxygen, O_2.

When two or more elements form a molecule, this is known as a molecular **compound**. When nitrogen gas (N_2) meets oxygen gas (O_2) under intense heat, the two-atom molecules can break apart and form new molecules called nitric oxide. In this case, one atom of nitrogen bonds with one atom of oxygen, so the formula is NO. O_2 and N_2 and NO are all examples of molecules that form due to shared electrons. This is called covalent bonding.

Compounds can also form via ionic bonding. An ion is an atom or molecule that has a positive or negative charge. For example, an atom of sodium on its own often has a charge of +1. It has one more proton than it has electrons, giving it a net charge of +1. On the other hand, a single chlorine atom has one more electron than it has protons. So it has a charge of –1.



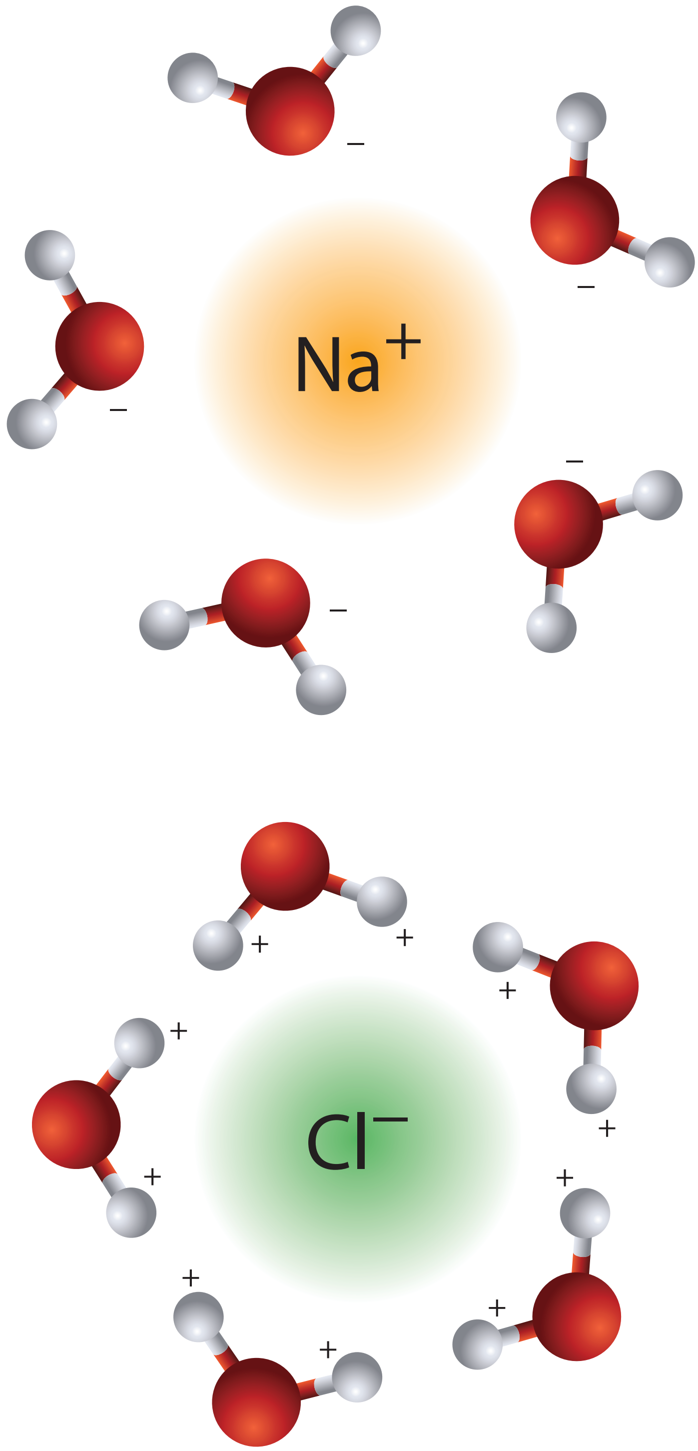
Many ions of sodium and chlorine make up the ionic compound we call table salt.

Because opposite electrical charges attract, a bond will form between the sodium ion and the chlorine ion. NaCl, table salt, is called an ionic compound, and people don't use the word molecule to describes ionic compounds.

Some compounds, such as table salt, occur naturally. Salt crystals can be found in large deposits in the ground, and salt is mined for many purposes, including for use as a flavor-enhancing seasoning and as a road deicer. When salt encounters water, the compound dissolves into its ions. Why does this occur if ionic bonds are considered strong?

When the compound encounters water, the many molecules of liquid water are moving freely. Water is a polar molecule. One end of this compound is slightly positive in charge, and the other is slightly negative. Water's positive, oxygen-headed ends face the chlorine ion, while its negative, hydrogen-headed ends face the sodium ion.

When water molecules leave a saltwater solution via evaporation, the sodium and chlorine ions re-form their ionic bonds. With multiple sodium and chlorine ions present, the ions can arrange into an alternating, stacked pattern, forming salt crystals. On a large scale, this is how sea salt is made.



Modeling Molecules

To visualize the wide variety of ways in which carbon and other reactive elements can get together, it's helpful to use different models.

Key = Carbon = Oxygen = Hydrogen

Methane is a hydrocarbon—a compound consisting of carbon and hydrogen. Hydrogen has just one electron on its own. To make its electron cloud more stable, it needs two electrons. Carbon has six electrons. The first cloud has two electrons, filling it. The next cloud needs eight electrons to be full. The four hydrogen atoms and the one carbon atom can form covalent bonds to meet all five atoms' needs.

Formula

CH_4

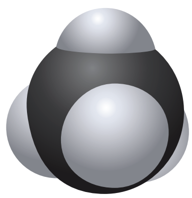
This formula indicates that there are four hydrogen atoms to one carbon.

Structural Formula

$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{H} & — & \mathrm{C} & — & \mathrm{H} \\ & & | & & \\ & & \mathrm{H} & & \end{array}$$

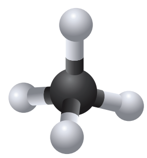
This formula indicates that the valence electrons of the five atoms are all shared.

Space-Filling Model



The space-filling model focuses on the relative sizes of the atoms and their relative positions to give the overall shape of the molecule.

Ball-and-Stick Model



The ball-and-stick model is like the space-filling model, but it focuses on the bonds, too.

Carbon dioxide can form when methane or other hydrocarbons are burned. The freed carbon atoms can combine with oxygen to form carbon dioxide. Carbon dioxide is also a product of cellular respiration.

Formula

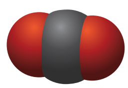
CO_2

Structural Formula

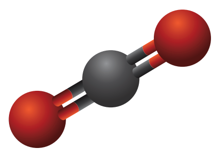
$$\mathrm{O{=}C{=}O}$$

Carbon is sharing two pairs of electrons with each oxygen atom. The double dashes indicate double bonds.

Space-Filling Model



Ball-and-Stick Model



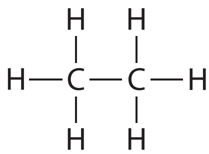
The ball-and-stick model captures the double bonds.

Ethane is another hydrocarbon, but it is larger than methane. After methane, it is the second most important component of natural gas. It is also found in petroleum.

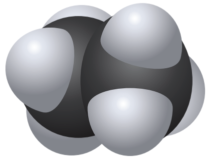
Formula

C_2H_6

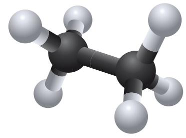
Structural Formula



Space-Filling Model



Ball-and-Stick Model



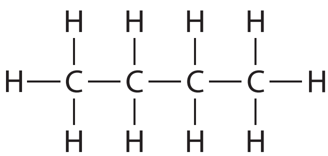
In a large molecule like this, the ball-and-stick model can make it easier to see how the atoms are connected.

Butane is another hydrocarbon. It's like a longer version of ethane. Liquid butane is often used as a fuel in lighters.

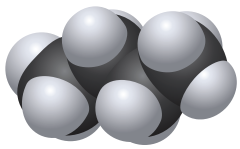
Formula

C_4H_{10}

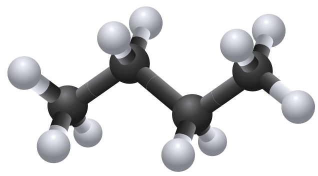
Structural Formula



Space-Filling Model



Ball-and-Stick Model

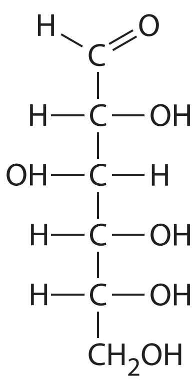


Glucose is a sugar. It is one of the reactants in cellular respiration, and it is a product of photosynthesis.

Formula

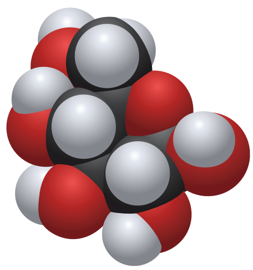
$C_6H_{12}O_6$

Structural Formula



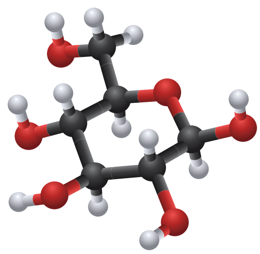
Glucose has two distinct ends in its structural formula. Like many organic compounds, its backbone is made of carbon.

Space-Filling Model



With this many atoms, the space-filling model is harder to read.

Ball-and-Stick Model



The ball-and-stick model is less dense, and the bonds are easier to interpret.

Ways That Atoms Recombine

Chemical reactions are processes in which substances combine with others to form different substances. The transformation is a result of atoms recombining in a different way. The starting substances are called **reactants**; the substances resulting from the reaction are called **products**.

Liquid water freezing into solid ice is a physical change, but the substance is still water—H_2O. By contrast, water taken up by plant roots might be combined with carbon dioxide gas, along with energy from sunlight, to produce, through a complex series of chemical reactions, glucose and oxygen. This set of reactions is called photosynthesis. The reactants are different substances from the products. Matter is neither created nor destroyed in this series of reactions or any other chemical reaction. The atoms in the reactants are simply recombined in the products.

The natural law of reactions starting and ending with the same amount of matter is called the law of conservation of matter (or mass). In an isolated system, however much "stuff" is present from one instant to the next does not change at all, even if there are chemical reactions and phase changes going on. This is true whether you measure the matter's mass or count the different numbers of atoms. If there are a million atoms of oxygen in the reactants, there will be a million atoms of oxygen in the products.

Look closely at the formulas for these reactions. The numbers of each type of atom are the same in the products as they are in the reactants.

Burning Methane

In the reaction of methane and oxygen, the number of atoms on one side of the reaction equals those on the other. The reaction also releases energy. The combustion of methane converts some of the energy of chemical bonds into thermal energy, or heat. The release of heat is a telltale sign that a chemical reaction has occurred.

Reactants		Products	
Methane gas	Oxygen gas	Carbon dioxide gas	Water vapor

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

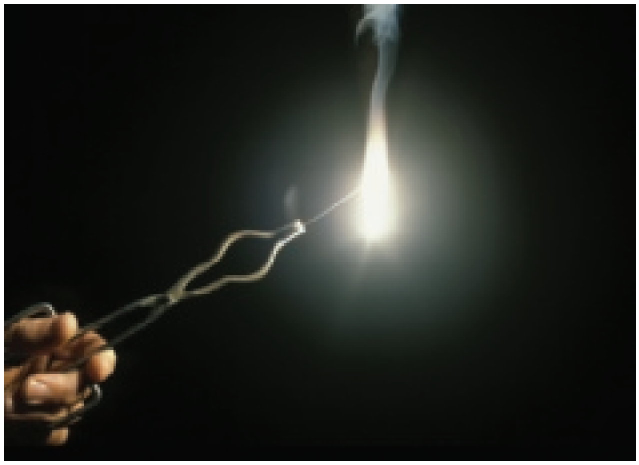
Forming a Precipitate

The formation of a precipitate is a telltale sign that a chemical reaction has occurred. This often occurs when two different liquid solutions are mixed as reactants. New compounds form, including one that is solid and can't dissolve in the resulting liquid. The solid that can no longer dissolve is called a precipitate. Precipitation of one of the new products is a sign that a chemical reaction has occurred.

Reactants		Products	
Potassium iodide solution	Lead nitrate solution	Potassium nitrate solution	Lead iodide precipitate

$$2KI + Pb(NO_3)_2 \rightarrow 2KNO_3 + PbI_2$$

Combining Two Substances into One



Here's an example where two reactants make one product. When a metal band of magnesium is exposed to oxygen and a spark or flame provides some energy, the two elements combine into a single product, magnesium oxide, which is a white powder. This is a combination reaction. The reaction creates a sudden bright white flame as it releases energy.

Reactants		Product
Magnesium	Oxygen gas	Magnesium oxide powder

$$2Mg + O_2 \rightarrow 2MgO$$

Vocabulary

chemical reaction, n. a chemical change in which two or more substances form a new substance with different properties

reactant, n. a substance that undergoes a change in a chemical reaction

product, n. a substance produced by a chemical reaction, different from the reactants

Spotting Chemical Reactions

At every moment on Earth, massive amounts of energy and matter are harnessed by photosynthetic organisms and transferred up food chains as consumers eat things. Chemical reactions are at the heart of this activity, as energy in sunlight becomes chemical bond energy in glucose. In turn, these compounds are broken down into molecules that then become compounds in other organisms.

Many other chemical reactions occur outside of food chains. For example, certain types of rock have minerals that can react with compounds in the air and in precipitation, resulting in chemical changes that slowly break down, or weather, rock formations. This is called chemical weathering. For example, the iconic rock formation Uluru, in the Australian Outback, is red due to a reaction between the iron in the rock's minerals and oxygen in the air. The same process turns shipwrecked ships into rust. The reaction equation:

Reactants			**Product**
Iron	Oxygen		Iron oxide
$4Fe$	$+ \; 3O_2$	$\rightarrow$	$2Fe_2O_3$

Uluru glows red in the light of the setting sun because it has been rusting for thousands of years. The shipwreck's hull contains more iron and is rusting very rapidly.

Another form of chemical weathering occurs when water becomes acidic. Water can get acidic if carbon dioxide, sulfur dioxide, or nitrogen oxide dissolves in water. This is the reaction equation for sulfur dioxide dissolving in water:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

When the acid contacts calcium carbonate ($CaCO_3$), the acid causes a breakdown into more ions. This dissolves the calcium carbonate, which is a key component of marble, limestone, and other types of rock.

$$CaCO_3 + H_2SO_4 \rightarrow Ca^{2+} + SO_4^{2-} + H_2O + CO_2$$

Emissions from coal-fired power plants put so much sulfur dioxide into the atmosphere in the latter part of the 20th century that the rain in many places became acidic. Many marble and limestone monuments, statues, gravestones, and other structures were heavily weathered.

A similar process is occurring in the ocean. Carbon dioxide emitted by human industry has been absorbed by the ocean, making it more acidic. The carbonic acid makes life difficult for small organisms that need calcium carbonate shells, and it also weathers the ancient reefs, which are made of the skeletons of corals and other organisms. Ocean acidification is considered a major challenge imposed by human-caused changes to the atmosphere.

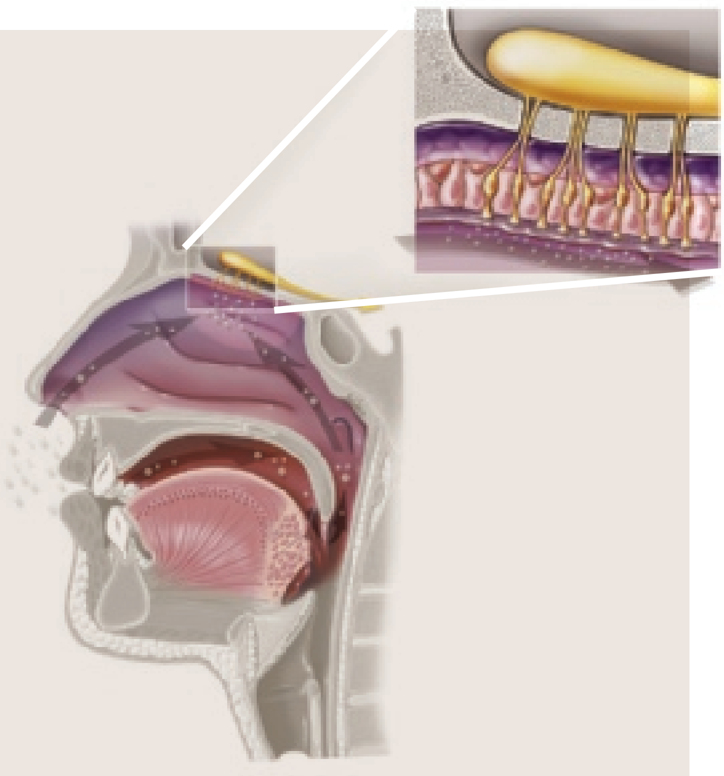
This marble gravestone has become less legible over time from acidic rain weathering the calcium carbonate.

Detecting Odor

Humans have five senses: touch, sight, hearing, taste, and smell. These senses help us navigate the world around us, including the fluid in which we spend most of our time—air. Air consists mostly of molecules such as nitrogen gas and oxygen gas that our senses do not perceive. But air also carries molecules of other substances. If you are near a freshly cooked pizza, for example, your sense of smell will detect the odors of some of the components of the pizza, such as the tomato sauce, the cheese, and the toasted edges of the crust. The odors of the cooked pizza are different from those of the uncooked pizza because in the oven chemical reactions occur. Other organisms are adept at detecting odors as well, but humans and other mammals appear to be the best at detecting and identifying thousands of different compounds in the air.

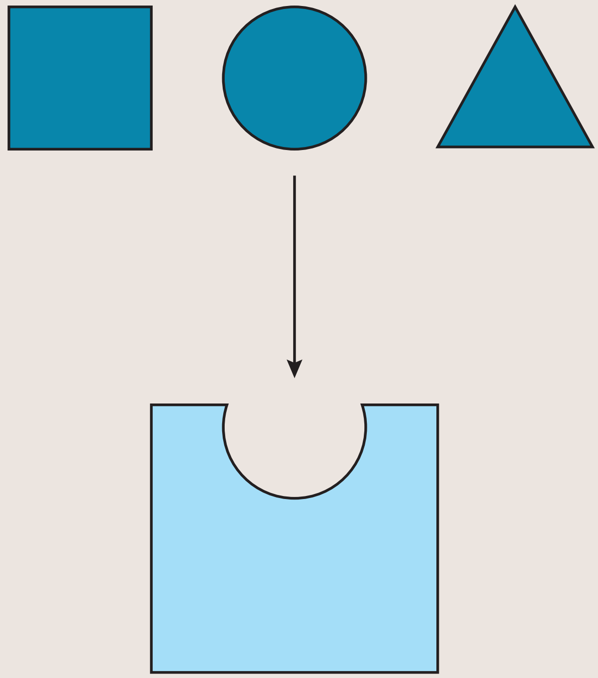
Smell and Taste

In the nose of humans or other species of mammal, olfaction (smelling) begins with the arrival of molecules from the source of the odor. In the nose, the inner nasal passages are lined with mucus that covers the olfactory epithelium. This is the tissue that contains sensory neurons that detect different compounds. We think of smells as coming in through the nose, but they also get into the nasal passages from the throat. In fact, about 80 percent of what we think of as "taste" is odor perception from the mouth and throat. You might realize this when you eat something that normally has a strong taste while suffering from a head cold that stuffs up your nasal passages and blocks odors from getting in.



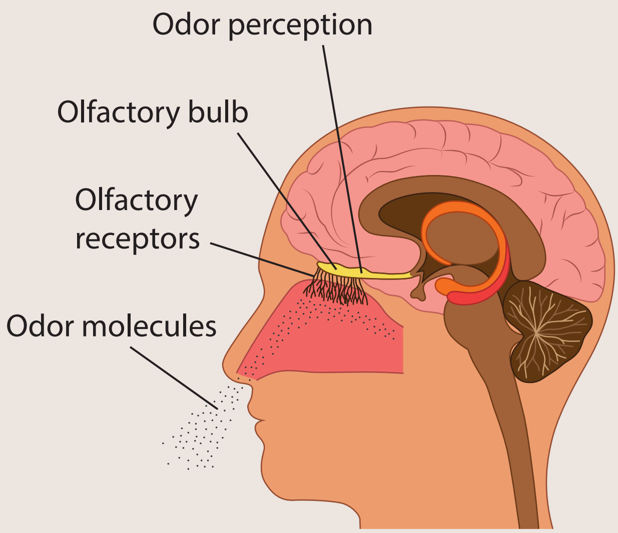
Locks and Keys

Airborne molecules land in the sticky mucus of the olfactory epithelium and dissolve into it. The molecules will either fit into the olfactory neuron receptors or not. The molecule and a receptor are like a lock and key. A neat fit will trigger the receptor to send a signal to the brain that that molecule is there. A poor fit will not trigger a response. One molecule and one receptor do not signal a particular smell. Instead, multiple signals from multiple receptors add up to a particular smell. For example, multiple receptors' signals could spell "pizza" in the brain, as different molecules from the sauce, cheese, and crust interact with receptors.



Processing Odor Info

When an olfactory receptor neuron is activated, it sends a signal to the brain. The front of the cortex usually interprets a common smell. The signal can trigger responses that are less conscious. For example, you might smell something, have little or no awareness of it at all, but respond in a very strong way—such as attraction or revulsion. The signal also goes to the hippocampus, where smells are stored as memories and can be tangled up with other memories. This is why a memory can sometimes make you experience a smell without the smell being in your nose and why an actual smell can trigger a strong memory.



Comparing Sense of Smell

Bloodhounds and other dogs are known for having a superior sense of smell. Dogs and some other mammals, including pigs and bears, have larger areas of olfactory epithelium odor-detecting (tissue surface) in their nasal passages, as well as higher densities of receptors within the epithelium. This is what makes some breeds of dogs exceptionally sensitive to smells and why police dogs, for example, are used to pick up and follow very light scent trails. However, humans are now thought to be capable of detecting and perceiving about a trillion different odors, whereas dogs detect a smaller number of odors with greater sensitivity. This makes sense, as humans feed on plants and animals, whereas dogs and bears have evolved to depend on finding meat that might be miles away.

The unconscious aspect of the human sense of smell has been unknown until recent times. With today's technology, neuroscientists can analyze peoples' brains while conducting various tests with the sense of smell. Our sense of smell is probably far more important to our social lives than we are aware.

- Humans perceive changes in emotion in other people, and they are likely to react to those changes in emotion with their own emotions. For example, if you smell a person who recently watched a horror movie, you are likely to express some level of anxiety yourself because you actually can smell fear or anxiety emanating from the other person.
- People are likely to be attracted to people whose body smell provides clues that their genetic makeup would make them good mates for producing children with strong immune systems.

Olfaction in Water

You might have heard that sharks can detect a drop of blood in millions of gallons of water or from a mile away. How do sharks and other fish smell things if they do not live in air? Like air, water is a fluid. Just as air carries molecules from things such as pizza and rotten eggs to the olfactory receptors in a person's nose, water carries molecules into the noses of sharks and other aquatic animals. In sharks, the holes that allow water in are called nares, not nostrils. Olfactory receptors and olfactory bulbs detect and identify substances that sharks are looking for. A great white shark can sense body fluids emitted by seals—a favorite prey—and then follow the trail of that scent until it finds a seal or, even better, a whole colony of seals. Some sharks use their olfactory senses to help them navigate. For example, leopard sharks can find their way back to their coastal habitat after being caught and transported into deeper water, but only if their nares are not blocked. Leopard sharks with blocked nares spend much more time wandering in deep water.

Connection

A shark would have no use for detecting edible vegetables, as it does not eat any vegetables. Humans have a diverse diet, so our sense of smell has evolved to detect a wider variety of substances.

Carbon in a Cycle

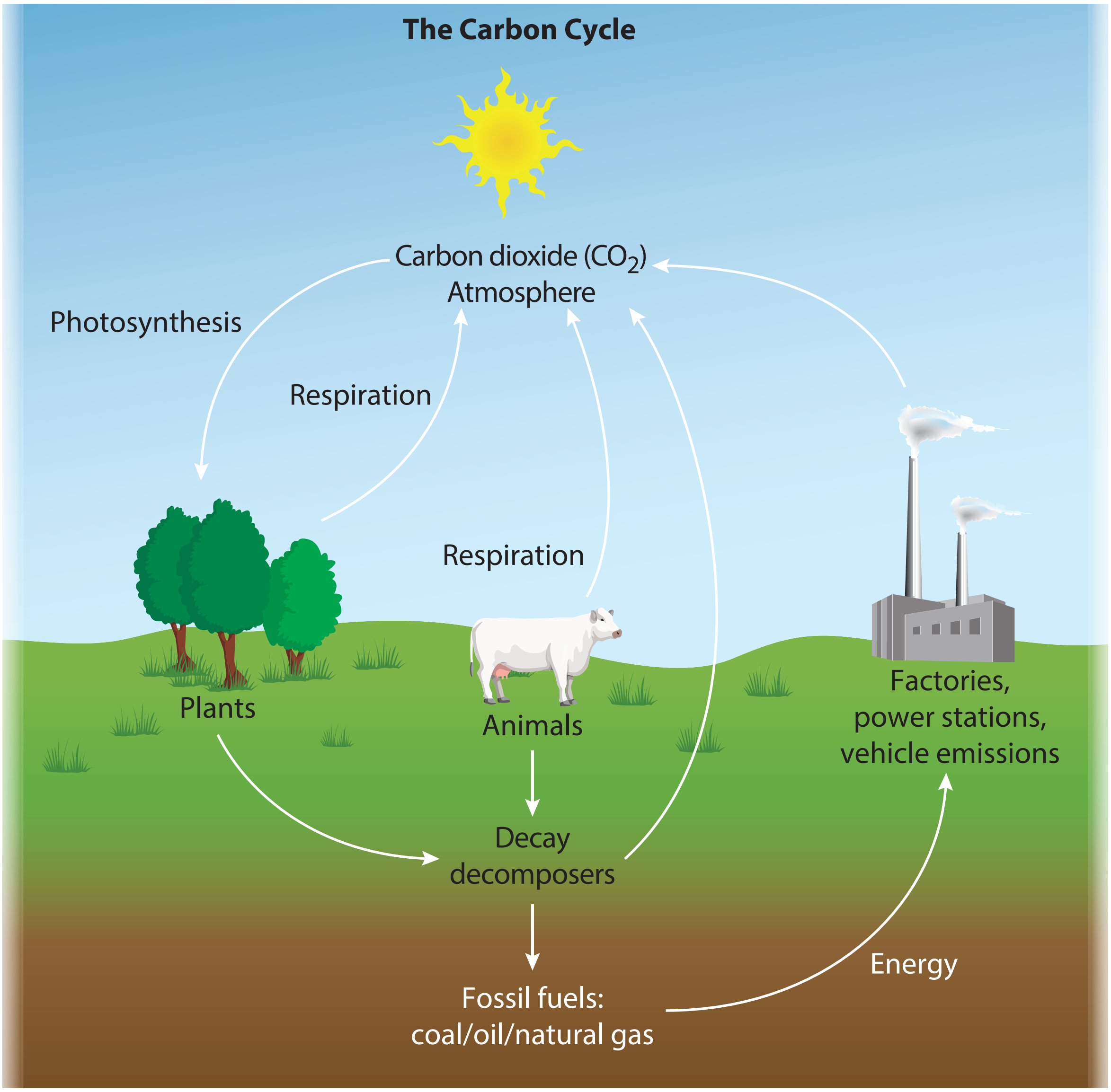
As the songwriter Joni Mitchell put it, *we are stardust*. The atoms that compose you and everything else on Earth were once parts of stars. A million years from now, the atoms that once made up you and everything that surrounds you will be elsewhere, recombined, and doing other things. Some might be on Earth. Others might be in a head of lettuce growing in a greenhouse on Mars.

We are also, like many things, absorbing, converting, and releasing different forms of energy all the time. Like a space heater that warms a bedroom, we radiate thermal energy. That energy is released by cellular respiration, a series of chemical reactions within our cells. Play basketball or dance for a few minutes, and you'll radiate more energy because this reaction is happening more. Jump in a cool swimming pool, and the water will most likely drain so much thermal energy from your body that you'll need to get out and warm up in the sunlight—the same source of energy for the food chains that produce the chemical energy you consume at breakfast, lunch, and dinner.

The laws of conservation of both mass and energy remind us that matter and energy are neither created nor destroyed. The energy in the sunlight that warms you up after the cold swim will later end up elsewhere. The chemical energy in the cheeseburger that you eat after a two-hour soccer practice can take several different paths through you. Some paths involve a long stay stored in the chemical bonds of proteins, fats, or other compounds that compose different tissues. Others may be much briefer, such as in a molecule of glucose that is "burned" within a muscle cell at your next practice, resulting in released heat and carbon dioxide and water vapor that you exhale into the atmosphere.

Similar processes are occurring with matter and chemical energy in other systems. Long ago, the conversion of sunlight (energy), carbon dioxide, and water into plants and algae led to an accumulation of decaying remains of these organisms under layers of sediment. Over time, these remains became fossilized, and after even more time they were converted into hydrocarbons: petroleum, methane, coal. For millions of years, these were sinks of chemical energy—where energy was basically trapped underground.

Humans have mined and pumped these substances, mainly to unlock their chemical energy and transform it into other forms of energy—heat, motion, electricity. Human pursuit of energy affects the movement of matter; it alters the cycle of carbon. There was already a carbon cycle at work on Earth, but human activity altered it. Combustion of hydrocarbons has transferred more carbon to the atmosphere.



In cycles of matter, no atoms are changed into atoms of other elements. A carbon atom locked in a layer of coal for 100 million years is still a carbon atom:

- after the coal has been burned and the atom has moved into a molecule of carbon dioxide
- that dissolves into the North Pacific Ocean
- and is taken up by a phytoplankton,
- which is eaten by a zooplankton,
- which is eaten by a herring,
- which is eaten by a humpback whale,
- which lives a long life before dying,
- to become a carcass on the seafloor,
- where the carbon atom eventually is released from the decomposing bones.

Glossary

acid, n. a substance that has a pH less than 7.0

atom, n. basic unit of matter consisting of a positively charged nucleus and negatively charged electrons

base, n. a substance that has a pH greater than 7.0

catalyst, n. something that helps a chemical reaction occur

chemical, n. a substance produced by a chemical process or producing a chemical effect

chemical energy, n. energy released by a chemical reaction or absorbed during the formation of a chemical compound

chemical reaction, n. a chemical change in which two or more substances form a new substance with different properties

chemical weathering, n. the chemical process in which minerals in rocks react with compounds in the air and in precipitation, resulting in chemical changes that slowly break down rock formations

chlorine, n. an element that occurs as a gas and makes up bleach and disinfectants

cohesion, n. the state of sticking together

combustion, n. a chemical reaction such as oxidation that produces heat and usually light

compound, n. a distinct substance formed by the chemical union of two or more ingredients

concentration, n. the density of a material in another substance

convection current, n. a stream of fluid that moves within surrounding fluid as a result of changes in temperature

dehydration, n. the process of removing water

density, n. the amount of matter in a volume of a substance or object, often measured in grams per milliliter or kilograms per cubic meter

dilute, v. to make thinner

dissolve, v. to become or cause to become incorporated into a liquid

ecosystem, n. all the organisms and the environment in which they are found

electrolyte, n. a mineral that becomes an electrically conductive ion when dissolved in a solution

element, n. a substance made of atoms of only one kind that cannot be made into simpler substances using ordinary means

elemental, adj. refers to things that are basic or primary; the most simplified versions or parts of things (also, elementary)

flammable, adj. the capacity to be easily set on fire

model, n. a representation of a real thing

molecule, n. an arrangement of two or more atoms that share electrons

nutrient, n. a substance that provides nourishment essential for an organism's life, including its growth

olfactory, adj. related to the sense of smell

phase change, n. a transition from a state of matter to a different state of matter

plasma, n. a superheated gas that is conducting electricity or otherwise being affected by electromagnetic fields or energy

precipitate, n. a substance, usually amorphous or crystalline, that separates out from a solution or suspension as a result of a chemical or physical change

pressure, n. the application of force due to direct contact

product, n. a substance produced by a chemical reaction, different from the reactants

property, n. a quality belonging to a particular thing

reactant, n. a substance that undergoes a change in a chemical reaction

scientific literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

solubility, n. how much a substance can dissolve into another

solute, n. the substance in a solution that dissolves in the solvent

solvent, n. the liquid substance in which a solute dissolves to form a solution

specific heat, n. the heat in calories necessary to raise the temperature of one gram of a substance by one degree Celsius

state, n. a particular condition that something is in at a specific time

state of matter, n. the form in which matter can be found, which occurs in nature as solid, liquid, gas, or plasma

substance, n. a particular kind of matter with uniform properties

system, n. a set of interconnected things working together

temperature, n. the average kinetic energy of the particles in an object or substance

thermoreceptor, n. a sensory organ that perceives heat or cold

viscous, adj. how thick, sticky, and semifluid a substance is

Key Sources

David Cox, “The Curse of the People Who Never Feel Pain.” BBC Future. BBC. Accessed September 30, 2021. https://www.bbc.com/future/article/20170426-the-people-who-never-feel-any-pain

“Particulate Matter (PM) Basics.” Particulate Matter (PM) Pollution, United States Environmental Protection Agency. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

“Proposition 65.” California Office of Environmental Health Hazard Assessment. https://oehha.ca.gov/proposition-65.

Boudreau, M.D., F.A. Beland, J.A. Nichols, and M. Pogribna. “Toxicology and carcinogenesis studies of a nondecolorized whole leaf extract of *Aloe barbadensis Miller* (Aloe vera) in F344/N rats and B6C3F1 mice (drinking water study).” *National Toxicology Program Technical Report Series*, 577 (2013) Aug: 1-266. https://europepmc.org/article/med/24042237

Alex Delany, “What Does Caramelized Mean, Anyway?” *Bon Appetit*, October 10, 2018. https://www.bonappetit.com/story/what-does-caramelized-mean

Sarah Mullen Gilbert, “Cheesy Science.” *ChemMatters*, American Chemical Society, January, 2018. https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/2017-2018/december2017/cheesy-science.html

Stephen M. Roth, “Why Does Lactic Acid Build Up in Muscles? And Why Does It Cause Soreness?” *Scientific American*, January 23, 2006. https://www.scientificamerican.com/article/why-does-lactic-acid-buil/

Lyu, Zhe, Nana Shao, Taiwo Akinyemi, and William B. Whitman. “Methanogenesis.” *Current Biology* 28, 13 (2018): 727-732. https://www.cell.com/current-biology/comments/S0960-9822(18)30623-7

Marta Zaraska. “The Sense of Smell in Humans is More Powerful Than We Think.” *Discover*, October 11, 2017. https://www.discovermagazine.com/mind/the-sense-of-smell-in-humans-is-more-powerful-than-we-think

Core Knowledge®

CKSci™

Core Knowledge Science™

Editorial Director

Daniel H. Franck

Core Knowledge Foundation
Science Literacy Subject Matter Expert

Joyce Latimer, PhD
Professor
School of Plant and Environmental Sciences
Virginia Tech
Blacksburg, Virginia

Core Knowledge Foundation
Science Literacy Development Partners

Six Red Marbles
Carri Walters
Executive Editor

Daniel Clem
Writer

Illustrations and Photo Credits

agefotostock / Alamy Stock Photo: 32, 52
Ammentorp Photography / Alamy Stock Photo: 30
Andras Gali / Alamy Stock Photo: 8a
Andres Court / Alamy Stock Photo: 15b
Anze Furlan / Alamy Stock Photo: 5a
Arterra Picture Library / Alamy Stock Photo: 7b
artpartner-images / Alamy Stock Photo: 22
Barbara Ash / Alamy Stock Photo: 51
Blue Planet Archive / Alamy Stock Photo: 13
BSIP SA / Alamy Stock Photo: 34, 48
Davide Lo Dico / Alamy Stock Photo: 44
Dorling Kindersley ltd / Alamy Stock Photo: Cover B, 45a
Drepicter / Alamy Stock Photo: 37b
Eric Douglas / Alamy Stock Photo: 7a
Erwan Gardan / Alamy Stock Photo: 6a
Eva Pruchova / Alamy Stock Photo: 31c
Ibex Anubis / Alamy Stock Photo: 9
ilian photo / Stockimo / Alamy Stock Photo: 31a
imageBROKER / Alamy Stock Photo: 12
Jeff J Daly / Alamy Stock Photo: 5c
Jeff Milisen / Alamy Stock Photo: 4b
Jens Pfeiffer / Alamy Stock Photo: 6c
Jim Holden / Alamy Stock Photo: 50
John Gaffen / Alamy Stock Photo: 46a
Kim Petersen / Alamy Stock Photo: Cover E, 46b
Lazyllama / Alamy Stock Photo: 37a
Lisa Howeler / Alamy Stock Photo: 4a
lucky-photographer / Alamy Stock Photo: 5b
MBI / Alamy Stock Photo: i, iii
MetokKarpo / Alamy Stock Photo: 8b
molekuul.be / Alamy Stock Photo: 40b
Panther Media GmbH / Alamy Stock Photo: 18-19
Peacefoo / Alamy Stock Photo: 23a
Phil Degginger / Alamy Stock Photo: 47
Pixel-shot / Alamy Stock Photo: 11, 20b
Robert Holland / Alamy Stock Photo: 35
Science History Images / Alamy Stock Photo: 33, 39a
Science Photo Library / Alamy Stock Photo: 21b
sciencephotos / Alamy Stock Photo: 45b
Sea Wave / Alamy Stock Photo: 2
Sergii Koval / Alamy Stock Photo: 20a
Shotshop GmbH / Alamy Stock Photo: 23b
Susan E. Degginger / Alamy Stock Photo: 6b
Tatiana Kornylyeva / Alamy Stock Photo: 36a
Tom Grundy / Alamy Stock Photo: 26
Vaclav Volrab / Alamy Stock Photo: 31b
vdbvsl / Alamy Stock Photo: 15a
YAY Media AS / Alamy Stock Photo: Cover A
Zoonar GmbH / Alamy Stock Photo: 21a

CKSci™

Core Knowledge SCIENCE™

A comprehensive program in science, integrating topics from Earth and Space, Life, and Physical Sciences with concepts specified in the ***Core Knowledge Sequence*** (content and skill guidelines for Grades K–8).

Core Knowledge SCIENCE™
units at this level include:

Chemical Reactions and Matter
Chemical Reactions and Energy
Metabolic Reactions
Matter Cycling and Photosynthesis
Ecosystem Dynamics
Earth's Resources and Human Impact

www.coreknowledge.org

ISBN: 978-1-68380-803-9

Core Knowledge Curriculum Series™