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Matter and Energy

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Chapter 1

Matter and Energy

1.1 What is Matter?

Lesson Objectives

The student will:

- define matter and explain how it is composed of building blocks known as atoms.
- explain the differences between substances and mixtures.
- classify mixtures as homogeneous or heterogeneous.
- identify the chemical symbols of common elements.
- explain the difference between an element and a compound by their symbols or formulas.
- demonstrate the proper use of parentheses and subscripts in writing chemical formulas.
- determine the number of atoms and name of each element in a compound.

Vocabulary

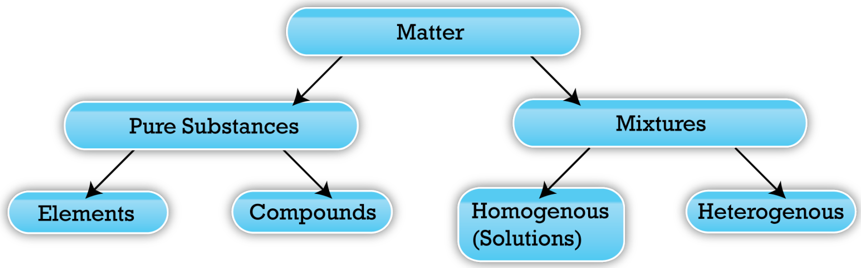
- atom
- compound
- element
- heterogeneous mixture
- homogeneous mixture
- law of constant composition
- matter
- molecule

Introduction

Matter is anything that has mass and volume. The entire universe is composed of matter, which is in turn composed of atoms. An **atom** is the basic building block of all matter. All matter in the universe, from a teaspoon of salt to the Pacific Ocean, has mass and occupies space. The salt and ocean, however, have very different properties and behaviors. Since everything in the universe is composed of matter, there are clearly many types of matter. In this lesson, you will learn about how scientists classify the different types of matter.

Categories of Matter

Matter can be classified into two broad categories: mixtures and pure substances, as illustrated below.



Mixtures are physical combinations of two or more substances. The term "physical combination" refers to mixing together different substances that do not chemically react with each other. The physical appearance of the substances may change, but the atoms in the substances do not.

In comparison, a pure substance is a form of matter that has a constant composition and constant properties throughout the sample. Elements and compounds are both example of pure substances.

Mixtures: Homogeneous and Heterogeneous

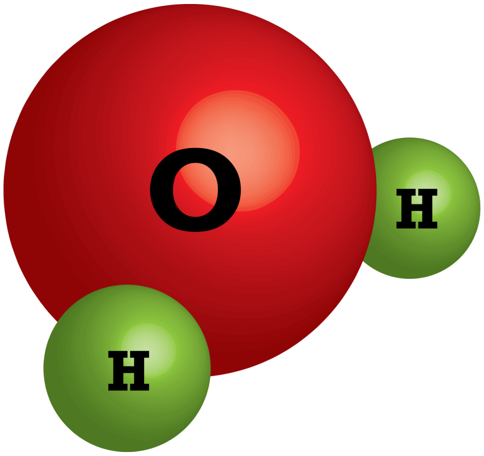
One example of a mixture is sand and gravel stirred together. In this case, you can see that there are two different substances present, each with the same properties that it had before it was mixed. When substances do not mix thoroughly and evenly (like sand and gravel), the mixture is said to be heterogeneous. A **heterogeneous mixture** consists of visibly different substances.

Another example of a mixture is salt dissolved in water. In this case, you cannot see the different substances, but you can test the solution to show that each substance (salt and water) has the same chemical properties it had before being mixed. When substances mix thoroughly and evenly (like salt in water), the mixture is said to be homogeneous. **Homogeneous mixtures** are often referred to as solutions. Solutions often may appear to be one pure substance, but some simple tests can show that the solutions are indeed mixtures.

Pure Substances: Elements and Compounds

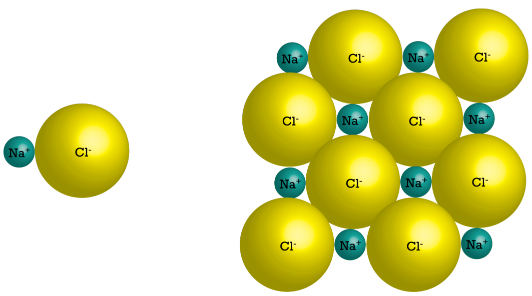
Elements are the simplest substances. An **element** is a substance that is made up of only one type of atom. It doesn't matter if the atoms are in groups, as in P_4 or S_8, or isolated, as in Na. As long as there is only one kind of atom, the substance is an element. Elements cannot be chemically broken down into anything smaller and still retain the properties of the element. For example, an atom of iron can be smashed into electrons, protons, and neutrons, but those pieces would not have the properties of iron.

Atoms from two or more elements can chemically combine to form a new substance. **Compounds** are substances that are made up of more than one type of atom. In other words, compounds are chemical combinations of elements. These combinations form new substances with completely different properties than the atoms from which they were formed.



The image above is a model of water. Water is a compound consisting of one atom of oxygen and two atoms of hydrogen. Hydrogen is an explosive gas, and oxygen is a gaseous substance that supports combustion. Yet, when these two elements are chemically combined to form water, the product neither burns nor supports combustion. In fact, water is used to put out fires.

A **molecule** is the smallest particle of a compound. If you break up the molecule, you no longer have the properties of the compound. Molecules, like atoms, are too small to be seen. Even with the most powerful microscopes, we have only seen the very largest of molecules.



The illustration above shows a single unit of the compound called sodium chloride on the left. This single unit is made up of one sodium ion and one chloride ion. Sodium is a very reactive metal that explodes in water and burns in air, while chlorine is a very deadly, poisonous gas. When these two are combined, we get table salt (sodium chloride). When sodium chloride is in solid form, many units join together, as illustrated above on the right.

Elements: Names and Symbols

Everything, from ants to galaxies, is composed of atoms. So far, scientists have discovered or created 118 different types of atoms. Scientists have given a name to each different type of element and organized them into a chart called the periodic table. As you can see in the table below, each square contains one of the elements.

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.01																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.8	6 **C** 12.0	7 **N** 14.0	8 **O** 16.0	9 **F** 19.0	10 **Ne** 20.2
11 **Na** 23.0	12 **Mg** 24.3											13 **Al** 27.0	14 **Si** 28.1	15 **P** 30.1	16 **S** 32.1	17 **Cl** 35.5	18 **Ar** 39.9
19 **K** 39.1	20 **Ca** 40.1	21 **Sc** 45.0	22 **Ti** 47.9	23 **V** 50.9	24 **Cr** 52.0	25 **Mn** 54.9	26 **Fe** 55.9	27 **Co** 58.9	28 **Ni** 58.7	29 **Cu** 63.6	30 **Zn** 65.4	31 **Ga** 69.7	32 **Ge** 72.6	33 **As** 74.9	34 **Se** 79.0	35 **Br** 79.9	36 **Kr** 83.8
37 **Rb** 85.5	38 **Sr** 87.6	39 **Y** 88.9	40 **Zr** 91.2	41 **Nb** 92.9	42 **Mo** 95.9	43 **Tc** [98]	44 **Ru** 101	45 **Rh** 103	46 **Pd** 106	47 **Ag** 108	48 **Cd** 112	49 **In** 115	50 **Sn** 119	51 **Sb** 122	52 **Te** 128	53 **I** 127	54 **Xe** 133
55 **Cs** 133	56 **Ba** 137	57 **La** 139	72 **Hf** 178	73 **Ta** 181	74 **W** 184	75 **Re** 186	76 **Os** 190	77 **Ir** 192	78 **Pt** 195	79 **Au** 197	80 **Hg** 201	81 **Ti** 204	82 **Pb** 207	83 **Bi** 209	84 **Po** [209]	85 **At** [210]	86 **Rn** [222]
87 **Fr** [223]	88 **Ra** 226	89 **Ac** 227	104 **Rf** [261]	105 **Db** [262]													
			58 **Ce** 140	59 **Pr** 141	60 **Nd** 144	61 **Pm** [145]	62 **Sm** 150	63 **Eu** 152	64 **Gd** 157	65 **Tb** 159	66 **Dy** 163	67 **Ho** 165	68 **Er** 167	69 **Tm** 169	70 **Yb** 173	71 **Lu** 175	
			90 **Th** 232	91 **Pa** 231	92 **U** 238	93 **Np** 237	94 **Pu** [244]	95 **Am** [243]	96 **Cm** [247]	97 **Bk** [247]	98 **Cf** [251]	99 **Ex** [252]	100 **Fm** [257]	101 **Md** [258]	102 **No** [259]	103 **Lr** [260]	

Each element not only has its own name, it also has its own symbol. Scientists use abbreviations called chemical symbols to represent the elements. Many of these symbols are the first one or two letters of the modern name of the element. The first letter of a chemical symbol must always be a capital letter, and the second letter, when there is a second letter, must always be a lowercase letter. **Table** 1.1 shows some examples of elements and their symbols.

Table 1.1: **Examples of Elements**

Element	Symbol
Hydrogen	H
Oxygen	O
Carbon	C
Calcium	Ca
Aluminum	Al

As seen in **Table** 1.2, the symbols for some of the elements consist of the first letter of the name and another letter (not the second letter) that comes later in the name.

Table 1.2: **More Examples of Elements**

Element	Symbol
Zinc	Zn
Magnesium	Mg
Chlorine	Cl
Arsenic	As
Zirconium	Zr

For other elements, the symbols were already used for other elements. When trying to decide on a symbol for silver, for example, the symbol S was already used for sulfur, and the symbol Si was already used for silicon. Since silver has been known to man for over a thousand years, it had a Latin name from ancient times. The old Latin name for silver was *argentum*, so it was decided that the symbol for silver would be Ag. There are a number of symbols chosen in this same manner, as seen in **Table** 1.3.

Table 1.3: **Examples of Elements Whose Symbol Comes from Latin**

Element	**Ancient Name**	**Symbol**
Silver	*Argentum*	Ag
Potassium	*Kalium*	K
Sodium	*Natrium*	Na
Gold	*Aurum*	Au
Lead	*Plumbum*	Pb
Copper	*Cuprum*	Cu
Iron	*Ferrum*	Fe

Compounds: Chemical Formulas

The chemical symbols are not only used to represent the elements, they are also used to write chemical formulas for the millions of different compounds. For a given chemical compound, the **law of constant composition** states that the ratio by mass of the elements in the compound is always the same, regardless of the source of the compound. The law of constant composition can be used to distinguish between compounds and mixtures. Compounds have a constant composition, and mixtures do not. Pure water is always 88.8% oxygen and 11.2% hydrogen by weight, regardless of the source of the water. Brass is an example of a mixture. Brass consists of two elements, copper and zinc, but it can contain as little as 10% or as much as 45% zinc.

The formula for a compound uses the symbols to indicate the type of atoms involved and uses subscripts to indicate the number of each atom in the formula. For example, aluminum combines with oxygen to form the compound aluminum oxide. Forming aluminum oxide requires two atoms of aluminum and three atoms of oxygen. Therefore, we write the formula for aluminum oxide as Al_2O_3. The symbol Al tells us that the compound contains aluminum, and the subscript 2 tells us that there are two atoms of aluminum in each molecule. The O tells us that the compound contains oxygen, and the subscript 3 tells us that there are three atoms of oxygen in each molecule. It was decided by chemists that when the subscript for an element is 1, no subscript needs to be used. Thus the chemical formula $MgCl_2$ tells us that one molecule of this substance contains one atom of magnesium and two atoms of chlorine. The formula for sodium chloride is NaCl, which indicates that the compound contains one atom each of sodium and chlorine. The formula for sodium carbonate, Na_2CO_3, indicates that there are two atoms of sodium, one atom of carbon, and three atoms of oxygen. In formulas that contain parentheses, the subscript outside of the parentheses applies to everything inside. For example, the subscript 2 in $Ca(OH)_2$, the subscript 2 applies to the (OH). Therefore, this molecule of calcium hydroxide contains one atom of calcium, two atoms of oxygen, and two atoms of hydrogen.

Lesson Summary

- All matter has mass and occupies space.
- Matter can be classified into two broad categories: pure substances and mixtures.

- A pure substance is a form of matter that has constant composition and constant properties throughout the sample.
- Mixtures are physical combinations of two or more substances.
- Elements and compounds are both example of pure substances.
- Compounds are substances that are made up of more than one type of atom.
- Elements are the simplest substances made up of only one type of atom.
- The elements are organized into a chart called the periodic table.
- Scientists use abbreviations called chemical symbols to represent the elements.
- The first letter of a chemical symbol is capitalized, and the second letter is not.

Further Reading / Supplemental Links

You may listen to Tom Lehrer's humorous song "The Elements" with animation at this website.

- http://www.privatehand.com/flash/elements.html

This website provides a review about matter and the categories of matter.

- http://www.thetech.org/exhibits/online/topics/50a.html

Review Questions

1. Pure substances contain only one type of
   (a) atoms only.
   (b) molecules only.
   (c) atoms or molecules.
   (d) mixture.
2. What type of mixture produces the same properties for every sample of the mixture?
   (a) heterogeneous
   (b) homogeneous
   (c) mechanical
   (d) environmental
3. Which of the following is a heterogeneous mixture?
   (a) pure gold
   (b) distilled water
   (c) helium
   (d) milk
4. Which of the following is *not* a heterogeneous mixture?
   (a) concrete
   (b) pizza
   (c) sugar water
   (d) soup
5. If you can easily see the different parts that make up a mixture, you know that it is a _________- mixture.
   (a) homogeneous
   (b) heterogeneous

(c) biodegradable
(d) plasma

6. What do we call a material that is composed of two or more pure substances?

    (a) a compound
    (b) an element
    (c) a mixture
    (d) a heterogeneous mixture

7. Identify the following mixtures as homogeneous or heterogeneous.

    (a) brass
    (b) sugar dissolved in water
    (c) vegetable soup

8. Identify which of the following pure substances are elements and which are compounds.

    (a) table salt
    (b) oxygen
    (c) water

9. A pure substance composed of two or more elements chemically combined is a

    (a) homogeneous mixture.
    (b) compound.
    (c) element.
    (d) heterogeneous mixture.

10. The smallest piece of a compound that still has all the properties of the compound is a(n)

    (a) atom.
    (b) formula.
    (c) mixture.
    (d) molecule.

11. Identify the elements involved in the compound H_2SO_4.
12. How many phosphorus atoms are present in one molecule of H_3PO_4?

1.2 Properties and Changes of Matter

Lesson Objectives

The student will:

- explain the difference between physical and chemical properties of matter.
- list examples of physical properties.
- list examples of chemical properties.
- classify properties as chemical properties or physical properties.
- explain the difference between physical and chemical changes in matter.
- list examples of physical changes.
- list examples of chemical changes.
- classify changes as physical changes or chemical changes.

Vocabulary

- chemical change
- chemical property
- physical change
- physical property

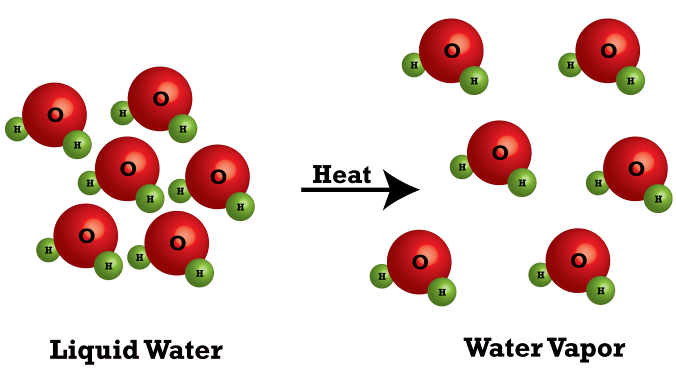
Introduction

What kinds of properties do chemists actually measure in the laboratory? Well, you can probably guess a few. Imagine that you are having dinner at a friend's house and are served something that you don't recognize. What types of observations might you make to determine what you've been given? You might note the smell or color of the food. You might observe whether the food is a liquid or a solid. You could also pick up a small amount of food with your fork and try to figure out how much it weighs. A light dessert might be something like an angel cake, while a heavy dessert is probably a pound cake. You might also want to know something about the food's texture. Is it hard and granular like sugar cubes, or soft and easy to spread like butter?

Believe it or not, the observations you are likely to make when trying to identify an unknown food are very similar to the observations that a chemists makes when trying to learn about a new material. In general, chemists are interested in characteristics that you can test and observe, such as a chemical's smell or color, and characteristics that are far too small to see, such as what the oxygen you breathe in or the carbon dioxide you breathe out looks like. Chemists rely on color, state (solid, liquid, or gas), temperature, volume, mass, and texture. There is, however, one property you might use to learn about a food but that you should definitely not use to learn about a chemical – taste!

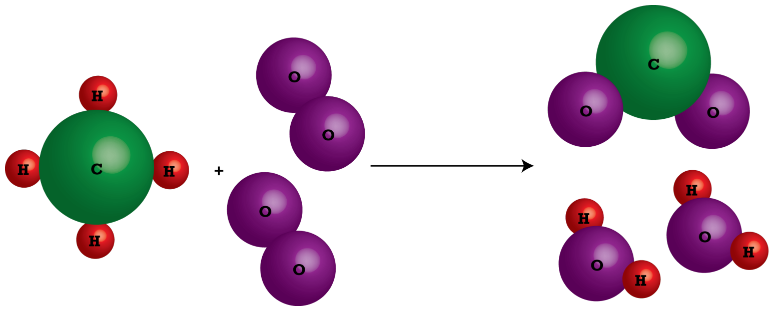
Physical and Chemical Properties

There are two basic types of properties that are used to identify or describe matter: physical properties and chemical properties. **Physical properties** are properties that can be observed without changing the identity of the substance. In the image below, we have water molecules that are held in liquid form on the left. Each molecule contains two atoms of hydrogen chemically bounded with one atom of oxygen. When we heat the liquid water, it changes to water vapor. The physical properties change - we can see the liquid water, but the water vapor cannot be seen. Liquid water has a higher density than water vapor, and so on. But even though the physical properties have changed, the molecules are exactly the same as before. Each water molecule still contains two hydrogen atoms and one oxygen atom chemically bounded together.



On the other hand, **chemical properties** can only be observed when a substance is changed into a new substance. In the image below, on the left we have a molecule of methane (CH_4) and two molecules of

oxygen (O_2). On the right, we have two molecules of water (H_2O) and one molecule of carbon dioxide (CO_2). In this case, not only has the appearance changed, but the structures of the molecules have also changed. The new substances do not have the same chemical properties as the original ones. Therefore, this is a chemical change. The chemical properties, such as how they react and what they react with, however, will still be the same as before.



Physical and Chemical Changes

Chemists make a distinction between two different types of changes that they study: physical changes and chemical changes. **Physical changes** are changes that do not alter the identity of a substance. Some types of physical changes include:

- changes of state (changes from a solid to a liquid or a gas, and vice versa)
- separation of a mixture
- physical deformation (cutting, denting, stretching)
- making solutions (special kinds of mixtures)

If you have a jar containing a mixture of pennies and nickels and you sort the mixture so that you have one pile of pennies and another pile of nickels, you have not altered the identity of either the pennies or the nickels. You've merely separated them into two groups. Similarly, if you have a piece of paper and you rip it up, you don't change the paper into something other than a piece of paper. These are examples of a physical change. For the most part, physical changes tend to be reversible, or capable of occurring in both directions. You can turn liquid water into solid water (ice) through cooling, and you can also turn solid water into liquid water through heating (**Figure** 1.1).

Chemical changes are changes that occur when one substance is turned into another substance. Chemical changes are frequently harder to reverse than physical changes. One good example of a chemical change is burning paper. In contrast to the act of ripping paper, the act of burning paper actually results in the formation of new chemicals (carbon dioxide and water, to be exact). Notice that whereas ripped paper can be at least partially reassembled, burned paper cannot be "unburned." In other words, burning only goes in one direction. The fact that burning is not reversible is another good indication that it involves a chemical change. Another example of a chemical change, illustrated in **Figure** 1.2, is the explosion of fireworks.

Lesson Summary

- There are two basic types of properties that are used to identify or describe matter: physical properties and chemical properties.
- Physical properties are those that can be observed without changing the identity of the substance.
- Chemical properties are those that can be observed only when a substance is changed into a new substance.

Figure 1.1: Melting snow is an example of a physical change.

Figure 1.2: Fireworks are an example of a chemical change.

- Chemists make a distinction between two different types of changes that they study: physical changes and chemical changes.
- Physical changes are changes that do not alter the identity of a substance
- Chemical changes are changes that occur when one substance is turned into another substance.
- Chemical changes are frequently harder to reverse than physical changes.

Further Reading / Supplemental Links

This website provides some free PowerPoint presentations. The presentation on "Matter and Energy" provides a review of some properties of matter, as well as provide examples of the topics covered in this lesson.

- http://science.pppst.com/energy.html

Review Questions

For questions 1-2, determine whether the description is of a physical property or a chemical property.

1. Water boils at 100°C.
   (a) This is a physical property.
   (b) This is a chemical property.
2. Diamonds will cut glass.
   (a) This is a physical property.
   (b) This is a chemical property.

For questions 3-7, determine whether the description is of a physical change or a chemical change.

3. Water can be separated by electrolysis into hydrogen gas and oxygen gas.
   (a) This is a physical change.
   (b) This is a chemical change.
4. Sugar dissolves in water.
   (a) This is a physical change.
   (b) This is a chemical change.
5. Vinegar and baking soda react to produce a gas.
   (a) This is a physical change.
   (b) This is a chemical change.
6. Yeast acts on sugar to form carbon dioxide and ethanol.
   (a) This is a physical change.
   (b) This is a chemical change.
7. Wood burns, producing several new substances.
   (a) This is a physical change.
   (b) This is a chemical change.

1.3 Energy

Lesson Objectives

The student will:

- explain the difference between kinetic and potential energy.
- state the law of conservation of matter and energy.
- define heat.
- define work.

Vocabulary

- chemical potential energy
- energy
- kinetic energy
- law of conservation of energy
- law of conservation of matter and energy
- potential energy
- work

Introduction

Just like matter, energy is a term that we are all familiar with and use on a daily basis. Before you go on a long hike, you eat an *energy* bar; every month, the *energy* bill is paid; on TV, politicians argue about the *energy* crisis. But have you ever wondered what energy really is? If you stop to think about it, energy is very complicated. When you plug a lamp into an electric socket, you see energy in the form of light, but when you plug a heating pad into that same socket, you only feel warmth. Without energy, we couldn't turn on lights, we couldn't brush our teeth, we couldn't make our lunch, and we couldn't travel to school. In fact, without energy, we couldn't even wake up because our bodies require energy to function. We use energy for every single thing that we do, whether we're awake or asleep. Although we all use energy, very few of us understand what it is.

Types of Energy: Kinetic and Potential

Energy is the ability to do work or cause change. Machines use energy, our bodies use energy, energy comes from the sun, energy causes forest fires, and energy helps us to grow food. With all these seemingly different types of energy, it's hard to believe that there are really only two different forms of energy: kinetic energy and potential energy.

Kinetic energy is energy associated with motion. When an object is moving, it has kinetic energy, and when the object stops moving, it has no kinetic energy. Although all moving objects have kinetic energy, not all moving objects have the same amount of kinetic energy. The amount of kinetic energy possessed by an object is determined by its mass and its speed. The heavier an object is and the faster it is moving, the more kinetic energy it has.

Kinetic energy is very common and is easy to spot in the world around you. Sometimes we even capture kinetic energy and use it to power things like our home appliances. Have you ever seen windmills lining the slopes of a hill like the ones in **Figure** 1.3? These windmills capture the kinetic energy of the wind

to provide power that people can use in their homes and offices. As wind rushes along the hills, the kinetic energy of the blowing air particles turns the windmills, which convert the wind's kinetic energy into electricity.

Figure 1.3: This is a photograph of a wind farm in Southern California. Kinetic energy from the rushing air particles turns the windmills, allowing us to capture the wind's kinetic energy and use it.

Capturing kinetic energy can be very effective, but you may already realize that there is a small problem: kinetic energy is only available when something is moving. When the wind stops blowing, there's no kinetic energy available. Imagine what it would be like trying to power your television set using the wind's kinetic energy. You could turn on the TV and watch your favorite program on a windy day, but every time the wind stopped blowing, your TV screen would flicker off because it would run out of energy.

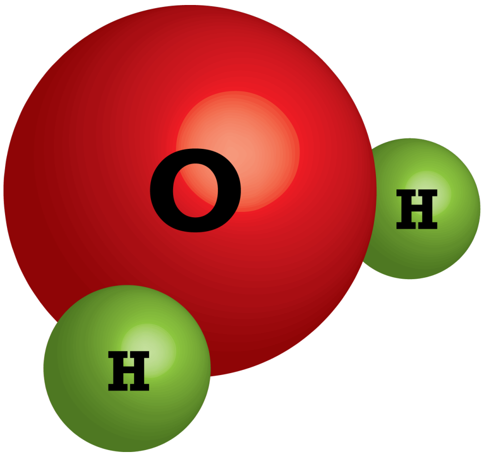
You'd have noticed, however, that you can usually rely on your TV to stay on. This is largely because we don't rely on kinetic energy alone for power. Instead, we primarily use energy in its other form as potential energy. **Potential energy** is stored energy that remains available until we choose to use it. Think of a battery in a flashlight. If you leave a flashlight on, the battery will run out of energy within a couple of hours. If, instead, you only use the flashlight when you need it and turn it off when you don't, the battery will last for days or even months. Because the battery stores potential energy, you can choose to use the energy all at once, or you can save it and use a small amount at a time.

Any stored energy is potential energy and has the "potential" to be used at a later time. Unfortunately, there are a lot of different ways in which energy can be stored, making potential energy very difficult to recognize. Generally speaking, an object has potential energy due to its position relative to another object. For example, when you hold a rock above the earth, it has more potential energy than a rock on the ground. As long as you're holding the rock, the rock has potential energy stored. Once you drop the rock, though, the stored energy is released. This can confuse students because it doesn't seem like a falling rock is releasing energy. Remember, however, that energy is defined as the ability to do work or cause change.

For some examples of potential energy, though, it's harder to see how "position" is involved. In chemistry, we are often interested in what is called chemical potential energy. **Chemical potential energy** is energy stored in the atoms, molecules, and chemical bonds that make up matter. How does this depend on position? As you learned earlier, the world and all of the chemicals in it are made up of atoms. These atoms store potential energy that is dependent on their positions relative to one another. Although we cannot see atoms, scientists know a lot about the ways in which atoms interact. This allows them to figure

out how much potential energy is stored in a specific quantity of a particular chemical. *Different chemicals have different amounts of potential energy* because they are made up of different atoms, and those atoms have different positions relative to one another.

The image below represents two hydrogen atoms chemically joined to an oxygen atom to form a water molecule. Scientists use their knowledge of what the atoms and molecules look like and how they interact to determine the potential energy that can be stored in any particular chemical substance.



Since different chemicals have different amounts of potential energy, scientists will sometimes say potential energy depends on not only position but also composition. Composition affects potential energy because it determines which molecules and atoms end up next to each other. For example, the total potential energy in a cup of pure water is different than the total potential energy in a cup of apple juice because the cup of water and the cup of apple juice are composed of different amounts of different chemicals.

The Law of Conservation of Matter and Energy

While it's important to understand the difference between kinetic energy and potential energy, the truth is energy is constantly changing. Kinetic energy is constantly being turned into potential energy, and potential energy is constantly being turned into kinetic energy. Even though energy can change form, it must still follow the fundamental law: *energy cannot be created or destroyed*, it can only be changed from one form to another. This law is known as the **law of conservation of energy**. In a lot of ways, energy is like money. You can exchange quarters for dollar bills and dollar bills for quarters, but no matter how often you convert between the two, you won't end up with more or less money than you started with.

Think about what happens when you throw a ball into the air. When the ball leaves your hand, it has a lot of kinetic energy. At some point, the ball will stop momentarily in the air and then falls back down. When the ball stops, it no longer has any kinetic energy. According to the law of conservation of energy, the initial kinetic energy that the ball had does not just disappear. Instead, as the ball moves higher and higher into the sky, the kinetic energy is converted to potential energy. When the ball stops moving upward, all of the kinetic energy has been converted to potential energy. The ball then starts to fall back down, and the potential energy is once again changed into kinetic energy.

As it turns out, the law of conservation of energy isn't completely accurate. Energy and matter are actually interchangeable. In other words, energy can be created (made out of matter) and destroyed (turned into matter). As a result, the law of conservation of energy has been changed into the **law of conservation of matter and energy**. This law states that: *the total amount of mass and energy in the universe is conserved (does not change).* This is one of the most important laws you will ever learn. Nevertheless, in chemistry we are rarely concerned with converting matter to energy or energy to matter. Instead, chemists

deal primarily with converting one form of matter into another form of matter (through chemical reactions) and converting one form of energy into another form of energy.

Heat and Work

When we talk about using energy, we are really referring to transferring energy from one place to another. When you use energy to throw a ball, you transfer energy from your body to the ball, which causes the ball to fly through the air. When you use energy to warm your house, you transfer energy from the furnace to the air in your home, which causes the temperature in your house to rise. Although energy is used in many kinds of different situations, all of these uses rely on energy being transferred in one of two ways: as heat or as work. Unfortunately, both "heat" and "work" are used commonly in everyday speech, so you might think that you already know their meanings. In science, the words "heat" and "work" have very specific definitions that may be different from what you expect. Do not confuse the everyday meanings of the words "heat" and "work" with the scientific meanings.

When scientists speak of heat, they are referring to energy that is transferred from an object with a higher temperature to an object with a lower temperature as a result of the temperature difference. Heat will "flow" from the hot object to the cold object until both end up at the same temperature. When you cook with a metal pot, you witness energy being transferred in the form of heat. Initially, only the stove element is hot; the pot and the food inside the pot are cold. As a result, heat moves from the hot element to the cold pot, as illustrated in **Figure** 1.4. After a while, enough heat is transferred from the element to the pot, raising the temperature of the pot and all of its contents.

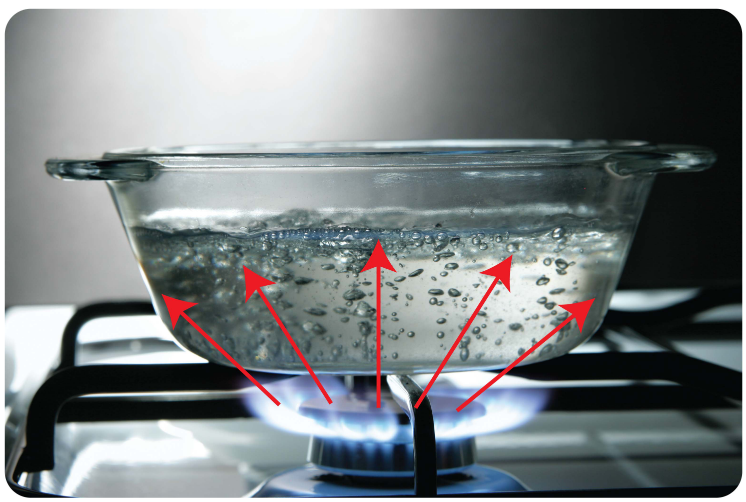
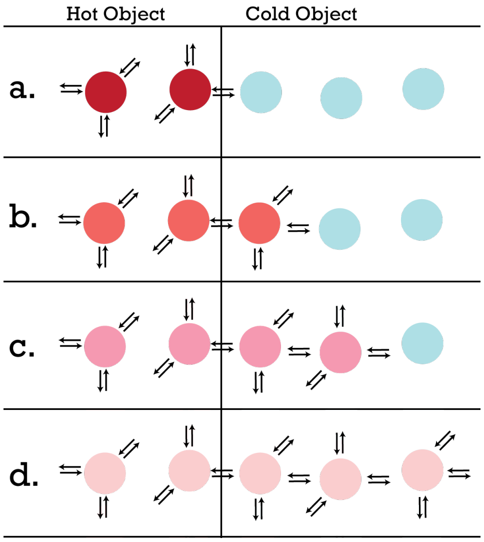


Figure 1.4: Energy is transferred as heat from the hot stove element to the cooler pot until the pot and its contents become just as hot as the element.

We've all observed heat moving from a hot object to a cold object, but you might wonder how the energy actually travels. Whenever an object is hot, the molecules within the object are shaking and vibrating vigorously. The hotter an object is, the more the molecules jiggle around. Anything that is moving has energy, and the more it's moving, the more energy it has. Hot objects have a lot of energy, and it's this energy that is transferred to the colder objects when the two come in contact.

The easiest way to visualize heat transfer is to imagine a domino effect. When the vibrating molecules of the hot object bump into the molecules of the colder object, they transfer some of their energy, causing the molecules in the colder object to start vibrating vigorously as well. In the image below, the red molecules are jiggling around and vibrating. As these molecules vibrate, they bump into their neighbors (the blue

molecules) and transfer some of their energy. These colder molecules begin to heat up and begin to vibrate faster. Just like dominoes, the heat gets passed along the chain until the energy is spread equally between all of the molecules. At the end, all of the molecules will be at the same temperature.



Heat is only one way in which energy can be transferred. Energy can also be transferred as work. The scientific definition of **work** is force (any push or pull) applied over a distance. Whenever you push an object and cause it to move, you've done work and transferred some of your energy to the object. At this point, it is important to warn you of a common misconception. Sometimes we think that the amount of work done can be measured by the amount of effort put in. This may be true in everyday life, but this is not true in science. By definition, scientific work requires that force be applied over a distance. It doesn't matter how hard you push or pull. If you haven't moved the object, you haven't done any work. For example, no matter how much you sweat, if you cannot lift a heavy object off the ground, you have not done any work.

Lesson Summary

- Energy is the ability to do work or cause change.
- The two forms of energy are kinetic energy and potential energy.
- Kinetic energy is energy associated with motion.
- Potential energy is stored energy.
- Kinetic energy is constantly being turned into potential energy, and potential energy is constantly being turned into kinetic energy.
- Even though energy can change form, it must still follow the law of conservation of energy.
- The law of conservation of energy states that energy cannot be created or destroyed, it can only be changed from one form to another.
- When scientists speak of heat, they are referring to energy that is transferred from an object with a higher temperature to an object with a lower temperature as a result of the temperature difference.
- Heat will "flow" from the hot object to the cold object until both end up at the same temperature.
- Energy can also be transferred as work.
- Work is force (any push or pull) applied over a distance.

Further Reading / Supplemental Links

Summary of concepts of matter and energy and benchmark review.

- http://broncho2.uco.edu/funeral/Bill%20Lewis/BoardReview/ChemLessons/Lesson%201.pdf

Classroom videos about energy.

- http://www.energyclassroom.com/

Review Questions

1. Classify each of the following as energy primarily transferred as heat or energy primarily transferred as work.
   (a) The energy transferred from your body to a shopping cart as you push the shopping cart down the aisle.
   (b) The energy transferred from a wave to your board when you go surfing.
   (c) The energy transferred from the flames to your hot dog when you cook your hot dog over a campfire.
2. Decide whether each of the following statements is true or false.
   (a) When heat is transferred to an object, the object cools down.
   (b) Any time you raise the temperature of an object, you have done work.
   (c) Any time you move an object by applying force, you have done work.
   (d) Any time you apply force to an object, you have done work.
3. Rank the following scenarios in order of *increasing* work.
   (a) You apply 100 N of force to a boulder and successfully move it by 2 m.
   (b) You apply 100 N of force to a boulder and successfully move it by 1 m.
   (c) You apply 200 N of force to a boulder and successfully move it by 2 m.
   (d) You apply 200 N of force to a boulder but cannot move the boulder.
4. In science, a vacuum is defined as space that contains absolutely no matter (no molecules, no atoms, etc.) Can energy be transferred as heat through a vacuum? Why or why not?
5. Classify each of the following energies as kinetic energy or potential energy:
   (a) the energy in a chocolate bar.
   (b) the energy of rushing water used to turn a turbine or a water wheel.
   (c) the energy of a skater gliding on the ice.
   (d) the energy in a stretched rubber band.
6. Decide which of the following objects has more kinetic energy.
   (a) A 200 lb man running at 6 mph or a 200 lb man running at 3 mph.
   (b) A 200 lb man running at 7 mph or a 150 lb man running at 7 mph.
   (c) A 400 lb man running at 5 mph or a 150 lb man running at 3 mph.
7. A car and a truck are traveling along the highway at the same speed.
   (a) If the car weighs 1500 kg and the truck weighs 2500 kg, which has more kinetic energy, the car or the truck?
   (b) Both the car and the truck convert the potential energy stored in gasoline into the kinetic energy of motion. Which do you think uses more gas to travel the same distance, the car or the truck?

Image Sources

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(4) Photograph by Stan Shebs. *Tehachapi wind farm*. CC-BY-SA-3.0.