CK-12 Physical Science Concepts For Middle School

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CHAPTER 2

Matter

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CHAPTER 2

Matter

2.1 Matter, Mass, and Volume

• Define matter.
• State what mass measures.
• State what volume measures.

Introduction

Do you know what atoms are? They are the basic building blocks of matter. Matter, in turn, is all the “stuff” in the universe. In this unit you will learn much more about matter—from things as simple as atoms to as complex as you!

What’s the Matter?

Matter is all the “stuff” that exists in the universe. Everything you can see and touch is made of matter, including
you! The only things that aren’t matter are forms of energy, such as light and sound. In science, matter is defined

as anything that has mass and volume. Mass and volume measure different aspects of matter.

Mass

Mass is a measure of the amount of matter in a substance or an object. The basic SI unit for mass is the kilogram (kg), but smaller masses may be measured in grams (g). To measure mass, you would use a balance. In the lab, mass may be measured with a triple beam balance or an electronic balance, but the old-fashioned balance pictured below may give you a better idea of what mass is.

If both sides of this balance were at the same level, it would mean that the fruit in the left pan has the same mass as the iron object in the right pan. In that case, the fruit would have a mass of 1 kg, the same as the iron. As you can see, however, the fruit is at a higher level than the iron. This means that the fruit has less mass than the iron, that is, the fruit's mass is less than 1 kg.

Q: If the fruit were at a lower level than the iron object, what would be the mass of the fruit?
A: The mass of the fruit would be greater than 1 kg.

Mass vs Weight

Mass is commonly confused with weight. The two are closely related, but they measure different things. Whereas

- mass measures the amount of matter in an object,
- weight measures the force of gravity acting on an object.

The force of gravity on an object depends on its mass but also on the strength of gravity. If the strength of gravity is held constant (as it is all over Earth), then an object with a greater mass also has a greater weight.

Q: With Earth's gravity, an object with a mass of 1 kg has a weight of 2.2 lb. How much does a 10 kg object weigh on Earth?
A: A 10 kg object weighs ten times as much as a 1 kg object: 10 x 2.2 lb = 22 lb

Volume

Volume is a measure of the amount of space that a substance or an object takes up. The basic SI unit for volume is the cubic meter (m^3), but smaller volumes may be measured in cm^3, and liquids may be measured in liters (L) or milliliters (mL).
How the volume of matter is measured depends on its state.

- The volume of a liquid is measured with a measuring container, such as a measuring cup or graduated cylinder.
- The volume of a gas depends on the volume of its container: gases expand to fill whatever space is available to them.
- The volume of a regularly shaped solid can be calculated from its dimensions. For example, the volume of a rectangular solid is the product of its length, width, and height.
- The volume of an irregularly shaped solid can be measured by the displacement method. You can read below how this method works.

Q: How could you find the volume of air in an otherwise empty room?
A: If the room has a regular shape, you could calculate its volume from its dimensions. For example, the volume of a rectangular room can be calculated with the formula:

$$\text{Volume} = \text{length} \times \text{width} \times \text{height}$$

If the length of the room is 5.0 meters, the width is 3.0 meters, and the height is 2.5 meters, then the volume of the room is:

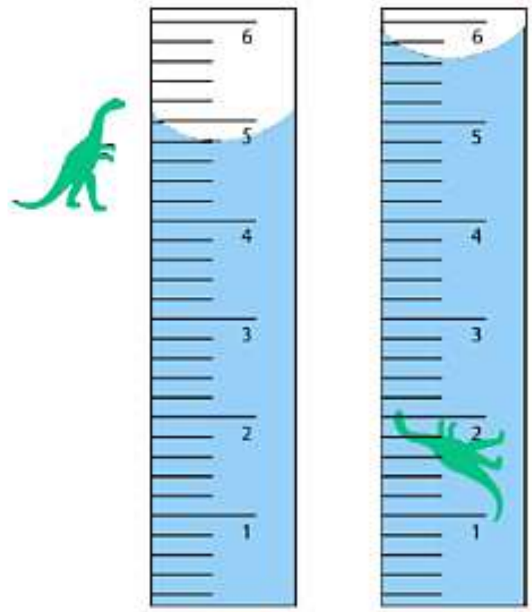
$$\text{Volume} = 5.0\ \text{m} \times 3.0\ \text{m} \times 2.5\ \text{m} = 37.5\ \text{m}^3$$

Displacement Method for Measuring Volume

1. Add water to a measuring container such as a graduated cylinder.
   Record the volume of the water.

2. Place the object in the water in the graduated cylinder. Measure the volume of the water with the object in it.

3. Subtract the first volume from the second volume.
   The difference represents the volume of the object.



Q: What is the volume of the dinosaur in the diagram above?
A: The volume of the water alone is 4.8 mL. The volume of the water and dinosaur together is 5.6 mL.
Therefore, the volume of the dinosaur alone is 5.6 mL – 4.8 mL = 0.8 mL.

Summary

- Matter is all the “stuff” that exists in the universe. It has both mass and volume.
- Mass measures the amount of matter in a substance or an object. The basic SI unit for mass is the kilogram (kg).
- Volume measures the amount of space that a substance or an object takes up. The basic SI unit for volume is the cubic meter (m^3).

Vocabulary

- **mass:** Amount of matter in a substance or object.
- **matter:** Anything that has mass and volume.
- **volume:** Amount of space taken up by matter.

Review

1. How do scientists define matter?
2. What is mass? What is the basic SI unit of mass?
3. What does volume measure? Name two different units that might be used to measure volume.
4. Explain how to use the displacement method to find the volume of an irregularly shaped object.

2.2 Physical Properties of Matter

- Define physical property.
- Give examples of physical properties of matter.

Introduction

Snow and sand are both kinds of matter, but they have different properties. What are some ways snow and sand differ? One difference is the temperature at which they melt. Snow melts at 0°C, whereas sand melts at about 1600°C!

The temperature at which something melts is its melting point. Melting point is just one of many physical properties of matter.

What Are Physical Properties?

Physical properties of matter are properties that can be measured or observed without matter changing to an entirely different substance. Physical properties are typically things you can detect with your senses.

For example, they may be things that you can see, hear, smell, or feel.

Q: What differences between snow and sand can you detect with your senses?
A: You can see that snow and sand have a different color. You can also feel that snow is softer than sand. Both color and hardness are physical properties of matter.

Additional Physical Properties

In addition to these properties, other physical properties of matter include the state of matter. States of matter include liquid, solid, and gaseous states. For example at 20°C, coal exists as a solid and water exists as a liquid.

Additional examples of physical properties include:

- odor
- boiling point
- ability to conduct heat
- ability to conduct electricity
- ability to dissolve in other substances

Q: The coolant that is added to a car radiator also has a lower freezing point than water. Why is this physical property useful?
A: When coolant is added to water in a car radiator, it lowers the freezing point of the water. This prevents the water in the radiator from freezing when the temperature drops below 0°C, which is the freezing point of pure water.

Q: Besides being able to conduct electricity, what other physical property of copper makes it well suited for electric wires?
A: Copper, like other metals, is ductile. This means that it can be rolled and stretched into long thin shapes such as wires.

Summary

- Physical properties of matter are properties that can be measured or observed without matter changing to an
- entirely different substance. Physical properties are typically things you can detect with your senses.
- Examples of physical properties of matter include melting point, color, hardness, state of matter, odor, and boiling point.

Vocabulary

- **physical property:** Property of matter that can be measured or observed without matter changing to an entirely different substance.

Review

1. What is a physical property of matter?
2. List three examples of physical properties.
3. Compare and contrast two physical properties of apples and oranges.

2.3 Density

- Define density.
- Demonstrate how to calculate density.

Introduction

Think of a man filling balloons with helium gas. What will happen if he lets go of the filled balloons?
They will rise up into the air until they reach the ceiling. Do you know why? It's because helium has less **density** than air.

Defining Density

Density is an important physical property of matter. It reflects how closely packed the particles of matter are. When particles are packed together more tightly, matter has greater density. Differences in density of matter explain many phenomena, not just why helium balloons rise. For example, differences in density of cool and warm ocean water explain why currents such as the Gulf Stream flow through the oceans.

To better understand density, think about a bowling ball and volleyball, pictured in the Figure shown. Imagine lifting each ball.

Bowling Ball vs Volleyball

The two balls are about the same size, but the bowling ball feels much heavier than the volleyball. That's because the bowling ball is made of solid plastic, which contains a lot of tightly packed particles of matter.

The volleyball, in contrast, is full of air, which contains fewer, more widely spaced particles of matter. In other words, the matter inside the bowling ball is denser than the matter inside the volleyball.

Q: If you ever went bowling, you may have noticed that some bowling balls feel heavier than others even though they are the same size. How can this be?
A: Bowling balls that feel lighter are made of matter that is less dense.

Calculating Density

The density of matter is actually the amount of matter in a given space. The amount of matter is measured by its **mass**, and the space matter takes up is measured by its **volume**.

Therefore, the density of matter can be calculated with this formula:

$$\text{Density} = \frac{mass}{volume}$$

Assume, for example, that a book has a mass of 500 g and a volume of 1000 cm^3. Then the density of the book is:

$$\text{Density} = \frac{500\ g}{1000\ \text{cm}^3} = 0.5\ \text{g/cm}^3$$

Q: What is the density of a liquid that has a volume of 30 mL and a mass of 300 g?
A: The density of the liquid is:

$$\text{Density} = \frac{300\ g}{30\ mL} = 10\ \text{g/mL}$$

Summary

- Density is an important physical property of matter. It reflects how closely packed the particles of matter are.
- The density of matter can be calculated by dividing its mass by its volume.

Vocabulary

- **density:** Amount of mass in a given volume of matter; calculated as mass divided by volume.

Review

1. What is density?
2. Find the density of an object that has a mass of 5 kg and a volume of 50 cm3.
3. Create a sketch that shows the particles of matter in two substances that differ in density. Label the sketch to show which substance has greater density.

2.4 Chemical Properties of Matter

- Define chemical property.
- Describe examples of chemical properties of matter.

Introduction

Look at the two garden trowels pictured here. Both trowels were left outside for several weeks. One tool became rusty, but the other did not. The tool that rusted is made of iron, and the other tool is made of aluminum.

The ability to rust is a chemical property of iron but not aluminum.

What Are Chemical Properties?

Chemical properties are properties that can be measured or observed only when matter undergoes a change to
become an entirely different kind of matter. For example, the ability of iron to rust can only be observed when iron
actually rusts. When it does, it combines with oxygen to become a different substance called iron oxide. Iron is very
hard and silver in color, whereas iron oxide is flakey and reddish brown. Besides the ability to rust, other chemical
properties include reactivity and flammability.

Reactivity

Reactivity is the ability of matter to combine chemically with other substances. Some kinds of matter are extremely reactive; others are extremely unreactive. For example, the metal magnesium is very reactive, even with water. When a pea-sized piece of magnesium is added to a small amount of water, it reacts explosively. In contrast, noble gases such as helium almost never react with any other substances.

Flammability

Flammability is the ability of matter to burn. When matter burns, it combines with oxygen and changes to different substances. Wood is an example of flammable matter. When wood burns, it changes to ashes, carbon dioxide, water vapor, and other gases.

Q: How can you tell that wood ashes are a different substance than wood?
A: Ashes have different properties than wood. For example, ashes are gray and powdery, whereas wood is brown and hard.

Q: What are some other substances that have the property of flammability?
A: Substances called fuels have the property of flammability. They include fossil fuels such as coal, natural gas, and petroleum, as well as fuels made from petroleum, such as gasoline and kerosene. Substances made of wood, such as paper and cardboard, are also flammable.

Summary

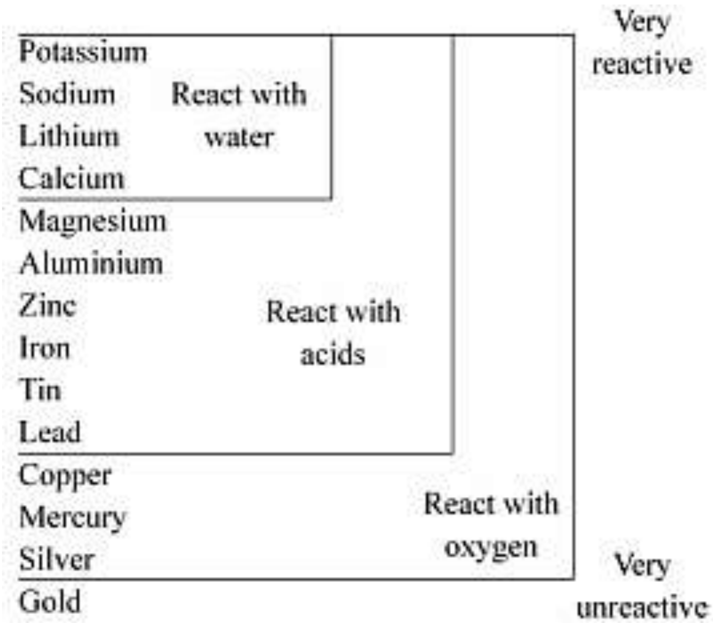
- *Chemical properties* are properties that can be measured or observed only when matter undergoes a change to become an entirely different kind of matter. They include reactivity, flammability, and the ability to rust.
- *Reactivity* is the ability of matter to react chemically with other substances.
- *Flammability* is the ability of matter to burn.

Vocabulary

- **chemical property:** property of matter that can be measured or observed only when matter changes to an entirely different substance.
- **flammability:** Ability of matter to burn.
- **reactivity:** Ability of a substance to combine chemically with other substances.

Practice

The chart below shows the reactivity of several different metals. The metals range from very reactive to very unreactive. Study the chart and then answer the questions below.



1. What is the most reactive metal in the chart? What is the least reactive metal?
2. Complete this sentence: Only the most reactive metals in the chart react with ______________.
3. Is this statement true or false? Most metals in the chart react with oxygen.
4. Which of the following metals reacts with oxygen and acids but not with water?
   a. calcium
   b. magnesium
   c. copper

Review

1. What is a chemical property?
2. Define the chemical property called reactivity.
3. What is flammability? Identify examples of flammable matter

2.5 Elements

- Define element.
- Describe how properties of different elements compare.
- Outline the history of elements.
- Relate atoms to elements.

Introduction

There are millions of different kinds of matter in the universe. Yet all kinds of matter actually consist of relatively few pure substances.

Pure Substances

A pure substance is called an **element**. An element is a pure substance because it cannot be separated into any other substances. Currently, 92 different elements are known to exist in nature, although additional elements have been formed in labs.

All matter consists of one or more of these elements. Some elements are very common; others are relatively rare. The most common element in the universe is **hydrogen,** which is part of Earth's atmosphere and a component of water.

The most common element in Earth's atmosphere is **nitrogen**, and the most common element in Earth's crust is **oxygen**.

Elemental Properties

Each element has a unique set of properties that is different from the set of properties of any other element. For example, the element iron is a solid that is attracted by a magnet and can be made into a magnet, like a compass needle. The element neon, on the other hand, is a gas that gives off a red glow when electricity flows through it.

Q: Do you know properties of any other elements? For example, what do you know about helium?
A: Helium is a gas that has a lower density than air. That's why helium balloons have to be weighted down so they won't float away.

Q: Living things, like all matter, are made of elements. Do you know which element is most common in living things?
A: Carbon is the most common element in living things. It has the unique property of being able to combine with many other elements as well as with itself. This allows carbon to form a huge number of different substances.

History of Elements

For thousands of years, people have wondered about the substances that make up matter. About 2500 years ago, the Greek philosopher Aristotle argued that all matter is made up of just four elements, which he identified as **earth, air, water**, and **fire**.

He thought that different substances vary in their properties because they contain different proportions of these four elements. Aristotle had the right idea, but he was wrong about which substances are elements. Nonetheless, his four elements were accepted until just a few hundred years ago. Then scientists started discovering many of the elements with which we are familiar today. Eventually they discovered dozens of different elements.

Particles of Elements

The smallest particle of an element that still has the properties of that element is the **atom**. Atoms actually consist of smaller particles, including **protons** and **electrons**, but these smaller particles are the same for all elements. All the atoms of an element are like one another, and are different from the atoms of all other elements. For example, the atoms of each element have a unique number of protons.

Consider carbon as an example. Carbon atoms have six protons. They also have six electrons. All carbon atoms are the same whether they are found in a lump of coal or a teaspoon of table sugar (see below).

Carbon is the main element in coal (left).
Carbon is also a major component of sugar (right).

On the other hand, carbon atoms are different from the atoms of hydrogen, which are also found in coal and sugar.

Each hydrogen atom has just one proton and one electron.

Q: Why do you think coal and sugar are so different from one another when carbon is a major component of each substance?
A: Coal and sugar differ from one another because they contain different proportions of carbon and other elements. For example, coal is about 85 percent carbon, whereas table sugar is about 42 percent carbon.

Both coal and sugar also contain the elements hydrogen and oxygen but in different proportions. In addition, coal contains the elements nitrogen and sulfur.

Summary

- An element is a pure substance that cannot be separated into any other substances. There are 92 naturally occurring elements.
- Each element has a unique set of properties that is different from the set of properties of any other element.
- For about 2000 years, people accepted Aristotle’s idea that all matter is made up of just four elements: earth, air, water, and fire. Starting about 500 years ago, scientists began discovering all of the elements that are known today.
- The smallest particle of an element that still has the properties of that element is the atom. All the atoms of an element are like one another, and are different from the atoms of all other elements.

Vocabulary

- **atom**: Smallest particle of an element that still has the element’s properties.
- **element:** Pure substance that cannot be separated into any other substances.

Review

1. What is an element?
2. Why can an element be identified by its properties?
3. Explain why the following statement is either true or false: The idea that all matter consists of the elements was first introduced a few hundred years ago.
4. How are atoms related to elements?

2.6 Compounds

- Define compound, and give examples of compounds.
- Contrast the properties of compounds and the properties of the elements that form compounds.
- Describe crystals and molecules.

Introduction

Some types of matter are elements, or pure substances that cannot be broken down into simpler substances. Many other types of matter are compounds. A common compound is carbon dioxide, a gas you exhale each time you breathe.

What Is a Compound?

A *compound* is a unique substance that forms when two or more elements combine chemically. For example, the compound carbon dioxide forms when one atom of carbon combines with two atoms of oxygen. Another example of a compound is water. It forms when two hydrogen atoms combine with one oxygen atom.

Q: How could a water molecule be represented?
A: It could be represented by a model like the one shown below. The grey represents two Hydrogen atoms and the red represents one Oxygen atom.

Water Model

Two things are true of all compounds:

- A compound always has the same elements in the same proportions. For example, carbon dioxide always has two atoms of oxygen for each atom of carbon, and water always has two atoms of hydrogen for each atom of oxygen.
- A compound always has the same composition throughout. For example, all the carbon dioxide in the atmosphere and all the water in the ocean have these same proportions of elements.

Q: How do you think the properties of compounds compare with the properties of the elements that form them?
A: You might expect the properties of a compound to be similar to the properties of the elements that make up the compound. But you would be wrong.

Properties of Compounds

The properties of compounds are different from the properties of the elements that form them—sometimes very different. That's because elements in a compound combine and become an entirely different substance with its own unique properties. Do you put salt on your food? Table salt is the compound sodium chloride. It contains sodium and chlorine.

As shown below, sodium is a solid that reacts explosively with water, and chlorine is a poisonous gas. But together in table salt, sodium and chlorine form a harmless unreactive compound (Sodium Chloride) that you can safely eat.

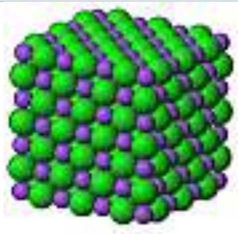
Q: The compound sodium chloride is very different from the elements sodium and chlorine that combine to form it.
What are some properties of sodium chloride?
A: Sodium chloride is an odorless white solid that is harmless unless consumed in large quantities. In fact, it is a necessary component of the human diet and is known as salt.

Structure of Compounds

Compounds like sodium chloride form structures called crystals. A crystal is a rigid framework of many ions locked together in a repeating pattern.

Ions are electrically charged forms of atoms. You can see a crystal of sodium chloride in the figure.

It is made up of many sodium and chloride ions.



A sodium chloride crystal consists of many sodium ions (blue) and chloride ions (green) arranged in a rigid framework.

Compounds such as carbon dioxide and water form molecules instead of crystals. A molecule is the smallest particle of a compound that still has the compound's properties. It consists of two or more atoms bonded together. You saw models of carbon dioxide and water molecules above.

Summary

- A compound is a unique substance that forms when two or more elements combine chemically.
  A compound always has the same elements in the same proportions.
- The properties of compounds may be very different from the properties of the elements that form them.
- Some compounds form rigid frameworks called crystals. Other compounds form individual molecules. A molecule is the smallest particle of a compound that still has the compound's properties.

Vocabulary

- **compound:** Unique substance that forms when two or more elements combine chemically.
- **crystal:** Rigid, lattice-like framework of many ions bonded together that is formed by some compounds such as table salt (NaCl).
- **molecule:** Smallest particle of a compound that still has the compound's properties.

Review

1. What are compounds? List three examples.
2. How do the properties of compounds compare with the properties of the elements that form them?
3. Compare and contrast crystals and molecules.

2.7 Mixtures

- Define mixture, and give examples of mixtures.
- Contrast homogeneous and heterogeneous mixtures.
- Identify types of mixtures based on particle size.
- Explain how to separate the components of mixtures.

Introduction

A tall glass of ice-cold lemonade is really refreshing on a hot day. Lemonade is a combination of lemon juice, water, and sugar. Do you know what kind of matter lemonade is? It's obviously not an element because it consists of more than one substance. Is it a compound? Not all combined substances are compounds.
Some—including lemonade—are mixtures.

What Is a Mixture?

A mixture is a combination of two or more substances in any proportion. This is different from a compound, which consists of substances in fixed proportions. The substances in a mixture also do not combine chemically to form a new substance, as they do in a compound. Instead, they just intermingle and keep their original properties.

Lemonade is a mixture because it doesn't have fixed proportions of ingredients. It could have more or less lemon juice, for example, or more or less sugar, and it would still be lemonade.

Q: What are some other examples of mixtures?

A: Other examples of liquid mixtures include salt water and salad dressing.

- *Air* is a mixture of gases, mainly nitrogen and oxygen.
- A *rock* is a solid mixture of smaller rocks and minerals.

Homogeneous or Heterogeneous?

Lemonade is an example of a homogeneous mixture. A homogeneous mixture has the same composition throughout. Another example of a homogeneous mixture is salt water. If you analyzed samples of ocean water in different places, you would find that the proportion of salt in each sample is the same: 3.5 percent.

A rock is an example of a heterogeneous mixture. A heterogeneous mixture varies in its composition. The black nuggets, for example, are not distributed evenly throughout the rock.

Types of Mixtures

Mixtures have different properties depending on the size of their particles. Three types of mixtures based on particle size are solutions, suspensions, and colloids, all of which are described in Table 2.1.

Solutions, Suspensions, and Colloids	
Type of Mixture	Description
 Solutions	A **solution** is a homogeneous mixture with tiny particles. The particles are too small to see and also too small to settle or be filtered out of the mixture. When the salt is thoroughly mixed into the water in this glass, it will form a solution. The salt will no longer be visible in the water, and it won't settle to the bottom of the glass.
 Colloids	A **colloid** is a homogeneous mixture with mediumsized particles. The particles are large enough to see but not large enough to settle or be filtered out of the mixture. The gelatin in this dish is a colloid. It looks red because you can see the red gelatin particles in the mixture. However, the particles are too small to settle to the bottom of the dish.
 Suspensions	A **suspension** is a heterogeneous mixture with large particles. The particles are large enough to see and also to settle or be filtered out of the mixture. The salad dressing in this bottle is a suspension. It contains oil, vinegar, herbs, and spices. If the bottle sits undisturbed for very long, the mixture will separate into its component parts. That's why you should shake it before you use it.

Q: If you buy a can of paint at a paint store, a store employee may put the can on a shaker machine to mix up the paint in the can. What type of mixture is the paint?
A: The paint is a suspension. Some of the components of the paint settle out of the mixture when it sits undisturbed for a long time. This explains why you need to shake (or stir) the paint before you use it.

Q: The milk you buy in the supermarket has gone through a process called homogenization. This process breaks up the cream in the milk into smaller particles. As a result, the cream doesn't separate out of the milk no matter how long it sits on the shelf. Which type of mixture is homogenized milk?
A: Homogenized milk is a colloid. The particles in the milk are large enough to see—that's why milk is white instead of clear like water, which is the main component of milk. However, the particles are not large enough to settle out of the mixture.

Separating Mixtures

The components of a mixture keep their own identity when they combine, so they retain their physical properties. Examples of physical properties include boiling point, ability to dissolve, and particle size. When components of mixtures vary in physical properties such as these, processes such as boiling, dissolving, or filtering can be used to separate them.

Look at the picture of the Great Salt Lake in Utah. The water in the lake is a solution of salt and water. Do you see the white salt deposits near the shore? How did the salt separate from the salt water? Water has a lower boiling point than salt, and it evaporates in the heat of the sun. With its higher boiling point, the salt doesn't get hot enough to evaporate, so it is left behind.

Q: Suppose you have a mixture of salt and pepper. What properties of the salt and pepper might allow you to separate them?
A: Salt dissolves in water but pepper does not. If you mix salt and pepper with water, only the salt will dissolve, leaving the pepper floating in the water. You can separate the pepper from the water by pouring the mixture through a filter, such as a coffee filter.
Q: After you separate the pepper from the salt water, how could you separate the salt from the water?
A: You could heat the water until it boils and evaporates. The salt would be left behind.

Summary

- A mixture is a combination of two or more substances in any proportions. The substances in a mixture do not combine chemically, so they retain their physical properties.
- A homogeneous mixture has the same composition throughout. A heterogeneous mixture varies in its composition.
- Mixtures can be classified on the basis of particle size into three different types: solutions, suspensions, and colloids.
- The components of a mixture retain their own physical properties. These properties can be used to separate the components by filtering, boiling, or other physical processes.

Vocabulary

- **colloid:** Homogeneous mixture in which the particles are large enough to reflect light but too small to settle or filter out of the mixture.
- **mixture:** Combination of two or more substances in any proportions.
- **solution:** Homogeneous mixture in which particles are too small to reflect light and too small to settle or be filtered out of the mixture.
- **suspension:** Heterogeneous mixture in which particles are large enough to reflect light and to settle or be filtered out of the mixture.

Review

1. What is a mixture?
2. What is the difference between a homogeneous and a heterogeneous mixture?
3. Make a table to compare and contrast solutions, colloids, and suspensions. Include an example of each type of mixture in your table.
4. Iron filings are attracted by a magnet. This is a physical property of iron but not of most other materials, including sand. How could you use this difference in physical properties to separate a mixture of iron filings and sand?

2.8 Physical Change

- Define physical change, and give examples of physical change.
- Explain how physical changes can be reversed.

What Is a Physical Change?

A physical change is a change in one or more physical properties of matter without any change in chemical properties. In other words, matter doesn't change into a different substance in a physical change.

Examples of physical change include changes in the size or shape of matter. Changes of state—for example, from solid to liquid or from liquid to gas—are also physical changes. Some of the processes that cause physical changes include cutting, bending, dissolving, freezing, boiling, and melting.

Four examples of physical change are pictured below.

			
The paper is being cut into smaller pieces, which is changing its size and shape.	The ice cubes are turning into a puddle of liquid water because they are melting. This is a change of state.	The tablet is disappearing in the glass of water as it is dissolving into particles that are too small to see.	The lighthouse is becoming coated with ice as ocean spray freezes on its surface. This is another change of state.

Reversing Physical Changes

When matter undergoes physical change, it doesn't become a different substance. Therefore, physical changes are often easy to reverse. For example, when liquid water freezes to form ice, it can be changed back to liquid water by heating and melting the ice.

Q: Salt dissolving in water is a physical change. How could this change be reversed?
A: The salt water could be boiled until the water evaporates, leaving behind the salt. Water vapor from the boiling water could be captured and cooled. The water vapor would condense and change back to liquid water.

Summary

- A physical change in matter is a change in one or more of matter’s physical properties. In a physical change, matter may change its size, shape, or state, but its chemical properties do not change.
- Because the chemical properties of matter remain the same in a physical change, a physical change is often easy to reverse.

Vocabulary

- **physical change:** Change in one or more of matter’s physical properties.

Review

1. Define physical change.
2. What are some examples of physical change?
3. A wooden log is being cut with a chainsaw. Is this a physical change? Why or why not?

2.9 Chemical Change

- Define chemical change, and give examples of chemical changes.
- List signs that a chemical change has occurred.
- Explain how some chemical changes can be reversed.

Introduction

Communities often use fireworks to celebrate important occasions. Fireworks certainly create awesome sights and sounds! Do you know what causes the brilliant lights and loud booms of a fireworks display? The answer is chemical changes.

What Is a Chemical Change?

A *chemical change* occurs whenever matter changes into an entirely different substance with different chemical properties. A chemical change is also called a *chemical reaction*. Many complex chemical changes occur to produce the explosions of fireworks.

An example of a simpler chemical change is the burning of methane. Methane is the main component of natural gas, which is burned in many home furnaces. During burning, methane combines with oxygen in the air to produce entirely different chemical substances, including the gases carbon dioxide and water vapor.

Identifying Chemical Changes

Most chemical changes are not as dramatic as exploding fireworks, so how can you tell whether a chemical change has occurred? There are usually clues. You just need to know what to look for. A chemical change has probably occurred if bubbles are released, there is a change of color, or an odor is produced. Other clues include the release of heat, light, or loud sounds.

Q: In addition to iron rusting, what is another example of matter changing color? Do you think this color change is a sign that a new chemical substance has been produced?
A: Another example of matter changing color is a penny changing from reddish brown to greenish brown as it becomes tarnished. The color change indicates that a new chemical substance has been produced. Copper on the surface of the penny has combined with oxygen in the air to produce a different substance called copper oxide.
Q: Besides food spoiling, what is another change that produces an odor? Is this a chemical change?
A: When wood burns, it produces a smoky odor. Burning is a chemical change.

Q: Which signs of chemical change do fireworks produce?
A: Fireworks produce heat, light, and loud sounds. These are all signs of chemical change.

Can Chemical Changes Be Reversed?

Because chemical changes produce new substances, they often cannot be undone. For example, you can't change ashes from burning logs back into wood. Some chemical changes can be reversed, but only by other chemical changes. For example, to undo tarnish on copper pennies, you can place them in vinegar. The acid in the vinegar combines with the copper oxide of the tarnish. This changes the copper oxide back to copper and oxygen, making the pennies reddish brown again. You can try this at home to see how well it works.

Summary

- A chemical change occurs whenever matter changes into an entirely different substance with different chemical properties. Burning is an example of a chemical change.
- Signs of chemical change include the release of bubbles, a change of color, production of an odor, release of heat and light, and production of loud sounds.
- Because chemical changes result in different substances, they often cannot be undone. Some chemical changes can be reversed, but only by other chemical changes.

Vocabulary

- **chemical change:** Change in matter that occurs when matter changes chemically into an entirely different substance with different chemical properties.

Review

1. What happens in any chemical change?
2. List three signs that a chemical change has occurred.
3. Give an example of a chemical change. Explain why you think it is a chemical change.
4. Why can chemical changes often not be reversed?

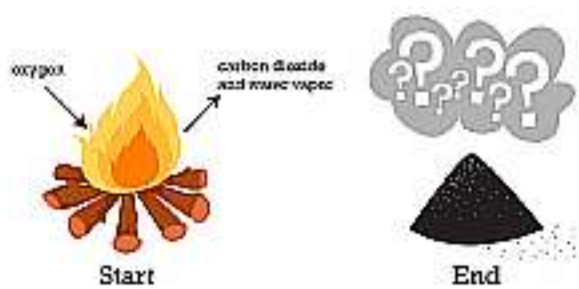
2.10 Conservation of Mass

- Describe an example of mass remaining the same in a change of matter.
- State the law of conservation of mass.

Introduction

If you build a campfire, you start with a big pile of logs. As the fire burns, the pile of logs slowly shrinks. By the end of the evening, all that's left is a small pile of ashes. What happened to the matter that you started with? Was it destroyed by the fire? Where's the Matter?

It may seem as though burning destroys matter, but the same amount, or mass, of matter still exists after a campfire as before. Look at the sketch below. It shows that when wood burns, it combines with oxygen and changes not only to ashes but also to carbon dioxide and water vapor. The gases float off into the air, leaving behind just the ashes.



Burning is a chemical process.

Suppose you had measured the mass of the wood before it burned and the mass of the ashes after it burned. Also suppose you had been able to measure the oxygen used by the fire and the gases produced by the fire. What would you find? The total mass of matter after the fire would be the same as the total mass of matter before the fire.

Q: What can you infer from this example?

A: You can infer that burning does not destroy matter. It just changes matter into different substances.

Law of Conservation of Mass

This burning campfire example illustrates a very important law in science: **the law of conservation of mass**. This law states that matter cannot be created or destroyed. Even when matter goes through a physical or chemical change, the total mass of matter always remains the same.

Q: How could you show that the mass of matter remains the same when matter changes state?
A: You could find the mass of a quantity of liquid water. Then you could freeze the water and find the mass of the ice. The mass before and after freezing would be the same, showing that mass is conserved when matter changes state.

Summary

- Burning and other changes in matter do not destroy matter. The mass of matter is always the same before and after the changes occur.
- The law of conservation of mass states that matter cannot be created or destroyed.

Vocabulary

- law of conservation of mass: Law stating that matter cannot be created or destroyed in chemical reactions.

Review

1. What is the law of conservation of mass?
2. Describe an example of the law of conservation of mass.

2.11 States of Matter

- Define state of matter, and list states of matter.
- Identify state of matter as a physical property of matter.
- Contrast the three states of matter that are most common on Earth.

Water, Water Everywhere

The photo above represents water in three common states of matter. States of matter are different phases in which any given type of matter can exist. There are actually four well-known states of matter: solid, liquid, gas, and plasma. Plasma isn’t represented in an iceberg photo, but the other three states of matter are. An iceberg itself consists of water in the solid state, and the lake consists of water in the liquid state.

Q: Where is water in the gaseous state in the photo of an iceberg?
A: You can’t see the gaseous water, but it’s there. It exists as water vapor in the air.
Q: Water is one of the few substances that commonly exist on Earth in more than one state. Many other substances typically exist only in the solid, liquid, or gaseous state. Can you think of examples of matter that usually exists in just one of these three states?
A: Just look around you and you will see many examples of matter that usually exists in the solid state. They include soil, rock, wood, metal, glass, and plastic.
Examples of matter that usually exist in the liquid state include cooking oil, gasoline, and mercury, which is the only metal that commonly exists as a liquid. Examples of matter that usually exists in the gaseous state include oxygen and nitrogen, which are the chief gases in Earth’s atmosphere.

Phases Are Physical

A given kind of matter has the same chemical makeup and the same chemical properties regardless of its state. That’s because state of matter is a physical property. As a result, when matter changes state, it doesn’t become a different kind of substance. For example, water is still water whether it exists as ice, liquid water, or water vapor.

Properties of Solids, Liquids, and Gases

The most common states of matter on Earth are solids, liquids, and gases. How do these states of matter differ?

Gas	Liquid	Solid
Shape of Container *Volume of Container*	*Shape of Container* *Free Surface* *Fixed Volume*	*Holds Shape* *Fixed Volume*

Q: The above figure shows that a liquid takes the shape of its container. How could you demonstrate this?
A: You could put the same volume of liquid in containers with different shapes. This is illustrated below with a beaker (left) and a graduated cylinder (right). The shape of the liquid in the beaker is short and wide like the beaker, while the shape of the liquid in the graduated cylinder is tall and narrow like that container, but each container holds the same volume of liquid.

Q: How could you show that a gas spreads out to take the volume as well as the shape of its container?
A: You could pump air into a bicycle tire. The tire would become firm all over as air molecules spread out to take the shape of the tire and also to occupy the entire volume of the tire.

Summary

- States of matter are different phases in which any given type of matter can exist. There are four well-known states of matter—solid, liquid, gas, and plasma—but only the first three states are common on Earth.
- State of matter is a physical property of matter. A given kind of matter has the same chemical makeup and the same chemical properties, regardless of state.
- Solids have a fixed volume and a fixed shape. Liquids have a fixed volume but take the shape of their container. Gases take both the volume and the shape of their container.

Vocabulary

• **state of matter:** Different phase (solid, liquid, gas, and plasma) in which matter can exist without the chemical makeup of matter changing.

Review

1. Define state of matter.
2. List four states of matter. Which states of matter are most common on Earth?
3. What type of property is state of matter? How could you demonstrate this?
4. Make a table comparing and contrasting solids, liquids, and gases.

2.12 Solids

- Identify properties of matter in the solid state.
- Compare crystalline and amorphous solids.

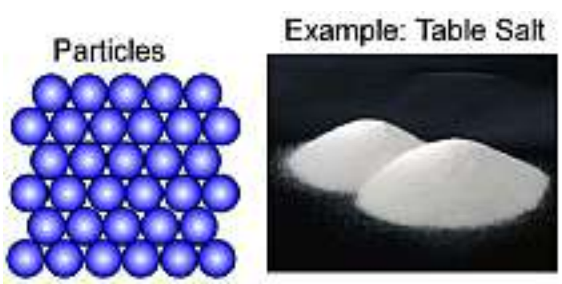
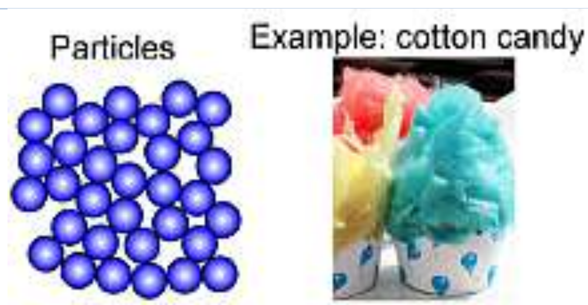
Snowflakes and Other Solids

A snowflake is made of ice, or water in the solid state. A solid is one of four well-known states of matter. The other three states are liquid, gas, and plasma. Compared with these other states of matter, solids have particles that are much more tightly packed together. The particles are held rigidly in place by all the other particles around them so they can't slip past one another or move apart. This gives solids a fixed shape and a fixed volume.

Types of Solids

Not all solids are alike. Some are crystalline solids; others are amorphous solids. Snowflakes are crystalline solids. Particles of crystalline solids are arranged in a regular repeating pattern, as you can see in the sketch below left. Another crystalline solid is table salt (sodium chloride).

Amorphous means "shapeless." Particles of amorphous solids are arranged more-or-less at random and do not form crystals, as you can see in the sketch below right.

 Crystalline Solid	 Amorphous Solid
The repeating particles form a geometric shape called a crystal. Crystals of table salt are pictured at right.	An example of an amorphous solid is cotton candy, also shown

Q: Imagine a quartz rock and a plastic bag. Which type of solid do you think each of them is?

A: The quartz is a crystalline solid. Rocks are made of minerals and minerals form crystals. You can see their geometric shapes. The bag is an amorphous solid. It is made of the plastic and most plastics do not form crystals.

Summary

- A solid is a state of matter in which particles of matter are tightly packed together. This holds the particles rigidly in place and gives solids a fixed shape and fixed volume.
- Crystalline solids have particles that are arranged in a regular repeating pattern. They form crystals. Amorphous solids have particles that are arranged more-or-less at random. They do not form crystals.

Vocabulary

- **solid:** State of matter that has a fixed volume and fixed shape.

Review

1. What is a solid?
2. Why does a solid have a fixed shape and fixed volume?
3. Create a table comparing and contrasting crystalline and amorphous solids. Include an example of each type of solid in your table.
4. Diamonds are the hardest of all minerals. Is a diamond a crystalline or an amorphous solid? How do you know?

2.13 Liquids

- Identify properties of matter in the liquid state.
- Describe surface tension and viscosity of liquids.

Water and Other Liquids

Water is the most common substance on Earth, and most of it exists in the liquid state. A liquid is one of four well-known states of matter, along with solid, gas, and plasma states. The particles of liquids are in close contact with each other but not as tightly packed as the particles in solids. The particles can slip past one another and take the shape of their container. However, they cannot pull apart and spread out to take the volume of their container, as particles of a gas can.

If the volume of a liquid is less than the volume of its container, the top surface of the liquid will be exposed to the air in the container.

Q: Why does most water on Earth's surface exist in a liquid state? In what other states does water exist on Earth?
A: Almost 97 percent of water on Earth's surface is found as liquid salt water in the oceans. The temperature over most of Earth's surface is above the freezing point (0°C) of water, so relatively little water exists as ice. Even near the poles, most of the water in the oceans is above the freezing point. And in very few places on Earth's surface do temperatures reach the boiling point (100°C) of water. Although water exists in the atmosphere in a gaseous state, water vapor makes up less than 1 percent of Earth's total water.

Surface Tension and Viscosity

Two unique properties of liquids are surface tension and viscosity.

Surface Tension is a force that pulls particles at the exposed surface of a liquid toward other liquid particles.

Surface tension explains why water forms droplets, like the water droplet that has formed on the leaky faucet pictured at right.

Viscosity is a liquid’s resistance to flowing. You can think of it as friction between particles of liquid. Thicker liquids are more viscous than thinner liquids. For example, the honey pictured below is more viscous than the vinegar.

Q: Which liquid do you think is more viscous: honey or chocolate syrup?
A: The viscosity of honey and chocolate syrup vary by brand and other factors, but chocolate syrup generally is more viscous than honey.

Summary

- A liquid is a state of matter in which particles can slip past one another and take the shape of their container. However, the particles cannot pull apart and spread out to take the volume of their container.
- Surface tension is a force that pulls particles at the exposed surface of a liquid toward other liquid particles.
- Viscosity is a liquid’s resistance to flowing.

Vocabulary

- **liquid:** State of matter that has a fixed volume but not a fixed shape.

Review

1. State the properties of matter in the liquid state.
2. What property of liquids explains why water beads up on a shiny car surface?
3. Predict which liquid has greater viscosity: olive oil or motor oil (SAE 40). Then do online research to find out if your prediction is correct.

2.14 Gases

- Identify properties of gases.
- Explain why gases exert pressure.
- Describe how atmospheric pressure changes as altitude increases.

Introduction

A hiker pauses to view the impressive peak of Mount Everest, the tallest mountain in the world. At the top of Mount Everest, the air is very thin. Climbers may need oxygen tanks to get enough oxygen to breathe, even though oxygen is the second most plentiful gas in the atmosphere.

What Is a Gas?

A gas is one of four well-known states of matter. (The other three are solid, liquid, and plasma). The particles of a gas can pull apart from each other and spread out. As a result, a gas does not have a fixed shape or a fixed volume. In fact, a gas always spreads out to take up whatever space is available to it. If a gas is enclosed in a container, it spreads out until it has the same volume as the container.

Pressure of Gases

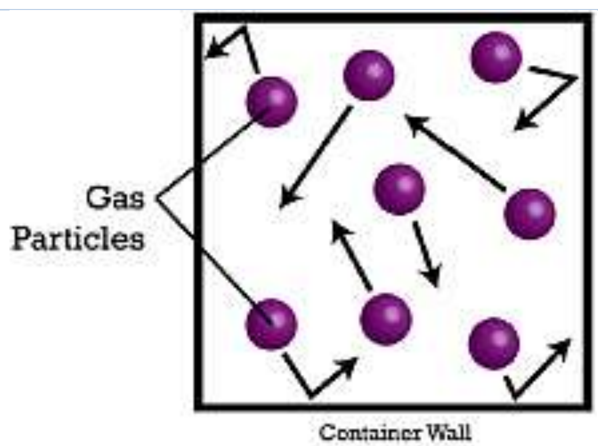
Particles of gas are constantly moving in all directions at random. As a result, they are always bumping into each other and other things. This is modeled in the figure below. The force of the particles against things they bump into creates pressure.

The arrows show that particles of a gas move randomly in all directions.

Pressure is defined in physics as the amount of force pushing against a given area.

How much pressure a gas exerts depends on the number of gas particles in a given space and how fast they are moving.

The more gas particles there are and the faster they are moving, the greater the pressure they create.



Pressure in the Atmosphere

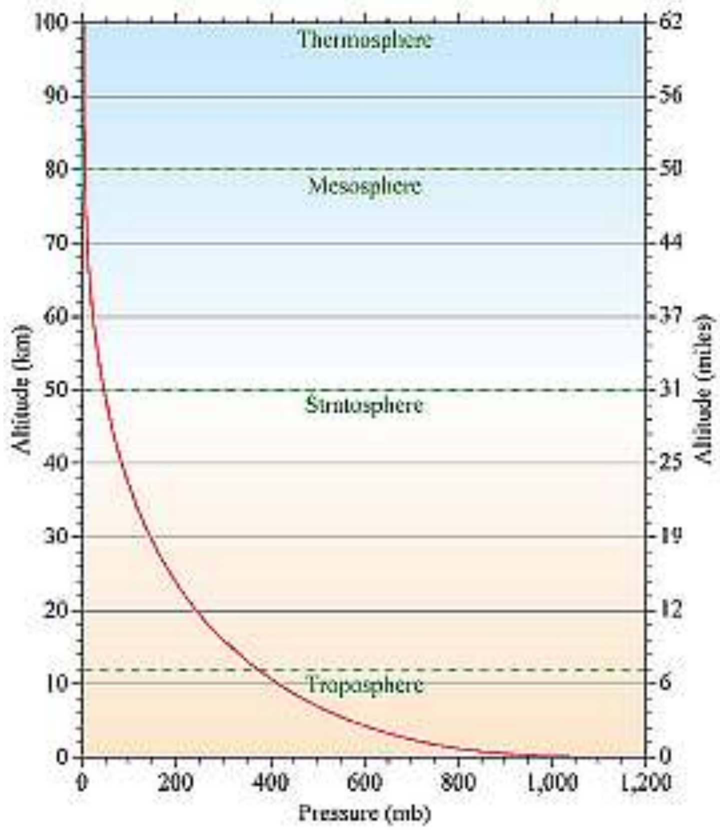
We live in a "sea" of air called the atmosphere. Can you feel the air in the atmosphere pressing against you? Not usually, but air actually exerts a lot of pressure because there's so much of it.

The atmosphere rises high above Earth's surface, so it contains a huge number of gas particles. Most of them are concentrated close to Earth's surface because of gravity and the weight of all the air in the atmosphere above them.

As a result, air pressure is greatest at sea level and drops rapidly as you go higher in altitude.

The Figure shows how air pressure falls from sea level to the top of the atmosphere. In the graph, air pressure is measured in a unit called the millibar (mb).

The SI unit of pressure is Newtons per square centimeter (N/cm^2).



Q: The top of Mount Everest is almost 9 km above sea level. What is the pressure of the atmosphere at this altitude?

A: Air pressure at the top of Mount Everest is about 260 mb. This is only about 25 percent of air pressure at sea level, which is 1013.2 mb.
No wonder it's hard for climbers to breathe when they get close to Mount Everest's summit!

Summary

- Gas is a state of matter in which particles of matter can pull apart from each other and spread out. As a result, a gas does not have a fixed shape or a fixed volume.
- Gas particles are constantly moving and bumping into things, and this creates force. The amount of force pushing against a given area is called pressure.
- The pressure of gases in the atmosphere is greatest at sea level and decreases rapidly as altitude increases.

Vocabulary

- **gas:** State of matter that has neither a fixed volume nor a fixed shape.
- **pressure:** Result of force acting on a given area.

Review

1. What is a gas?
2. Why does a gas not have a fixed shape or a fixed volume?
3. Explain why a gas exerts force
4. What does pressure measure?

2.15 Plasma

- State properties of matter in the plasma state.
- Identify where plasma is found.

Introduction

This glowing sphere is matter in a particular state. You're probably familiar with the states of matter most common on Earth—solid, liquid, and gas. But the glowing sphere is a state of matter called **plasma.** The plasma ball pictured was made by humans, but plasma is also found in nature. In fact, plasma makes up most of the matter in the universe.	

What Is Plasma?

Plasma is a state of matter that resembles a gas but has certain properties that gases do not have. Like a gas, plasma consists of particles of matter than can pull apart and spread out, so it lacks a fixed volume and a fixed shape. Unlike a gas, plasma can conduct electricity and respond to a magnetic field. That's because plasma consists of electrically charged particles called ions, instead of uncharged particles such as atoms or molecules. This gives plasma other interesting properties as well. For example, plasma glows with colored light when electricity passes through it.

Where Is Plasma Found?

The sun and other stars consist of plasma. Plasma is also found naturally in lightning. Human-made plasmas are found in fluorescent lights, plasma TV screens, and plasma spheres like the one pictured in the opening image.

Q: What properties of plasma do you think explain why this state of matter is used in artificial lights? **A:** Plasma consists of charged particles called ions, so it conducts electric current and glows when electricity passes through it. These properties explain why plasma is used in artificial lights.	 Neon Sign

Summary

- Plasma is a state of matter that lacks a fixed volume and a fixed shape and consists of charged particles called ions. Because it consists of charged particles, plasma can conduct electricity and respond to a magnetic field.
- The sun and other stars consist of plasma. Plasma is also found naturally in lightning and the northern and southern lights. Human-made plasma is found in fluorescent lights, plasma TV screens, and plasma spheres.

Vocabulary

- **plasma:** State of matter lacking a fixed volume and fixed shape that contains ions so it can conduct electricity and respond to magnetism.

Review

1. What is plasma?
2. What are some properties of plasma?
3. Explain why plasma can conduct electricity and respond to magnetism.
4. Give examples of plasma in nature.

2.17 Changes of State

- Define change of state.
- Identify processes that cause changes of state.
- Explain the role of energy in changes of state.

What Are Changes of State?

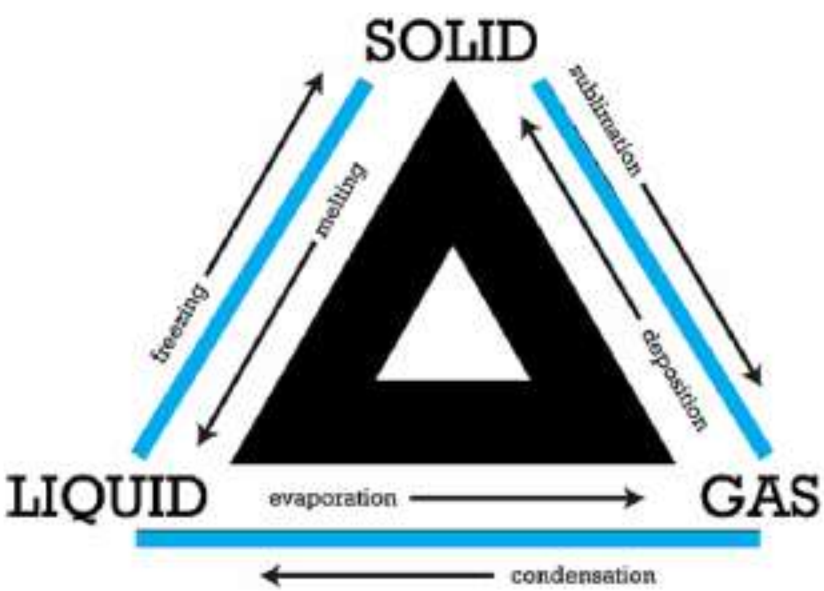
The water droplets of fog form from water vapor in the air. Fog disappears when the water droplets change back to water vapor. These changes are examples of changes of state.

A change of state occurs whenever matter changes from one state to another. Common states of matter on Earth are solid, liquid, and gas. Matter may change back and forth between any two of these states. Changes of state are physical changes in matter. They are reversible changes that do not change matter's chemical makeup or chemical properties. For example, when fog changes to water vapor, it is still water and can change back to liquid water again.

Processes that Cause Changes of State

Several processes are involved in common changes of state. They include *melting, freezing, sublimation, deposition, condensation, and evaporation*.

The Figure below shows how matter changes in each of these processes.



Q: Which two processes result in matter changing to the solid state?
A: The processes are deposition, in which matter changes from a gas to a solid, and freezing, in which matter changes from a liquid to a solid.

The Role of Energy in Changes of State

Suppose that you leave some squares of chocolate candy in the hot sun. A couple of hours later, you notice that the chocolate has turned into a puddle.
Q: What happened to the chocolate?
A: The chocolate melted. It changed from a solid to a liquid.
In order for solid chocolate to melt and change to a liquid, the particles of chocolate must gain energy. The chocolate in this example gained energy from sunlight. Energy is the ability to cause changes in matter, and it is always involved in changes of state. When matter changes from one state to another, it either absorbs energy—as when chocolate melts—or loses energy. For example, if you were to place the melted chocolate in a refrigerator, it would lose energy to the cold air inside the refrigerator. As a result, the liquid chocolate would change to a solid again.

Q: Why is energy always involved in changes of state?
A: The energy of particles of matter determines the matter's state. Particles of a gas have more energy than particles of a liquid, and particles of a liquid have more energy than particles of a solid. Therefore, in order for matter to change from a solid to a liquid or from a liquid to a gas, particles of matter must absorb energy. In order for matter to change from a gas to a liquid or from a liquid to a solid, particles of matter must lose energy.

Summary

- A change of state occurs whenever matter changes from one state to another. Changes of state are physical changes in matter. They are reversible changes that do not change matter's chemical makeup or chemical properties.
- Processes involved in changes of state include melting, freezing, sublimation, deposition, condensation, and evaporation.
- Energy is always involved in changes of state. Particles of matter either absorb or lose energy when matter changes from one state to another.

Review

1. Define change of state, and give an example.
2. Identify processes that change matter to a liquid state.
3. Why must energy be absorbed to change a liquid to a gas?

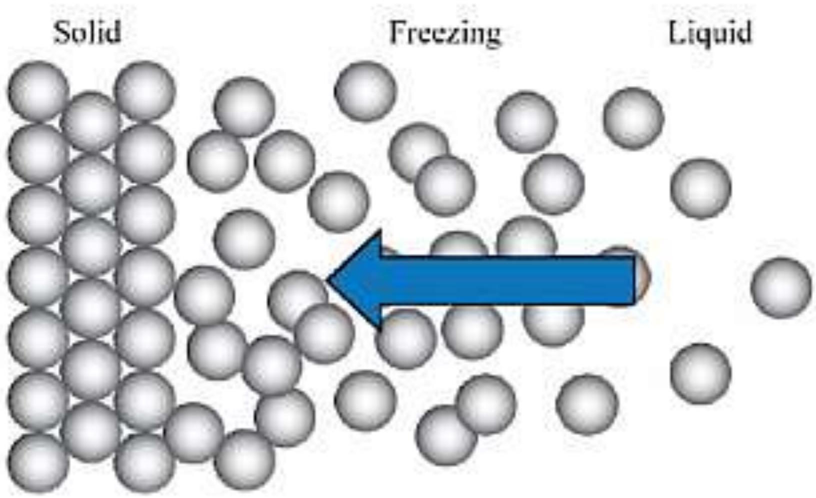
2.18 Freezing

- Describe what happens to the particles of matter when it freezes.
- Define freezing point, and state the freezing point of water.

From Liquid to Solid

You don't have to be an ice climber to enjoy ice. Skating and fishing are two other sports that are also done on ice.

What is ice? It's simply water in the solid state. The process in which water or any other liquid changes to a solid is called freezing. Freezing occurs when a liquid cools to a point at which its particles no longer have enough energy to overcome the force of attraction between them. Instead, the particles remain in fixed positions, crowded closely together, as shown in the figure below.



Freezing Point

The temperature at which a substance freezes is known as its freezing point. Freezing point is a physical property of matter. The freezing point of pure water is 0°C. Below this temperature, water exists as ice. Above this temperature, it exists as liquid water or water vapor. Many other substances have much lower or higher freezing points than water. You can see some examples in the Table 2.3. The freezing point of pure water is included in the table for comparison.

Substance	Freezing Point (ºC)
Helium	-272 ºC
Oxygen	-222 ºC
Nitrogen	-210 ºC
Pure Water	0 ºC
Lead	328 ºC
Iron	1535 ºC
Carbon	3500 ºC

Q: What trend do you see in this table?
A: Substances in the table with freezing points lower than water are gases. Substances in the table with freezing points higher than water are solids.

Q: Sodium is a solid at room temperature. Given this information, what can you infer about its freezing point?
A: You can infer that the freezing point of sodium must be higher than room temperature, which is about 20°C. The freezing point of sodium is actually 98°C.

Summary

- Freezing is the process in which a liquid changes to a solid. It occurs when a liquid cools to a point at which its particles no longer have enough energy to overcome the force of attraction between them.
- The freezing point of a substance is the temperature at which it freezes. The freezing point of pure water is 0°C.

Vocabulary

- **freezing:** Process in which a liquid changes to a solid.

Review

1. What is the freezing point of a substance? What is the freezing point of water?
2. Adding antifreeze to water lowers its freezing point. Based on this statement, what can you infer about the freezing point of antifreeze?

2.19 Melting

- Describe what happens to particles of matter when it melts.
- Define melting point, and state the melting point of ice.

From Solid to Liquid

The process in which rocks or other solids change to liquids is called melting. Melting occurs when particles of a solid absorb enough energy to partly overcome the force of attraction holding them together. This allows them to move out of their fixed positions and slip over one another. Melting, like other changes of state, is a physical change in matter, so it doesn’t change the chemical makeup or chemical properties of matter.

Q: The molten rock that erupts from a volcano comes from deep underground. How is this related to its liquid state?
A: It is always very hot deep underground where molten rock originates. The high temperatures give rock enough energy to melt and remain in a molten state. Underground rock in this state is called magma.

Q: What happens to magma after it erupts and starts flowing over the surface of the ground?
A: After magma erupts, it is called lava. On the surface, lava eventually cools and hardens to form solid rock.

Other substances that are normally solids on Earth can also be heated until they melt. You can see an example in the Figure 2.39. The photo shows molten gold being poured into a mold. When the gold cools, it will harden into a solid gold bar that has the same shape as the mold.

Melting Point

The temperature at which a substance melts is called its melting point. Melting point is a physical property of matter. The gold pictured above, for example, has a melting point of 1064°C. This is a high melting point, and most other metals also have high melting points. The melting point of ice, in comparison, is much lower at 0°C. Many substances have even lower melting points. For example, the melting point of oxygen is -222°C.

Melting and Global Climate Change

Because of global climate change, temperatures all over Earth are rising. However, the melting points of Earth's substances, including ice, are constant.
The result? Glaciers are melting at an alarming rate. Melting glaciers cause rising sea levels and the risk of dangerous river flooding on land.

Summary

- Melting occurs when particles of a solid absorb enough energy to partly overcome the force of attraction holding them together. This allows them to move out of their fixed positions and slip over one another, forming a liquid.
- The temperature at which a substance melts is called its melting point. The melting point of ice is 0°C.

Vocabulary

- **melting:** Process in which a solid changes to a liquid.

Practice

An alloy is a mixture of a metal with one or more other substances. The following Table 2.6 lists melting points of two metals and three alloys that they form together. Examine the table and then answer the questions below.

TABLE 2.4: Melting Points of Selected Metals and Alloys

Metal or Alloy	Melting Point (°C)
Iridium metal (pure)	2454 ºC
Platinum metal (pure)	1773 ºC
Platinum-iridium alloy (15% iridium)	1821 ºC
Platinum-iridium alloy (10% iridium)	1788 ºC
Platinum-iridium alloy (5% iridium)	1779 ºC

1. Based on the information in the table, what conclusion might you draw about the melting points of alloys relative to the melting points of the metals they contain?
2. Bronze is another alloy. It is a mixture that contains mainly copper with some added tin. The melting point of copper is 1084°C, and the melting point of tin is 232°C. What might be a reasonable prediction for the melting point of bronze?

Review

1. Define melting.
2. What happens to particles of matter when it changes from a solid to a liquid?
3. What is the melting point of a substance? What is the melting point of ice?

2.20 Boiling

- Describe how vaporization occurs.
- Contrast vaporization and evaporation.
- Define boiling point, and give the boiling point of water.

Why do we see steam rising from a kettle on the stove? It's because the water is boiling hot. The bubbles in the water show that it is boiling. The water in the kettle is hot enough to boil because it is being heated on the stove.

All Steamed Up

Steam actually consists of tiny droplets of liquid water which is known as water vapor. Water vapor is water in the gaseous state. It constantly rises up from the surface of boiling hot water. Why? At high temperatures, particles of a liquid gain enough energy to completely overcome the force of attraction between them, so they change to a gas. The gas forms bubbles that rise to the surface of the liquid because gas is less dense than liquid. The bubbling up of the liquid is called boiling. When the bubbles reach the surface, the gas escapes into the air. The entire process in which a liquid boils and changes to a gas that escapes into the air is called **vaporization**.

Q: Why does steam form over the hot kettle?
A: Steam forms when some of the water vapor from the boiling water cools in the air and condenses to form droplets of liquid water.

Vaporization vs. Evaporation

Vaporization is easily confused with evaporation, but the two processes are not the same. Evaporation also changes a liquid to a gas, but it doesn't involve boiling. Instead, evaporation occurs when particles at the surface of a liquid gain enough energy to escape into the air. This happens without the liquid becoming hot enough to boil.

Boiling Point

The temperature at which a substance boils and changes to a gas is called its boiling point. Boiling point is a physical property of matter. The boiling point of pure water is 100°C. Other substances may have higher or lower boiling points. Several examples are listed in the Table 2.5. Pure water is included in the table for comparison.

TABLE 2.5: Boiling Points	
Substance	Boiling Point (°C)
Hydrogen	-253 ºC
Nitrogen	-196 ºC
Carbon dioxide	-79 ºC
Ammonia	-36 ºC
Pure water	100 ºC
Salty ocean water	101 ºC
Petroleum	210 ºC
Olive oil	300 ºC
Sodium chloride	1413 ºC

Q: Assume you want to get the salt (sodium chloride) out of salt water. Based on information in the table, how could you do it?
A: You could heat the salt water to 101°C. The water would boil and vaporize but the salt would not. Instead, the salt would be left behind as solid particles.

Q: Oxygen is a gas at room temperature (20°C). What does this tell you about its boiling point?
A: The boiling point of oxygen must be lower than 20°C. Otherwise, it would be a liquid at room temperature.

Summary

- Vaporization is the process in which a liquid boils and changes to a gas.
- Vaporization is easily confused with evaporation, but evaporation doesn't involve boiling.
- The temperature at which a liquid boils and starts changing to a gas is called its boiling point. The boiling point of pure water is 100°C.

Vocabulary

- **vaporization:** Process in which a liquid boils and changes to a gas.

Review

1. What is vaporization? Outline how vaporization occurs.
2. Make a table comparing and contrasting vaporization and evaporation.
3. Define boiling point. What is the boiling point of pure water?
4. Suppose you place an aluminum pot containing water over the flame on a stovetop. Before long, the water starts boiling and turning to water vapor. The pot becomes very hot but otherwise appears to be unchanged by the increase in temperature. Based on these observations, what can you conclude about the boiling point of aluminum?

2.21 Evaporation

- Define evaporation, and describe how it occurs.
- Identify factors that affect the rate of evaporation.
- Explain evaporative cooling.

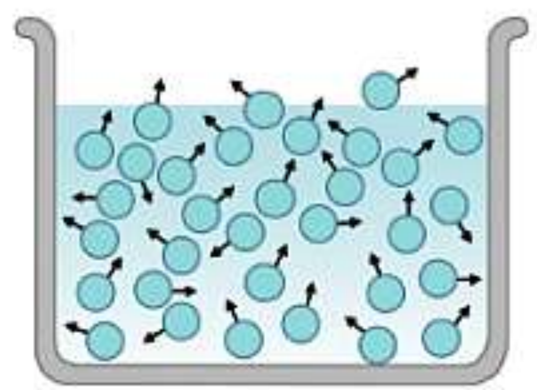
Introduction

The clothes on a clothesline are soaking wet, but before too long they will be completely dry. How does this happen? Where does the water go? And what factors might help the clothes on the line dry more quickly?

From Liquid to Gas Without Boiling

Evaporation explains why clothes dry on a clothesline. Evaporation is the process in which a liquid changes to a gas without becoming hot enough to boil. It occurs when individual liquid particles at the exposed surface of the liquid absorb just enough energy to overcome the force of attraction with other liquid particles. If the surface particles are moving in the right direction, they will pull away from the liquid and move into the air.

This is illustrated in the figure shown.



Liquid particles escaping from the surface of the liquid.

Factors that Affect the Rate of Evaporation

Many factors influence how quickly a liquid evaporates. They include:

- Temperature of the liquid. A cup of hot water will evaporate more quickly than a cup of cold water.
- Exposed surface area of the liquid. The same amount of water will evaporate more quickly in a wide shallow bowl than in a tall narrow glass.
- Presence or absence of other substances in the liquid. Pure water will evaporate more quickly than salt water.
- Air movement. Clothes on a clothesline will dry more quickly on a windy day than on a still day.
- Concentration of the evaporating substance in the air. Clothes will dry more quickly when air contains little water vapor.

Evaporative Cooling

Did you ever notice that moving air cools you down when you're hot and sweaty? For example, if you sit in front of a fan, you feel cooler. That's because moving air helps to evaporate the sweat on your skin. But why does the evaporation of sweat cool you down? When a liquid such as sweat evaporates, energetic particles on the surface of the liquid escape into the air. After these particles leave, the remaining liquid has less energy, so it is cooler. This is called evaporative cooling.

Q: On a hot day, high humidity makes you feel even hotter. Can you explain why?
A: Humidity is a measure of the amount of water vapor in the air. When humidity is high, sweat evaporates more slowly because there is already a lot of water vapor in the air. The slower evaporation rate reduces the potential for evaporative cooling.

Summary

- Evaporation is the process in which a liquid changes to a gas without becoming hot enough to boil. It occurs only at the exposed surface of a liquid.
- Many factors affect how quickly a liquid evaporates, including the temperature of the liquid and air movement.
- When particles evaporate from the surface of a liquid, the remaining liquid is cooler because it has less energy. This is called evaporative cooling.

Vocabulary

- **evaporation:** Process in which a liquid changes to a gas without boiling.

Review

1. Define evaporation, and describe how it occurs.
2. List four factors that influence the rate of evaporation.
3. What is evaporative cooling? Why does it happen?
4. Nancy mopped the floor and now it is wet. She wants the floor to dry more quickly, so she plugs in an electric fan, aims it at the floor, and turns it on. Do you think this will help the floor dry faster? Why or why not?

2.22 Condensation

- Describe how condensation occurs.
- Relate dew point to condensation.
- Identify the role of condensation in the water cycle.

From Gas to Liquid

When air cools, it can hold less water vapor, so some of the water vapor in the air changes to liquid water. The process in which water vapor - or another gas - changes to a liquid is called **condensation**.

Dew Point

When air is very humid, it doesn’t have to cool very much for water vapor in the air to start condensing. The temperature at which condensation occurs is called the *dew point.* The dew point varies depending on air temperature and moisture content. It is always less than or equal to the actual air temperature, but warmer air and moister air have dew points closer to the actual air temperature. That’s why glasses of cold drinks “sweat” more on a hot, humid day than they do on a cool, dry day.

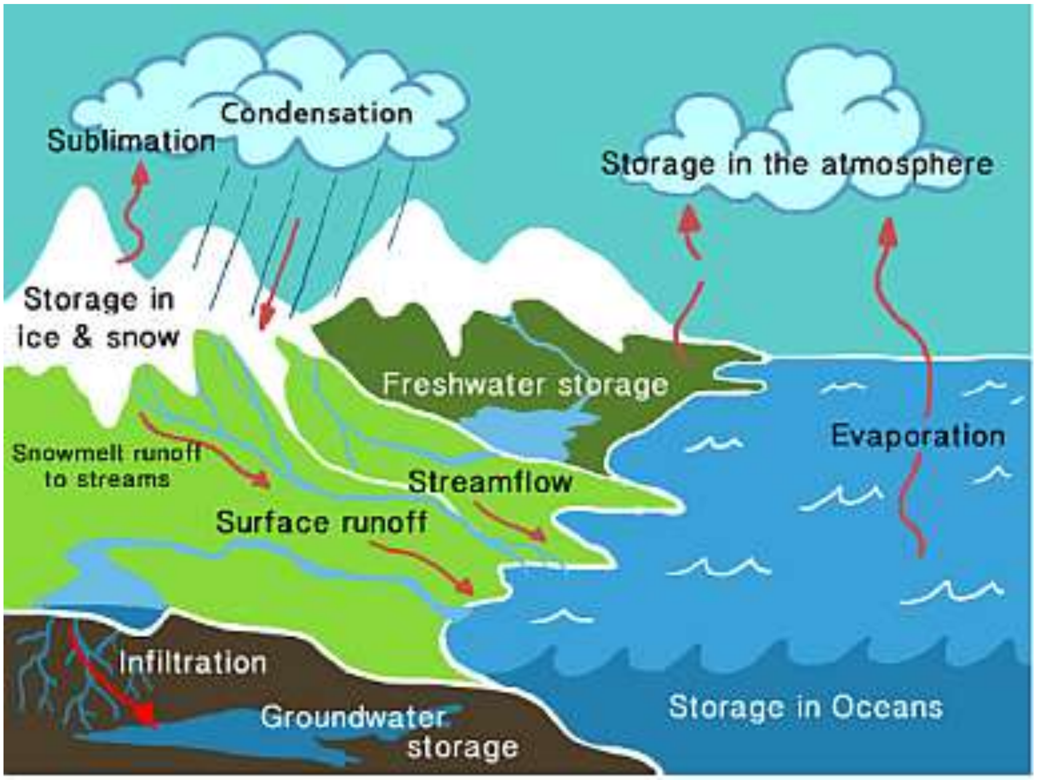
Q: What happens when air temperature reaches the dew point?

A: When air temperature reaches the dew point, water vapor starts condensing. It may form dew, clouds, or fog.

- **Dew** forms on solid objects on the ground.
- **Clouds** form on tiny particles in the air high above the ground.
- **Fog** is a cloud that forms on tiny particles in the air close to the ground.

Condensation and the Water Cycle

The water cycle continuously recycles Earth's water. Condensation plays an important role in this cycle. Find condensation in the water cycle Figure 2.43. It changes water vapor in the atmosphere to liquid water that can fall to Earth again. Without condensation, the water cycle would be interrupted and Earth's water could not recycle.



Q: In the water cycle, what happens to water after it condenses?
A: After water condenses, it may form clouds that produce precipitation such as rain.

Summary

- The process in which water vapor or any other gas changes to a liquid is called condensation.
- The temperature at which condensation of water vapor occurs is called the dew point. The dew point varies depending on air temperature and moisture content.
- Condensation plays an important role in the water cycle. Without it, Earth's water could not recycle.

Vocabulary

- **condensation:** Process in which a gas changes to a liquid.

Review

1. What is condensation? Give an example.
2. Define dew point. What factors influence dew point?
3. In the water cycle, how does water vapor in the atmosphere change to liquid water on the ground?

2.23 Sublimation

- Define sublimation, and give an example.
- State conditions under which sublimation of snow or ice occurs.

Introduction

Entertainers (Rock bands) often use special stage effects, like fake fog. Real fog forms when water vapor in the air condenses into tiny droplets of water. Fake fog is formed when solid carbon dioxide changes directly to carbon dioxide gas.

How Sublime!

Solid carbon dioxide is also called dry ice. That's because when it gets warmer and changes state, it doesn't change to a liquid by melting. Instead, it changes directly to a gas without going through the liquid state. The process in which a solid changes directly to a gas is called **sublimation**. It occurs when energy is added to a solid such as dry ice.

Q: Alyssa's mom put some mothballs in her closet in the spring to keep moths away from her wool clothes. By autumn, the mothballs were much smaller. What happened to them?
A: Mothballs are made of naphthalene, a substance that undergoes sublimation at room temperature. The solid mothballs slowly changed to a gas during the summer months, explaining why they were much smaller by autumn.

Sublimation of Snow and Ice

Snow and ice may also undergo sublimation under certain conditions. This is most likely to happen where there is intense sunlight, very cold temperatures, and dry winds. These conditions are often found on mountain peaks. As snow sublimates, it gradually shrinks without any runoff of liquid water.

Summary

- Sublimation is the process in which a solid changes directly to a gas without going through the liquid state. Solid carbon dioxide is an example of a substance that undergoes sublimation.
- Snow and ice undergo sublimation under certain conditions. This is most likely to happen where there is intense sunlight, very cold temperatures, and dry winds.

Vocabulary

- **sublimation:** Process in which a solid changes directly to a gas without going through the liquid state.

Review

1. What is sublimation? Give an example.
2. Describe conditions under which snow or ice is most likely to undergo sublimation.
3. The plastic container pictured in the Figure below is filled with solid air freshener. The solid gradually shrinks after the holes in the top of the container are opened. Explain why this occurs.

2.24 Deposition

- Define the change of state called deposition
- Describe examples of deposition in nature.

What Is Deposition?

Deposition refers to the process in which a gas changes directly to a solid without going through the liquid state. For example, when warm moist air inside a house comes into contact with a freezing cold windowpane, water vapor in the air changes to tiny ice crystals. The ice crystals are deposited on the glass, often in beautiful patterns. Be aware that deposition has a different meaning in Earth science than in chemistry. In Earth science, deposition refers to the dropping of sediments by wind or water, rather than to a change of state.

Examples of Deposition in Nature

Deposition as a change of state often occurs in nature. For example, when warm moist air comes into contact with very cold surfaces—such as the ground or objects on the ground—ice crystals are deposited on them. These ice crystals are commonly called frost.

Look at the dead leaf and blades of grass in the Figure. They are covered with frost. If you look closely, you can see the individual crystals of ice.

In everyday life, you can watch a demonstration of frost forming on the side of a very cold can of soda. The ice in the can has been cooled to a very low temperature by adding salt to it.

The figure shows frost forming on beer bottles that were placed in a freezer.

Q: In places with very cold winters, why might frost be more likely to form on the ground in the fall than in the winter?
A: Frost forms when the air is warmer than the ground. This is more likely to be the case in the fall. In the winter, the air is likely to be as cold as the ground.

Deposition also occurs high above the ground when water vapor in the air changes to ice crystals. In the atmosphere, the ice crystals are deposited on tiny dust particles. These ice crystals form clouds, generally cirrus clouds, which are thin and wispy.

Q: Cirrus clouds form only at altitudes of 6 kilometers or higher above sea level. Do you know why?
A: At this altitude, the atmosphere is always very cold. Unless the air is cold, water vapor will condense to form water droplets instead of ice crystals.

Summary

- In chemistry, deposition refers to the process in which a gas changes directly to a solid without going through the liquid state.
- Examples of deposition in nature include frost forming on the ground and cirrus clouds forming high in the atmosphere.

Vocabulary

- **deposition:** Process in which a gas changes directly to a solid without going through the liquid state.

Review

1. What is deposition, as defined in chemistry?
2. Describe an example of deposition in nature.

2.47 Metals

- Identify the metals class of elements.
- Describe properties of metals.
- Explain why metals are good conductors of electricity.

What Are Metals?

Metals are elements that can conduct electricity. They are one of three classes of elements (the other two classes are nonmetals and metalloids). Metals are by far the largest of the three classes. In fact, most elements are metals.

There are several different types of metals, including alkali metals, alkaline Earth metals, and transition metals. The majority of metals are transition metals.

Properties of Metals

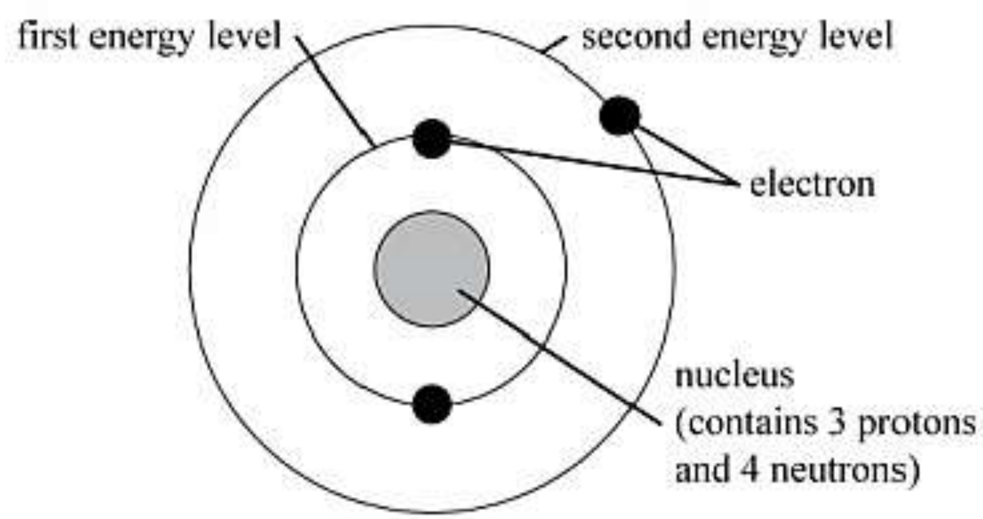
Elements in the same class share certain basic similarities. In addition to conducting electricity, many metals have several other shared properties, including those listed below.

- Metals have relatively high melting points. This explains why all metals except for mercury are solids at room temperature.
- Most metals are good conductors of heat. That's why metals such as iron, copper, and aluminum are used for pots and pans.
- Metals are generally shiny. This is because they reflect much of the light that strikes them. For example, Mercury is very shiny.
- The majority of metals are ductile. This means that they can be pulled into long, thin shapes.
- Metals tend to be malleable. This means that they can be formed into thin sheets without breaking. An example is aluminum foil, which is a common household item used in baking.

Q: The defining characteristic of metals is their ability to conduct electricity. Why do you think metals have this property?
A: The properties of metals—as well as of elements in the other classes—depend mainly on the number and arrangement of their electrons. This will be discussed below.

Explaining the Properties of Metals

To understand why metals can conduct electricity, consider the metal lithium as an example. An atom of lithium is modeled below. Look at lithium's electrons. There are two electrons at the first energy level. This energy level can hold only two electrons, so it is full in lithium. The second energy level is another story. It can hold a maximum of eight electrons, but in lithium it has just one. A full outer energy level is the most stable arrangement of electrons.



Lithium would need to gain seven electrons to fill its outer energy level and make it stable. It's far easier for lithium to give up its one electron in energy level 2, leaving it with a full outer energy level (now level 1).

Electricity is a flow of electrons. Because lithium (like most other metals) easily gives up its "extra" electron, it is a good conductor of electricity. This tendency to give up electrons also explains other properties of metals such as lithium.

Vocabulary

- **metal:** Class of elements that are good conductors of electricity.

Review

1. What are metals?
2. List several properties of metals.
3. Explain why metals can conduct electricity.

2.48 Nonmetals

- Identify the nonmetals class of elements.
- List properties of nonmetals.
- Explain why nonmetals vary in their reactivity and cannot conduct electricity.

The three pure substances pictured above have the distinction of being among the top ten elements that make up the human body. All three of them belong to the class of elements called **nonmetals**. Most of the elements that comprise the human body—as well as the majority of other living things—are nonmetals. In fact, seven of the top ten elements in your own body belong to this class of elements.

What do you know about nonmetals? What are their properties, and how are they different from other elements? In this article, you'll find out.

What Are Nonmetals?

Nonmetals are elements that generally do not conduct electricity. They are one of three classes of elements (the other two classes are metals and metalloids.) Nonmetals are the second largest of the three classes after metals.

Nonmetals have more electrons in their outer energy level and this determines many of its properties.

Properties of Nonmetals

As their name suggests, nonmetals generally have properties that are very different from the properties of metals.

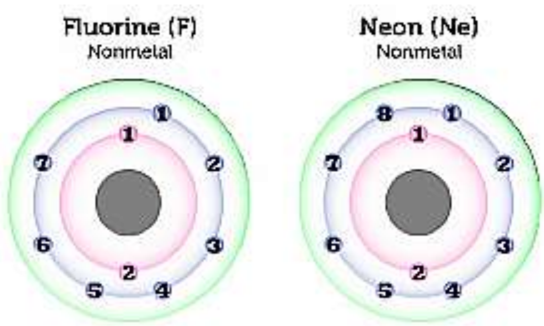
Properties of nonmetals include a relatively low boiling point, which explains why many of them are gases at room temperature. However, some nonmetals are solids at room temperature, including the three pictured above, and one nonmetal—bromine—is a liquid at room temperature. Other properties of nonmetals are described below.

- Most nonmetals are poor conductors of heat. In fact, they are such poor conductors of heat that they are often used for insulation. For example, the down filling in a sleeping bag is full of air, which consists primarily of the nonmetal gases oxygen and nitrogen. These gases prevent body heat from escaping to the cold outside air.

- Solid nonmetals are generally dull and brittle like the pieces of iodine. Like other nonmetals, iodine lacks the luster of metals and will easily crack and crumble.

Reactivity of Nonmetals

Reactivity is how likely an element is to react chemically with other elements. Some nonmetals are extremely reactive, whereas others are completely nonreactive. What explains this variation in nonmetals? The answer is their number of valence electrons. These are the electrons in the outer energy level of an atom that are involved in interactions with other atoms. Let's look at two examples of nonmetals, fluorine and neon. Simple atomic models of these two elements are shown in the Figure below.



Q: Which element, fluorine or neon, do you predict is more reactive?
A: Fluorine is more reactive than neon. That's because it has seven of eight possible electrons in its outer energy level, whereas neon already has eight electrons in this energy level.

Although neon has just one more electron than fluorine in its outer energy level, that one electron makes a huge difference. Fluorine needs one more electron to fill its outer energy level in order to have the most stable arrangement of electrons. Therefore, fluorine readily accepts an electron from any element that is equally "eager" to give one up, such as the metal lithium or sodium. As a result, fluorine is highly reactive. In fact, reactions with fluorine are often explosive. Neon, on the other hand, already has a full outer energy level. It is already very stable and never reacts with other elements. It neither accepts nor gives up electrons. Neon doesn't even react with fluorine, which reacts with all other elements except helium.

Why Most Nonmetals Cannot Conduct Electricity

Like most other nonmetals, fluorine cannot conduct electricity, and its electrons explain this as well. An electric current is a flow of electrons. Elements that readily give up electrons (the metals) can carry electric current because their electrons can flow freely. Elements that gain electrons instead of giving them up cannot carry electric current. They hold onto their electrons so they cannot flow.

Summary

- Nonmetals are elements that generally cannot conduct electricity. They are the second largest class of elements after metals. Examples of nonmetals include hydrogen, carbon, chlorine, and helium.
- Properties of nonmetals include a relatively low boiling point, so many nonmetals are gases. Nonmetals are also poor conductors of heat, and solid nonmetals are dull and brittle.
- Some nonmetals are very reactive, whereas others are not reactive at all. It depends on the number of electrons in their outer energy level.
- Reactive nonmetals tend to gain electrons. This explains why they cannot conduct electricity, which is a flow of electrons.

Vocabulary

- **nonmetal:** Class of elements that do not conduct electricity.

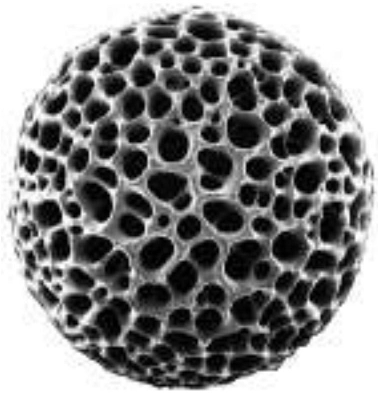
Review

1. What are nonmetals?
2. List properties of nonmetals.
3. Explain why nonmetals vary in their reactivity.
4. Carbon cannot conduct electricity. Why not?

2.49 Metalloids

- Identify the metalloids class of elements.
- List physical properties of metalloids.
- Explain why some metalloids react like metals and others react like nonmetals.

Introduction



What is this intricate orb? It is the greatly magnified skeleton of single-celled ocean organisms call radiolarian. The skeleton is made of an element that is extremely common on Earth. In fact, it is the second most abundant element in Earth's crust. It is also one of the most common elements in the entire universe. What is this important element? Its name is silicon, and it belongs to a class of elements called metalloids.

What Are Metalloids

Metalloids are the smallest class of elements. (The other two classes of elements are metals and nonmetals). There are just six metalloids. In addition to silicon, they include boron, germanium, arsenic, antimony, and tellurium.

Metalloids fall between metals and nonmetals in the periodic table of elements. They also fall between metals and nonmetals in terms of their properties.

Chemical Properties of Metalloids

How metalloids behave in chemical interactions with other elements depends mainly on the number of electrons in the outer energy level of their atoms. Metalloids have from three to six electrons in their outer energy level.

– Boron, is the only metalloid with just three electrons in its outer energy level. It tends to act like metals by giving up its electrons in chemical reactions.
– Metalloids with more than four electrons in their outer energy level (arsenic, antimony, and tellurium) tend to act like nonmetals by gaining electrons in chemical reactions.
– Those with exactly four electrons in their outer energy level (silicon and germanium) may act like either metals or nonmetals, depending on the other elements in the reaction.

Physical Properties of Metalloids

Most metalloids have some physical properties of metals and some physical properties of nonmetals. For example, metals are good conductors of both heat and electricity, whereas nonmetals generally cannot conduct heat or electricity.

And metalloids? They fall between metals and nonmetals in their ability to conduct heat, and if they can conduct electricity, they usually can do so only at higher temperatures. Metalloids that can conduct electricity at higher temperatures are called semiconductors. Silicon is an example of a semiconductor. It is used to make the tiny electric circuits in computer chips. You can see a sample of silicon and a silicon chip in the Figure below.

Metalloids tend to be shiny like metals but brittle like nonmetals. Because they are brittle, they may chip like glass or crumble to a powder if struck. Other physical properties of metalloids are more variable, including their boiling and melting points, although all metalloids exist as solids at room temperature.

Summary

- Metalloids are the smallest class of elements, containing just six elements. They fall between metals and nonmetals in the periodic table.
- How metalloids behave in chemical interactions with other elements depends mainly on the number of electrons in the outer energy level of their atoms. Metalloids may act either like metals or nonmetals in chemical reactions.
- Most metalloids have some physical properties of metals and some physical properties of nonmetals. They fall between metals and nonmetals in their ability to conduct heat and electricity. They are shiny like metals but brittle like nonmetals. All exist as solids at room temperature.

Vocabulary

- **metalloid:** Class of elements that have some properties of metals and some properties of nonmetals.

Review

1. What are metalloids? Which elements are placed in this class of elements?
2. Identify physical properties of metalloids that resemble those of metals.
3. Which physical property of metalloids is like that of nonmetals?
4. Explain the variation in how metalloids react with other elements.