CHAPTER 3: MATTER AND ENERGY

INTRODUCTION

This chapter provides you with a basic foundation of facts and concepts about matter you will need throughout your chemistry course. There are fewer mathematical calculations in this chapter than in other chapters you will study.

Pay careful attention to Sections 3.2 (Physical and Chemical Properties and Changes) and 3.4 (Mixtures and Pure Substances) in your textbook. The concepts in these sections often seem confusing when you are first introduced to them. Look carefully at the examples in your text that will help you distinguish between physical and chemical changes and between mixtures and pure substances.

Section 3.6 introduces you to heat energy, and you will calculate the amount of energy needed to heat water and other substances. Practice setting up good dimensional analysis equations with the energy problems. Make sure all numbers have a unit and that all the units cancel. Now is a good time to gain some confidence with your problem solving skills.

GOALS FOR THIS CHAPTER

1. To define matter and be able to state the distinguishing characteristics of the three states of matter. (Section 3.1)
2. Know the difference between chemical and physical properties, and chemical and physical changes. (Section 3.2)
3. Know what elements and compounds are, and be able to identify which substances are elements and which are compounds. (Section 3.3)
4. Be able to tell whether a substance is a pure substance or a mixture, and if a mixture, whether it is homogeneous or heterogeneous. (Section 3.4)
5. Be able to describe how distillation and filtration work, and how you would use them to separate a mixture. (Section 3.5)
6. Know the relative amounts of energy associated with the three states of matter, and which units are commonly used when discussing heat energy. (Section 3.6)
7. Be able to use the formula $Q = s \times m \times \Delta T$ to calculate Q. Rearrange the equation to calculate any one of the quantities, if you are given any of the other three. (Section 3.6)

QUICK DEFINITIONS

Matter — Everything that has mass and takes up space. (Section 3.1)

Physical property — A characteristic such as odor, color, or physical state. You can observe a physical property of a substance without changing the composition of the substance. (Section 3.2)

Chemical property	A characteristic such as the kind of elements a substance will react with to form new substances. When you observe a chemical property of a substance, the composition and properties of the substance changes. (Section 3.2)
Physical change	A change that does not affect the composition of the material undergoing the change, although it can affect the physical properties or physical states. Some examples are changes in temperature, and change from the solid state to the liquid state. (Section 3.2)
Chemical change	A change that causes the substance to become a new substance with a different composition. When a chemical change occurs we say that a chemical reaction has taken place. (Section 3.2)
Element	A fundamental unit that cannot be broken into smaller units by chemical means. (Section 3.3)
Compound	A unit composed of two or more elements that can be broken into elements by chemical means. A compound always has the same relative numbers and kinds of elements. (Section 3.3)
Mixture	Anything whose composition varies if you sample different parts of it. (Section 3.4)
Pure substance	Anything whose composition stays the same, even if you examine samples taken from different locations within the substance. (Section 3.4)
Homogeneous mixture	A mixture whose composition is constant throughout. Also called a solution. (Section 3.4)
Heterogeneous mixture	A mixture whose composition is different depending upon where you sample it. (Section 3.4)
Distillation	A method for separating mixtures. Heat is applied to a mixture until one of the substances begins to boil and becomes a vapor. The second substance stays behind because its boiling point is higher. The vapor of the first substance moves through the apparatus until it becomes cooled and recondenses to a liquid. Distillation is a good method for separating homogeneous mixtures. (Section 3.5)

Filtration — A method for separating mixtures that works by trapping large particles but allowing smaller ones to flow through. Pour a heterogeneous mixture through a mesh that catches the larger particles, but allows the liquid to pass through. Often the mesh is made of paper, but it can be made of other materials as well. (Section 3.5)

Energy — A measure of the ability to do work. (Section 3.6)

Calorie — A unit of energy that is equal to the amount of heat energy it takes to raise the temperature of one gram water one degree Celsius. (Section 3.6)

Joule — The SI unit of energy. 1 calorie = 4.184 joules. (Section 3.6)

Specific heat capacity — The amount of heat energy it takes to raise the temperature of one gram of some substance by one degree Celsius. Each substance has a different specific heat capacity. (Section 3.6)

PRETEST

1. When liquid nitrogen boils at -196 °C is this a physical or a chemical change?

2. Does KI represent a compound or an element?

3. Is the color of a substance a physical or a chemical property?

4. Is a 14 K gold ring a mixture or a pure substance?

5. Is a box of Raisin Bran cereal a homogeneous or heterogeneous mixture?

6. Is filtration a good way to separate the sugar in sweetened tea from the tea?

7. If one liquid boils at a temperature of 118 °C and a second liquid boils at 68 °C is it likely that a mixture of the two can be separated by distillation?

8. How many calories are there in 8.63 J?

9. How many calories are required to convert 6.8 g liquid water from 11°C to 55 °C?

10. What is the mass of a piece of silver if 26.7 calories are required to cause a temperature change of 46.5 °C? The specific heat capacity of silver is 0.24 J/g °C.

PRETEST ANSWERS

1. When liquid nitrogen boils to form a gas, both the gas and the liquid are composed of nitrogen molecules. This is a physical change. (3.2)

2. KI is a compound formed from the elements potassium (K), and iodine (I). (3.3)

3. Color is a physical property. Observing color does not change the properties of a substance. (3.2)

4. A 14 K gold ring contains gold and copper. 14 K gold is a mixture, it is not pure gold. (3.4)

5. A box of Raisin Bran cereal is a heterogeneous mixture. Not every bite contains a raisin. Some bites have two raisins. (3.4)

6. Filtration is not a good way to separate sugar from tea. Dissolved sugar molecules are small enough to pass through the filter paper along with the other ingredients of the tea. (3.5)

7. Because the two liquids have boiling points that are far apart, it is likely that they can be separated by distillation. (3.5)

8. Use the conversion 1 cal = 4.184 J to convert from joules to calories. (3.6)

$$8.63\,\not{J} \times \frac{1\text{ cal}}{4.184\,\not{J}} = 2.06\text{ cal}$$

9. One calorie is required to raise each gram of water by 1°C. 6.8 g water requires 6.8 cal for every °C increase. The temperature has increased by 44 °C, so the number of calories required is $6.8 \times 44 = 3.0 \times 10^2$ cal. (3.6)

10. The formula $Q = s \times m \times \Delta T$ can be used to find the mass of silver. Rearrange the equation to isolate mass, m, on one side.

$$m = \frac{Q}{s \times \Delta T}$$

Remember that s is the specific heat capacity of silver, Q is the heat required, and ΔT is the change in temperature. Q is given in calories, but s has units of joules. Convert Q to joules so that units in the equation cancel. (3.6)

$$26.7 \text{ cal} \times \frac{4.184 \text{ J}}{1 \text{ cal}} = 112 \text{ J}$$

Now solve the problem.

$$m = \frac{112 \text{ J}}{\frac{0.24 \text{ J}}{\text{g °C}} \times 46.5\text{°C}}$$

$$m = 10.0 \text{ g silver}$$

CHAPTER REVIEW

3.1 MATTER

What Is Matter?

Everything in the universe that has mass and occupies space is made of **matter**. We can see large masses of matter everywhere we look, from automobiles to tree trunks. Some pieces of matter are so small we can't see them. When many of the small pieces of matter are together in one spot, they form a mass large enough to see; for example, a gold nugget is made of many small pieces of matter, each one too small to see. Much of the science of chemistry concerns what happens to matter.

3.2 PHYSICAL AND CHEMICAL PROPERTIES AND CHANGES

How Can You Tell Physical Properties from Chemical Properties?

A **physical property** is anything you can observe without destroying or changing the composition of a substance. Odor, color, and the temperature at which a substance melts are examples of physical properties. A **chemical property** describes how a substance(s) can change chemically to form a new substance. A chemical property of the element sodium is that it will combine with the element chlorine to form a new substance, sodium chloride.

How Can You Tell Physical Changes from Chemical Changes?

Sometimes it can be difficult to tell the difference between a physical change and a chemical change. Section 6.1 of Chapter 6 will provide more information that can help you tell whether or not a chemical change has occurred.

A **physical change** often involves a change in the state of matter. Ice is made of water molecules in the solid state. When ice melts, the resulting liquid is also made of water molecules, but now in the liquid state. The difference between ice and liquid water is the difference in physical state.

Other physical changes involve changes in appearance. For example, dissolving salt crystals in water doesn't change the composition of the salt. Although the salt has dissolved into particles so small you can no longer see them, they are still salt particles. A taste of the water will tell you the salt is still there. If you evaporate the water in a hot oven, the salt remains on the bottom of the container. You can recover it in its original state.

A **chemical change** involves a change in composition. Burning a piece of oak firewood produces substances such as water vapor, carbon dioxide and ash as well as heat and light. The new products are chemically different from the original oak firewood. When fresh milk is stored for a long time in the refrigerator, it spoils. Spoiled milk has a sour taste and smell. A chemical change has occurred which caused the characteristics and the composition of the milk to change.

3.3 ELEMENTS AND COMPOUNDS

What Are Elements and Compounds?

Matter is composed of over 100 fundamental units called **elements**. Elements cannot be decomposed into smaller units by chemical means. Some examples of elements are oxygen, iron, and gold. Any sample of the element oxygen contains only oxygen atoms, and any sample of the element gold contains only gold atoms.

Some elements can combine with each other to form **compounds**. A compound is always made from the same relative numbers and kinds of elements, that is, its composition is constant. For example, the compound water is made from the elements oxygen and hydrogen. Regardless of the source of the water, there are always two hydrogen atoms and one oxygen atom in each molecule of water. You will learn more about atoms and molecules in Chapter 4.

3.4 MIXTURES AND PURE SUBSTANCES

How Can You Tell Mixtures from Pure Substances?

Because they have constant composition, compounds are pure substances even though they are composed of a combination of elements. A **pure substance** contains only 1 compound, or 1 kind of element or molecule. Water is a pure substance because it is always composed of one oxygen atom and two hydrogen atoms.

Sodium bicarbonate, called baking soda, is another example of a pure substance. It contains one sodium atom, one hydrogen atom, one carbon atom and three oxygen atoms. Pure baking soda is always the same, no matter where you buy it, or what brand you buy, or where in the box you take a sample.

Most of the substances in our environment are **mixtures**. The quantity and types of ingredients in a mixture change from time to time, and a mixture can have several different areas with different ingredients. Milk is a mixture, although we can't see each of the individual ingredients. Milk contains sugars, proteins, fats, and other components. Whole milk has approximately four percent fat, while skim milk has one percent fat. The ingredients in milk will also depend upon the diet of the cow. When you order a glass of milk at a restaurant, you are not guaranteed to get exactly the same product each time, because milk is a mixture.

How Can You Distinguish Homogeneous and Heterogeneous Mixtures?

Some mixtures contain pure substances evenly distributed throughout the mixture, so that if you took different samples from the same mixture, you would find the same quantities of pure substances in each sample. These are called **homogeneous mixtures**. Table sugar dissolved in water is a homogeneous mixture since the sugar is evenly distributed throughout the water. You can't see areas in the sugar and water mixture which look different from other areas.

Some other mixtures have an uneven distribution of pure substances. These mixtures are called **heterogeneous mixtures**. For example, a mixture of oil and water is a heterogeneous mixture. The top part of the mixture contains more oil, and the bottom part of the mixture has more water. The two components do not dissolve in each other. If you take samples of the mixture from both the top and the bottom, the two samples will contain completely different amounts of oil andwater.

3.5 SEPARATION OF MIXTURES

Remember that even the best separation methods are not 100 percent complete. There is always a little bit of one substance left with the other substance. The better your laboratory skill, and the better the equipment, the better the final separation will be.

How Can You Separate a Mixture by Distillation?

Distillation is useful as a separation method only when the two materials to be separated boil at different temperatures. Table salt boils at 1413 °C while water boils at 100 °C. When you separate a mixture of salt and water by distillation, you apply heat to the mixture and raise the temperature until the water starts to boil. The salt has a much higher boiling point than water does, and does not boil at the temperature which boils the water. As the water boils, it is converted to steam, which rises in the distillation apparatus. You can collect the steam in a separate container, and cool it until water vapor condenses to liquid water. The salt remains behind in the original container because the temperature is never high enough for the salt to boil. Both have retained their original chemical properties. You haven't changed either of them by the separation process. Therefore you can say that distillation causes a physical change but not a chemical change. Distillation is only useful as a separation method when the two materials to be separated have different boiling points.

How to Separate a Mixture by Filtration.

Filtration is another common way to separate mixtures containing liquids and solids. Filtration is non-destructive because after filtration, the two substances you have separated are the same chemically as they were before the separation. Filtration is a good way to separate heterogeneous mixtures. If we pour a mixture of water and aquarium sand through a mesh of paper, the water molecules pass through the paper, but the grains of sand are too large to pass through, and are trapped on the paper.

3.6 ENERGY AND ENERGY CHANGES

Energy is the capacity to do work. We often use heat energy to change the temperature of various substances. When substances change temperature, heat energy is either absorbed or lost. One unit used to measure the amount of heat gained or lost is the **calorie**, abbreviated cal. A calorie is the amount of heat it takes to raise the temperature of one gram of water by one degree Celsius. Another common unit of heat energy is the joule, abbreviated J.

How Can You Convert Energy Given in Joules to Calories?

Many energy problems require conversion from a given energy unit to another energy unit. The conversion factor for calories to joules is 1 cal/4.184 J. Using this conversion factor you can convert from one unit to the other.

Example:

How can you convert 2.31 J to calories?

$$2.31\ \cancel{J} \times \frac{1\ \text{cal}}{4.184\ \cancel{J}} = 0.552\ \text{cal}$$

Set up the problem so that the joules cancel and you are left with calories, the desired unit. The answer should be expressed to three significant figures because the given 2.31 J has three significant figures.

How Can You Calculate the Amount of Energy Needed to Change the Temperature of Liquid Water a Given Number of Degrees?

Example:

How many calories does it take to convert 1.0 kg water from 12.9 °C to 14.2 °C? From the definition of a calorie you know that it takes one calorie to raise the temperature of one gram of water by one degree Celsius. You can write the definition in the form of a conversion factor: 1 cal/g °C which reads "one calorie per gram of water per degree Celsius increase in temperature". The initial temperature in the example is 12.9 °C and the final temperature is 14.2 °C, a temperature increase of 14.2 minus 12.9 which is equal to 1.3 °C.

$$1.3\ ^\circ\cancel{C} \times \frac{1\ \text{cal}}{\text{g} \times ^\circ\cancel{C}} = 1.3\ \text{cal/g}$$

The equation above tells us how many calories it takes to raise 1 g by 1.3°C. But in this example we have 1.0 kg of water, not 1 g, so we must convert kg to g. The appropriate conversion factor is 1000 g/1 kg. The correct answer is 1.3 cal/g x 1000 g = 1.3 x 10^3 cal. If we solve the problem in one equation,

$$1.0 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times 1.3\ ^\circ\text{C} \times \frac{1 \text{ cal}}{\text{g} \times {}^\circ\text{C}} = 1.3 \times 10^3 \text{ cal}$$

Remember that using scientific notation leaves no doubt that we mean to indicate two significant figures. 1.0 kg has two significant figures so our answer should also have two significant figures.

How Can You Calculate the Amount of Energy Needed to Change the Temperature of Any Substance?

You have seen that it takes one calorie to raise the temperature of 1 gram of water by 1 degree Celsius. How much energy does it take to raise the temperature of 1 gram of other substances by 1 degree Celsius? Each substance takes a different amount of energy. This amount of energy is known as the **specific heat capacity**, or sometimes as **specific heat**. Specific heats are given in units of joules.

Example:

Solid lead has a specific heat capacity of 0.16 J/g x °C. How much energy, in joules, is required to raise the temperature of 32.8 g solid lead from -24.4 °C to 56.4 °C? The specific heat capacity of solid lead is 0.16 J for **each** gram lead and for **each** °C. In this problem you are presented with 32.8 g lead, and a temperature increase of 80.8 °C. You can set the problem up as

$$\frac{0.16 \text{ J}}{\text{g} \times {}^\circ\text{C}} \times 32.8 \text{ g} \times 80.8\ ^\circ\text{C} = 420 \text{ J}$$

A generalized way of solving problems like the one above would be to state the following. The heat energy needed (Q) equals the specific heat capacity of the substance (s) times the mass of the substance in g (m) times the change in temperature in degrees Celsius (ΔT). To write the equation with symbols only:

$$Q = s \times m \times \Delta T.$$

If you know any three of the quantities, you can find the fourth by rearranging the equation to isolate the quantity you want to find on the left side of the equation.

LEARNING REVIEW

1. Which of the properties below is/are physical properties, and which are chemical properties?

    a. Oxygen atoms can combine with hydrogen atoms to form water molecules.
    b. Ethyl alcohol boils at 78 °C.
    c. Liquid oxygen is pale blue in color.

2. Which of the changes below are physical changes, and which are chemical changes?

    a. A copper strip is hammered flat to make a bracelet.
    b. Copper and sulfur react to form a new substance, copper(I) sulfide.
    c. Liquid water freezes at 273 K.
    d. Oxygen gas condenses to a liquid at -183 °C.
    e. You prepare a 3 minute egg for breakfast.

3. Which of the symbols below represent elements, and which represent compounds?

    a. S
    b. H_2O
    c C
    d. N_2O_5
    e. NaOH

4. Is each of the properties below a physical or chemical property?

    a. temperature at which a solid is converted to a liquid
    b. odor
    c. temperature at which a compound breaks down into its elements
    d. oxygen reacts with a substance to produce energy

5. Which of the substances below are mixtures, and which are pure substances?

    a. gasoline
    b. table sugar (sucrose)
    c. garden soil
    d. sterling silver necklace

6. Which of the mixtures is homogeneous and which is heterogeneous?

    a. sweetened hot tea
    b. plastic bag filled with leaves and grass clippings
    c. a weak solution of rubbing alcohol in water
    d. devil's food cake mix

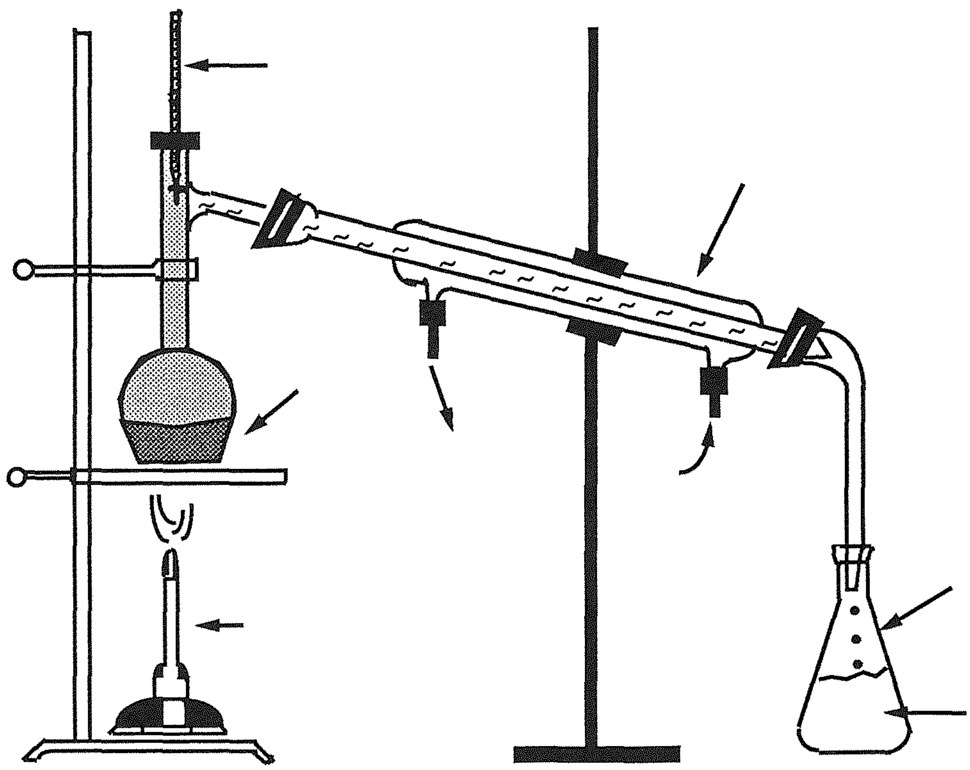
7. Describe how you can separate a mixture by filtration.

8. What type of mixture is best separated by filtration, a homogeneous mixture or a heterogeneous mixture?

9. Describe how you would separate the following mixtures.

   a. sand from gravel
   b. salt from sand
   c. sugar from water

10. Label each part of the distillation apparatus below.



11. Convert the energy values below to the desired units.

   a. 45.8 cal to J
   b. 0.561 cal to J
   c. 5.96 J to cal
   d. 76 J to cal

12. Calculate the number of calories required to change the temperature of each of the quantities of water below.

   a. 100.1 g of water from 6 °C to 25 °C
   b. 2.32 g of water from 36 °F to 42 °F
   c. 40. g of water by 12 °C
   d. 16.9 g of water from 75.0 °C to 80.0 °C

13. How much energy (in joules) is required to raise the temperature of 25.2 g of solid carbon rod from 25 °C to 50. °C? The specific heat capacity of solid carbon is 0.71 J/g °C.

14. How much energy (in calories) is required to raise the temperature of 10. g steam from 122.2 °C to 130.4 °C? The specific heat capacity of water(g) is 2.0 J/g °C.

15. How much of a temperature change would occur if 2736.8 J of energy were applied to a piece of iron bar weighing 450.5 g? The specific heat capacity of solid iron is 0.45 J/g °C.

16. What is the mass in grams of a piece of aluminum wire if a change in temperature of 5.67 °C required 8.53 J? The specific heat capacity of solid aluminum is 0.89 J/g °C.

17. What is the specific heat capacity of ethyl alcohol if 1972.4 J of energy is necessary to raise the temperature of 53.4 g ethyl alcohol by 15.2 °C?

ANSWERS TO LEARNING REVIEW

1. a. Oxygen can combine with hydrogen to produce a new substance, water. Because oxygen and hydrogen have the potential to combine to form a new substance, this is an example of a chemical property.
   b. Observing ethyl alcohol boiling does not destroy or change the ethyl alcohol molecules. Therefore, boiling point is a physical property.
   c. Observing the color of a substance does not change its composition. The pale blue color of liquid oxygen is a physical property.

2. a. When a copper strip is hammered into a bracelet, the shape of the copper is changed, but not the composition. This is a physical change.
   b. The new substance, copper sulfide, is a black solid which does not have any of the characteristics of copper metal or yellow elemental sulfur. This is a chemical change.
   c. When liquid water freezes to become solid ice, the molecules are still those of water. No change in composition has occurred. This is a physical change.
   d. Liquid oxygen molecules become solid oxygen molecules at -183 °C. This is a physical change.