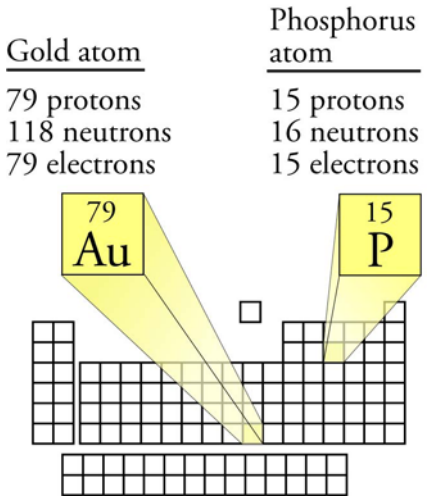
Chapter 3
The Structure of Matter and the Chemical Elements



Section Goals and Introductions

Section 3.1 Liquids, Solids, and Gases

Goals

To describe a model that allows you to visualize the particle nature of matter.

To describe the similarities and differences among solids, liquids, and gases in terms of this model.

This is a very important section because it presents a model that you will use throughout your chemistry education and beyond to visualize matter at the submicroscopic level. Be sure you take the time and try to actually visualize the interactions among particles and visualize the movement of these particles. It will be time well spent. The animation found in Chapter 3 of our Web site will help you develop your ability to visualize the particle nature of matter.

Internet: The Structure of Matter

Section 3.2 The Chemical Elements

Goal: To describe the chemical elements, which are the building blocks of matter.

This section introduces the chemical elements. It is best to memorize all of the element names and symbols for the elements found in Table 3.1. Many instructors will consider this excessive, but I think it really pays off in saved time later. Be sure to ask your instructor which names and symbols you are expected to learn for exams. The tutorial in Chapter 3 of our Web site will help you practice converting between names and symbols of elements.

Internet: Element Names and Symbols

Section 3.3 The Periodic Table of the Elements

Goal: To describe the periodic table of the elements and show you how you can use it.

The periodic table shown in this section is one of the most important tools of the chemist. It organizes the chemical elements in a way that allows you to quickly obtain a lot of information about them. Be sure that when you are done studying this section, you know (1) how the columns and rows on the periodic table are numbered; (2) how to classify an element as a metal, nonmetal, or metalloid; (3) how to classify an element as a representative (or main-group) element, transition metal, or inner transition metal; (4) how to identify the number for the period in which an element is found; and (5) how to identify an element as a gas, liquid, or solid at room temperature. You should also be able to identify the elements that are alkali metals, alkaline earth metals, halogens, and noble gases.

Section 3.4 The Structure of the Elements

Goal: To describe the structure of the atoms that provide the structure of the elements.

This section introduces atoms for the first time. You will learn about the protons, neutrons, and electrons that form atoms, and you will get an introduction to how these particles are arranged in the atom. Knowledge of the structure of the atom allows us to understand why each element is different from the others. You will discover that electrons can be lost or gained by atoms to form ions, and you will discover why all atoms of an element are not necessarily the same. Different species of atoms of the same element are called isotopes. Chapter 3 of our Web site contains information on the notation used to describe isotopes.

Internet: Isotope Notation

Section 3.5 Common Elements

Goal: To apply the information described in the first four sections of this chapter to the description of some common elements.

This section brings the chapter full circle back to the particle nature of solids, liquids, and gases, but after reading this section, you will know more about the particles that compose solid, liquid, and gaseous elements. The section helps you to visualize the particle nature of the elements instead of relating to them as just symbols on the page.

Chapter 3 of our Web site contains an animation will help you visualize the elements mentioned in this section.

Internet: Element Properties

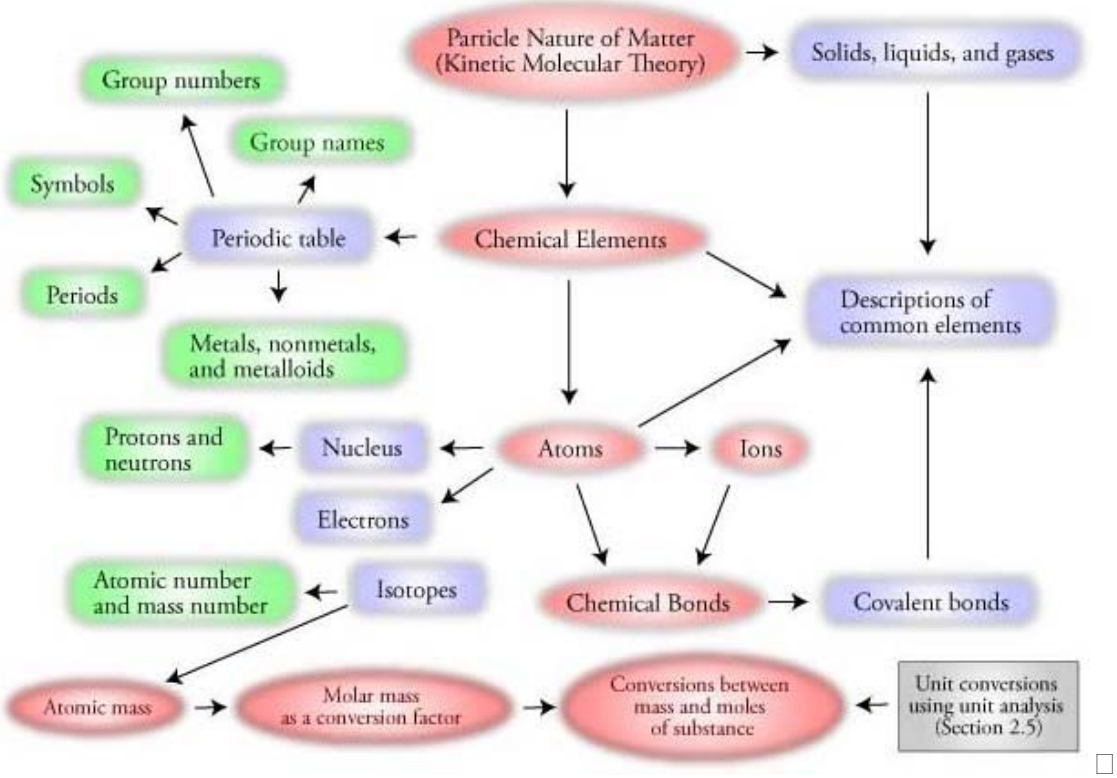
Section 3.6 Relating Mass to Number of Particles

Goals

- *To show how to do a procedure called counting by weighing.*
- *To introduce atomic mass and show how it can be used to convert between the mass of a sample of an element and the number of atoms that the sample contains.*

Even a tiny sample of an element contains a huge number of atoms. There's no way that you could ever count that high, even if you were able to count atoms one at a time (which you can't). So if you want to know the number of atoms in a sample of an element, you have to do it by an indirect technique called counting by weighing. This section introduces this technique and shows how it can be applied to the conversions between mass of a sample of an element and the number of atoms in the sample. An important unit called the mole is introduced in this section. It is very important that you understand what it is and how it is used.

Chapter 3 Map



Chapter Checklist

☐ Read the Review Skills section. If there is any skill mentioned that you have not yet mastered, review the material on that topic before reading this chapter.

☐ Read the chapter quickly before the lecture that describes it.

☐ Attend class meetings, take notes, and participate in class discussions.

☐ Work the Chapter Exercises, perhaps using the Chapter Examples as guides.

☐ Study the Chapter Glossary and test yourself on our Web site:

Internet: Glossary Quiz

☐ Study all of the Chapter Objectives. You might want to write a description of how you will meet each objective. (Although it is best to master all of the objectives, the following objectives are especially important because they pertain to skills that you will need while studying other chapters of this text: 2, 11, 12, 13, 15, 16, 17, 20, 22, 24, and 30.)

☐ Memorize the names and symbols of the elements on the following table. Be sure to check with your instructor to determine how many of these you are expected to know and ask whether your instructor wants to add any others.

Element	Symbol	Element	Symbol	Element	Symbol
aluminum	Al	gold	Au	oxygen	O
argon	Ar	helium	He	phosphorus	P
barium	Ba	hydrogen	H	platinum	Pt
beryllium	Be	iodine	I	potassium	K
boron	B	iron	Fe	silicon	Si
bromine	Br	lead	Pb	silver	Ag
cadmium	Cd	lithium	Li	sodium	Na
calcium	Ca	magnesium	Mg	strontium	Sr
carbon	C	manganese	Mn	sulfur	S
chlorine	Cl	mercury	Hg	tin	Sn
chromium	Cr	neon	Ne	uranium	U
copper	Cu	nickel	Ni	xenon	Xe
fluorine	F	nitrogen	N	zinc	Zn

☐ Learn how to use the periodic table to classify the elements with respect to the following categories:

Groups 1 to 18

Groups 1A to 8A

Alkali metals, alkaline earth metals, halogens, and noble gases

Metals, nonmetals, and metalloids

Representative (main-group) elements, transition metals, and inner transition metals

Periods 1 to 7

Solids, liquids, or gases at room temperature

☐ To get a review of the most important topics in the chapter, fill in the blanks in the Key Ideas section.

☐ Work all of the selected problems at the end of the chapter, and check your answers with the solutions provided in this chapter of the study guide.

☐ Ask for help if you need it.

Web Resources

Internet: The Structure of Matter
Internet: Element Names and Symbols
Internet: Isotope Notation
Internet: Element Properties
Internet: Glossary Quiz

Exercises Key

Exercise 3.1 - Elements and the Periodic Table: Complete the following table. (*Objs 12 & 15-18*)

Name	Symbol	Group number	Metal, nonmetal or metalloid?	Representative element, transition metal, or inner transition metal?	Number for period	Solid, liquid, or gas?
aluminum	Al	**13, 3A or IIIA**	**metal**	**representative element**	**3**	**solid**
silicon	**Si**	**14, 4A or IVA**	**metalloid**	**representative element**	**3**	**solid**
nickel	Ni	**10, 8B or VIIIB**	**metal**	**transition metal**	**4**	**solid**
sulfur	**S**	**16, 6A or VIA**	**nonmetal**	**representative element**	**3**	**solid**
fluorine	F	**17, 7A or VIIA**	**nonmetal**	**representative element**	**2**	**gas**
potassium	**K**	**1, 1A or IA**	**metal**	**representative element**	**4**	**solid**
mercury	Hg	**12, 2B or IIB**	**metal**	**transition metal**	**6**	**liquid**
uranium	**U**	(No group number)	**metal**	**inner transition metal**	**7**	**solid**
manganese	Mn	**7, 7B or VIIB**	**metal**	**transition metal**	**4**	**solid**
calcium	**Ca**	**2, 2A or IIA**	**metal**	**representative element**	**4**	**solid**
bromine	**Br**	17	**nonmetal**	**representative element**	4	**liquid**
silver	**Ag**	1B	**metal**	**transition metal**	5	**solid**
carbon	**C**	14	nonmetal	**representative element**	**2**	**solid**

Exercise 3.2 - Group Names and the Periodic Table: Write the name of the group on the periodic table to which each of the following elements belongs. (*Obj 13*)

a. helium **noble gases**
b. Cl **halogens**
c. magnesium **alkaline earth metals**
d. Na **alkali metals**

Exercise 3.3 - Cations and Anions: Identify each of the following as a cation or an anion, and determine the charge on each. *(Obj 22)*

a. magnesium atom with 12 protons and 10 electrons

(+12) + (–10) = +2 *This is a* **+2 cation.**

b. fluorine atom with 9 protons and 10 electrons

(+9) + (–10) = –1 *This is a* **–1 anion**.

Exercise 3.4 - Atomic Mass Calculations: Gold is often sold in units of troy ounces. There are 31.10 grams per troy ounce. *(Objs 29 & 30)*

a. What is the atomic mass of gold?

196.9665 *(from periodic table)*

b. What is the mass in grams of 6.022×10^{23} gold atoms?

196.9665 g *(There are 6.022×10^{23} atoms per mole of atoms, and one mole of an element has a mass in grams equal to its atomic mass.)*

c. Write the molar mass of gold as a conversion factor that can be used to convert between grams of gold and moles of gold.

$$\left(\frac{\mathbf{196.9665\ g\ Au}}{\mathbf{1\ mol\ Au}}\right)$$

d. What is the mass in grams of 0.20443 mole of gold?

$$?\ \text{g Au} = 0.20443\ \text{mol Au}\left(\frac{196.9665\ \text{g Au}}{1\ \text{mol Au}}\right) = \mathbf{40.266\ g\ Au}$$

e. What is the mass in milligrams of 7.046×10^{-3} mole of gold?

$$?\ \text{mg Au} = 7.046\times10^{-3}\ \text{mol Au}\left(\frac{196.9665\ \text{g Au}}{1\ \text{mol Au}}\right)\left(\frac{10^3\ \text{mg}}{1\ \text{g}}\right) = \mathbf{1388\ mg\ Au}$$

f. How many moles of gold are in 1.00 troy ounce of pure gold?

$$?\ \text{mol Au} = 1.00\ \text{troy oz Au}\left(\frac{31.10\ \text{g}}{1\ \text{troy oz}}\right)\left(\frac{1\ \text{mol Au}}{196.9665\ \text{g Au}}\right) = \mathbf{0.158\ mol\ Au}$$

Review Questions Key

1. Define the term matter.

   Matter is anything that occupies space and has mass.

2. Look around you. What do you see that has a length of about a meter? What do you see that has a mass of about a gram?

   The distance between the floor and a typical doorknob is about one meter. A penny weighs about 2.5 grams.

3. Complete each of the following conversion factors by filling in the blank on the top of the ratio.

   a. $\left(\frac{\mathbf{10^3}\ \text{g}}{1\ \text{kg}}\right)$

   b. $\left(\frac{\mathbf{10^3}\ \text{mg}}{1\ \text{g}}\right)$

   c. $\left(\frac{\mathbf{10^3}\ \text{kg}}{1\ \text{metric ton}}\right)$

   d. $\left(\frac{\mathbf{10^6}\ \mu\text{g}}{1\ \text{g}}\right)$

4. Convert 3.45×10^4 kg into grams.

$$?\,\text{g} = 3.45 \times 10^4\ \text{kg}\left(\frac{10^3\ \text{g}}{1\,\text{kg}}\right) = \mathbf{3.45 \times 10^7\ g}$$

5. Convert 184.570 g into kilograms.

$$?\,\text{kg} = 184.570\,\text{g}\left(\frac{1\,\text{kg}}{10^3\ \text{g}}\right) = \mathbf{0.184570\ kg}$$

6. Convert 4.5000×10^6 g into megagrams.

$$?\,\text{Mg} = 4.5000 \times 10^6\ \text{g}\left(\frac{1\,\text{Mg}}{10^6\ \text{g}}\right) = \mathbf{4.5000\ Mg}$$

7. Convert 871 Mg into grams.

$$?\,\text{g} = 871\,\text{Mg}\left(\frac{10^6\ \text{g}}{1\,\text{Mg}}\right) = \mathbf{8.71 \times 10^8\ g}$$

Key Ideas Answers

8. Scientific models are like architects' models; they are **simplified but useful** representations of something real.
10. According to the model presented in this chapter, particles of matter are in constant **motion**.
12. Solids, gases, and liquids differ in the freedom of motion of their particles and in how strongly the particles **attract** each other.
14. Particles in a liquid are still close together, but there is generally more **empty space** between them than in a solid. Thus, when a solid substance melts to form a liquid, it usually **expands** to fill a slightly larger volume.
16. When a liquid's temperature is higher, its particles are moving faster and are therefore more likely to **escape** from the liquid.
18. According to our model, each particle in a gas moves freely in a **straight-line path** until it collides with another gas particle or with the particles of a liquid or solid.
20. Elements are substances that cannot be chemically converted into **simpler** ones.
22. The periodic table is arranged in such a way that elements in the same **vertical column** have similar characteristics.
24. At room temperature (20 °C) and normal pressures, most of the elements are **solid**, two of them are **liquid** (Hg and Br), and eleven are **gas** (H, N, O, F, Cl, and the noble gases).
26. A ½-carat diamond contains about 5×10^{21} atoms of carbon. If these atoms, tiny as they are, were arranged in a straight line with each one touching its neighbors, the line would stretch from here to the **sun**.
28. The diameter of a typical nucleus is about $\mathbf{10^{-15}}$ meter.
30. Chemists use a model for electrons in which each electron is visualized as generating a **cloud** of negative charge that surrounds the nucleus.
32. When an atom **gains** one or more electrons, it then has more electrons than protons and more minus charge than plus charge. Thus it becomes an anion, which is an ion with a negative charge.
34. Atoms are assigned to elements on the basis of their **chemical** characteristics.
36. Each noble gas particle consists of a **single atom**.

38. Because of the size and number of carbon atoms in any normal sample of carbon, it is **impossible** to count the atoms directly.
40. The atomic mass of any element is the **weighted** average of the masses of the **naturally** occurring isotopes of the element.
42. The number of grams in the molar mass of an element is the same as the element's **atomic mass**.

Problems Key

Section 3.1 Solids, Liquids, and Gases

For each of the questions in this section, illustrate your written answers with simple drawings of the particles that form the structures of the substances mentioned. You do not need to be specific about the nature of the particles. Think of them as simple spheres, and draw them as circles.

43. If you heat white sugar very carefully, it will melt. *(Objs 2, 3, 4, & 6)*

    a. Before you begin to heat the sugar, the sugar granules maintain a constant shape and volume. Why?

       Strong attractions between the particles keep each particle at the same average distance from other particles, keeping the volume constant, and the strong attractions between particles also keep each particle in a confined volume, causing the solid to maintain a constant shape.

    b. As you begin to heat the solid sugar, what changes are taking place in its structure?

       The velocity of the particles increases, causing more violent collisions between them. This causes them to move apart, so the solid expands. See Figure 3.1 in the textbook.

    c. What happens to the sugar's structure when sugar melts?

       The particles break out of their positions in the solid and move more freely throughout the liquid, constantly breaking old attractions and making new ones, allowing the liquid to easily change its shape. Although the particles are still close together in the liquid, they are more disorganized, and there is a little more empty space between them than in the solid.

45. Ethylene glycol, an automobile coolant and antifreeze, is commonly mixed with water and added to car radiators. Because it freezes at a lower temperature than water and boils at a higher temperature than water, it helps to keep the liquid in your radiator from freezing or boiling. *(Objs 2, 3, 6, & 8)*

    a. At a constant temperature, liquid ethylene glycol maintains a constant volume but takes on the shape its container. Why?

       The attractions between liquid particles are not strong enough to keep the particles in position like the solid. The movement of particles allows the liquid to take the shape of its container. The attractions are strong enough to keep the particles at the same average distance, leading to constant volume.

    b. The ethylene glycol-water mixture in your car's radiator heats up as you drive. What is happening to the particles in the liquid?

       The velocity of the particles increases, so they will move throughout the liquid more rapidly. The particles will collide with more force. This causes them to move apart, so the liquid expands slightly.

c. If you spill some engine coolant on your driveway, it evaporates without leaving any residue. Describe the process of evaporation of liquid ethylene glycol, and explain what happens to the ethylene glycol particles that you spilled.

Particles that are at the surface of the liquid and that are moving away from the surface fast enough to break the attractions that pull them back will escape to the gaseous form. The gas particles will disperse throughout the neighborhood as they mix with the particles in the air. See Figures 3.3 and 3.4 in the textbook.

47. As the summer sun heats up the air at the beach, what is changing for the air particles?

The air particles are moving faster.

49. A gaseous mixture of air and gasoline enters the cylinders of a car engine and is compressed into a smaller volume before being ignited. Explain why gases can be compressed.

There is plenty of empty space between particles in a gas.

Section 3.2 The Chemical Elements and Section 3.3 The Periodic Table of the Elements

50. Write the chemical symbols that represent the following elements. *(Obj 11)*

a. chlorine **Cl** c. phosphorus **P**

b. zinc **Zn** d. uranium **U**

53. Write the element names that correspond to the following symbols. *(Obj 11)*

a. C **carbon** c. Ne **neon**

b. Cu **copper** d. K **potassium**

56. Complete the following table. *(Objs 11, 12, 15, 16, & 17)*

Element name	Element symbol	Group number on periodic table	Metal, nonmetal, or metalloid?	Representative element, transition metal, or inner transition metal?	Number of period
sodium	Na	**1 or 1A or IA**	**metal**	**Representative element**	**3**
tin	**Sn**	**14 or 4A or IVA**	**metal**	**Representative element**	**5**
helium	He	**18 or 8A or VIIIA**	**nonmetal**	**Representative element**	**1**
nickel	**Ni**	**10 or 8B or VIIIB**	**metal**	**Transition metal**	**4**
silver	Ag	**11 or 1B or IB**	**metal**	**Transition metal**	**5**
aluminum	**Al**	**13 or 3A or IIIA**	**metal**	**Representative element**	**3**
silicon	Si	**14 or 4A or IVA**	**metalloid**	**Representative element**	**3**
sulfur	**S**	16	**nonmetal**	**Representative element**	3
mercury	**Hg**	2B	**metal**	**Transition metal**	6

58. Write the name of the group to which each of the following belongs. *(Obj 13)*

a. bromine **halogens** c. potassium **alkali metals**

b. neon **noble gases** d. beryllium **alkaline earth metals**

60. Identify each of the following elements as a solid, a liquid, or a gas at room temperature and pressure. *(Obj 18)*

a. Kr	**gas**	d. fluorine	**gas**
b. bromine	**liquid**	e. Ge	**solid**
c. Sb	**solid**	f. sulfur	**solid**

62. Which two of the following elements would you expect to be most similar: lithium, aluminum, iodine, oxygen, and potassium?

Lithium and potassium; they are both alkali metals in group 1.

64. Write the name and symbol for the elements that fit the following descriptions.

a. the halogen in the third period **chlorine, Cl**
b. the alkali metal in the fourth period **potassium, K**
c. the metalloid in the third period **silicon, Si**

66. Which element would you expect to be malleable, manganese or phosphorus? Why?

Because manganese is a metal, we expect it to be malleable.

Section 3.4 The Structure of the Elements

68. Describe the nuclear model of the atom, including the general location of the protons, neutrons, and electrons, the relative size of the nucleus compared to the size of the atom, and the modern description of the electron. *(Obj 20)*

Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter of about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.

70. Identify each of the following as a cation or an anion, and determine the charge on each. *(Obj 22)*

a lithium atom with 3 protons and 2 electrons

(+3) + (–2) = +1 *This is a* **cation** *with a* **+1** *charge.*

a sulfur atom with 16 protons and 18 electrons

(+16) + (–18) = –2 *This is an* **anion** *with a* **–2** *charge.*

73. Write the atomic number for each of the following elements.

a. Oxygen	**8**	d. Li	**3**
b. Mg	**12**	e. lead	**82**
c. uranium	**92**	f. Mn	**25**

76. Write the name and symbol for the elements that fit the following descriptions.

a. 27 protons in the nucleus of each atom **cobalt, Co**
b. 50 electrons in each uncharged atom **tin, Sn**
c. 18 electrons in each +2 cation **calcium, Ca**
d. 10 electrons in each –1 anion **fluorine, F**

Section 3.5 Common Elements

78. Describe the hydrogen molecule, including a rough sketch of the electron-charge cloud created by its electrons. *(Obj 25)*

See the image of the hydrogen molecule in Figure 3.13 of the textbook. The cloud around the two hydrogen nuclei represents the negative charge cloud generated by the two electrons in the covalent bond that holds the atoms together in the H_2 molecule.

80. Describe the structure of each of the following substances, including a description of the nature of the particles that form each structure. *(Obj 24)*

a. neon gas

Neon is composed of separate neon atoms. Its structure is very similar to the structure of He shown in Figure 3.12 in the textbook.

b. bromine liquid

Bromine is composed of Br_2 molecules. See Figure 3.16 in the textbook.

c. nitrogen gas

Nitrogen is composed of N_2 molecules. Its structure is very similar to the structure of H_2 shown in Figure 3.15 in the textbook.

82. Describe the "sea-of-electrons" model for metallic solids. *(Obj 27)*

Each atom in a metallic solid has released one or more electrons, allowing the electrons to move freely throughout the solid. When the atoms lose these electrons, the atoms become cations, which form the organized structure we associate with solids. The released electrons flow between the stationary cations like water flows between islands in the ocean. See Figure 3.18 in the textbook.

Section 3.6 Relating Mass to Numbers of Particles

84. What is the weighted average mass in atomic mass units (u) of each atom of the following elements?

The atomic mass for each element in the periodic table tells you the weighted average mass in atomic mass units (u) of each atom of that element.

a. sodium **22.9898 u** b. oxygen **15.9994 u**

86. What is the weighted average mass in grams of 6.022×10^{23} atoms of the following elements?

The atomic mass for each element in the periodic table tells you the mass, in grams, of 6.022×10^{23} atoms of that element.

a. sulfur **32.066 g** b. fluorine **18.9984 g**

88. What is the molar mass for each of the following elements?

The atomic mass for each element in the periodic table tells you the molar mass, in grams per mole, of that element.

a. zinc **65.39 g/mol** b. aluminum **26.9815 g/mol**

90. For each of the following elements, write a conversion factor that converts between mass in grams and moles of the substance. *(Obj 29)*

    a. iron $\left(\frac{55.845\text{ g Fe}}{1\text{ mol Fe}}\right)$

    b. krypton $\left(\frac{83.80\text{ g Kr}}{1\text{ mol Kr}}\right)$

92. A vitamin supplement contains 50 micrograms of the element selenium in each tablet. How many moles of selenium does each tablet contain? *(Obj 30)*

$$?\text{ mol Se} = 50\ \mu\text{g Se}\left(\frac{1\text{ g}}{10^6\ \mu\text{g}}\right)\left(\frac{1\text{ mol Se}}{78.96\text{ g Se}}\right) = \mathbf{6.3 \times 10^{-7}\ mol\ Se}$$

94. A multivitamin tablet contains 1.6×10^{-4} mole of iron per tablet. How many milligrams of iron does each tablet contain? *(Obj 30)*

$$?\text{ mg Fe} = 1.6 \times 10^{-4}\text{ mol Fe}\left(\frac{55.845\text{ g Fe}}{1\text{ mol Fe}}\right)\left(\frac{10^3\text{ mg}}{1\text{ g}}\right) = \mathbf{8.9\ mg\ Fe}$$