Chapter 2: Atoms and Molecules

CHAPTER OUTLINE

2.1 Symbols and Formulas
2.2 Inside the Atom
2.3 Isotopes
2.4 Relative Masses of Atoms
2.5 Isotopes and Atomic Weights
2.6 Avogadro’s Number: The Mole
2.7 The Mole and Chemical Formulas

LEARNING OBJECTIVES/ASSESSMENT

When you have completed your study of this chapter, you should be able to:

1. Use symbols for chemical elements to write formulas for chemical compounds. (Section 2.1; Exercise 2.4)
2. Identify the characteristics of protons, neutrons, and electrons. (Section 2.2; Exercises 2.10 and 2.12)
3. Use the concepts of atomic number and mass number to determine the number of subatomic particles in isotopes and to write correct symbols for isotopes. (Section 2.3; Exercises 2.16 and 2.22)
4. Use atomic weights of the elements to calculate molecular weights of compounds. (Section 2.4; Exercise 2.32)
5. Use isotope percent abundances and masses to calculate atomic weights of the elements. (Section 2.5; Exercise 2.38)
6. Use the mole concept to obtain relationships between number of moles, number of grams, and number of atoms for elements, and use those relationships to obtain factors for use in factor-unit calculations. (Section 2.6; Exercises 2.44 a & b and 2.46 a & b)
7. Use the mole concept and molecular formulas to obtain relationships between number of moles, number of grams, and number of atoms or molecules for compounds, and use those relationships to obtain factors for use in factor-unit calculations. (Section 2.7; Exercise 2.50 b and 2.52 b)

SOLUTIONS FOR THE END OF CHAPTER EXERCISES

SYMBOLS AND FORMULAS (SECTION 2.1)

2.2
a. A triatomic molecule of a compound* 

b. A molecule of a compound containing two atoms of one element and two atoms of a second element*

c. A molecule of a compound containing two atoms of one element, one atom of a second element, and four atoms of a third element*

d. A molecule containing two atoms of one element, six atoms of a second element, and one atom of a third element*

*Note: Each of these structures could be drawn in many different ways.

2.4
a. A molecule of water (two hydrogen atoms and one oxygen atom) H₂O; like Exercise 2.2 a*
b. A molecule of hydrogen peroxide (two hydrogen atoms and two oxygen atoms) H₂O₂; like Exercise 2.2 b*

*The number and variety of atoms are alike. The actual structures of the molecules are different.
c. A molecule of sulfuric acid (two hydrogen atoms, one sulfur atom, and four oxygen atoms) H₂SO₄; like Exercise 2.2 c*
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d. A molecule of ethyl alcohol (two carbon atoms, six hydrogen atoms, and one oxygen atom) 
C₂H₆O; like Exercise 2.2 d*

*The number and variety of atoms are alike. The actual structures of the molecules are different.

2.6  a. sulfur dioxide (SO₂) 1 sulfur atom; 2 oxygen atoms
    b. butane (C₄H₁₀) 4 carbon atoms; 10 hydrogen atoms
    c. chlorous acid (HClO₂) 1 hydrogen atom; 1 chlorine atom; 2 oxygen atoms
    d. boron trifluoride (BF₃) 1 boron atom; 3 fluorine atoms

2.8  a. HSH (hydrogen sulfide) More than one H is part of the compound; a subscript should be used: H₂S
    b. HCLO₂ (chlorous acid) The elemental symbol for chlorine is Cl (the second letter of a symbol must be lowercase): HClO₂
    c. 2HN₂ (hydrazine – two hydrogen atoms and four nitrogen atoms) The subscripts should reflect the actual number of each type of atom in the compound: H₂N₄
    d. C₂H₆ (ethane) The numbers should be subscripted: C₂H₆

INSIDE THE ATOM (SECTION 2.2)

2.10  a. 5 protons and 6 neutrons 5 11
    b. 11 protons and 10 neutrons 11 21
    c. 36 protons and 50 neutrons 36 86
    d. 50 protons and 68 neutrons 50 118

2.12  The number of protons and electrons are equal in a neutral atom.
    a. 5 electrons b. 11 electrons c. 36 electrons d. 50 electrons

ISOTOPES (SECTION 2.3)

2.14  a. silicon 14 14
    b. Sn 50 50
    c. element number 74 74 74

2.16  a. ³⁷Li 3 4 3
    b. ²²Ne 10 12 10
    c. ⁴⁰Ca 20 24 20

2.18  a. silicon-28 ²⁸Si
    b. argon-40 ⁴⁰Ar
    c. strontium-88 ⁸⁸Sr

2.20  a. 5 protons and 6 neutrons 11 5 ¹¹B
    b. 11 protons and 10 neutrons 21 11 ²¹Na
<table>
<thead>
<tr>
<th>MASS NUMBER</th>
<th>ATOMIC NUMBER</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>36</td>
<td>$^{36}_{36}$Kr</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>$^{118}_{50}$Sn</td>
</tr>
</tbody>
</table>

2.22 a. contains 17 electrons and 20 neutrons $^{37}_{17}$Cl
b. a copper atom with a mass number of 65 $^{65}_{29}$Cu
c. a zinc atom that contains 36 neutrons $^{66}_{30}$Zn

d. 50 protons and 68 neutrons

d. 36 protons and 50 neutrons

d. 50 protons and 68 neutrons

d. 36 protons and 50 neutrons

d. 50 protons and 68 neutrons

RELATIVE MASSES OF ATOMS AND MOLECULES (SECTION 2.4)

2.24 $\frac{12 \text{ u}}{4 \text{ u He}} = \frac{1}{4} \text{ atom He}$

2.26 $77.1% \times 52.00 \text{ u} = 0.771 \times 52.00 \text{ u} = 40.1 \text{ u}; \text{Ca; calcium}$

2.28 $\frac{1}{2} \times 28.09 \text{ u} = 14.05 \text{ u}; \text{N; nitrogen}$

2.30 a. nitrogen dioxide (NO$_2$) $(1 \times 14.01 \text{ u}) + (2 \times 16.00 \text{ u}) = 46.01 \text{ u}$
b. ammonia (NH$_3$) $(1 \times 14.01 \text{ u}) + (3 \times 1.008 \text{ u}) = 17.03 \text{ u}$
c. glucose (C$_6$H$_{12}$O$_6$) $(6 \times 12.01 \text{ u}) + (12 \times 1.008 \text{ u}) + (6 \times 16.00 \text{ u}) = 180.16 \text{ u}$
d. ozone (O$_3$) $3 \times 16.00 \text{ u} = 48.00 \text{ u}$
e. ethylene glycol (C$_2$H$_6$O$_2$) $(2 \times 12.01 \text{ u}) + (6 \times 1.008 \text{ u}) + (2 \times 16.00 \text{ u}) = 62.07 \text{ u}$

2.32 The gas is most likely to be ethylene based on the following calculations:
acetylene: $(2 \times 12.01 \text{ u}) + (2 \times 1.008 \text{ u}) = 26.04 \text{ u}$
ethylene: $(2 \times 12.01 \text{ u}) + (4 \times 1.008 \text{ u}) = 28.05 \text{ u}$
ethane: $(2 \times 12.01 \text{ u}) + (6 \times 1.008 \text{ u}) = 30.07 \text{ u}$

The experimental value for the molecular weight of a flammable gas known to contain only carbon and hydrogen is 28.05 u, which is identical to the theoretical value of 28.05 u, which was calculated for ethylene.

2.34 The y in the formula for serine stands for 3, the number of carbon atoms in the chemical formula.
$(y \times 12.01 \text{ u}) + (7 \times 1.008 \text{ u}) + (1 \times 14.01 \text{ u}) + (3 \times 16.00 \text{ u}) = 105.10 \text{ u}$
y $\times 12.01 \text{ u} + 69.07 \text{ u} = 105.10 \text{ u}$
y $\times 12.01 \text{ u} = 36.03 \text{ u}$
y = 3

ISOTOPES AND ATOMIC WEIGHTS (SECTION 2.5)

2.36 a. The number of neutrons in the nucleus $26.982 - 13 = 13.982 \approx 14$ neutrons
b. The mass (in u) of the nucleus (to three significant figures) $27.0 \text{ u}$
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2.38 \[ 60.40\% \times 68.9257 \, \text{u} + 39.60\% \times 70.9249 \, \text{u} = \]
\[ 0.6040 \times 68.9257 \, \text{u} + 0.3960 \times 70.9249 \, \text{u} = 69.7173832 \, \text{u} ; 69.72 \, \text{u with SF} \]
or
\[ \frac{60.40 \times 68.9257 \, \text{u}}{100} + \frac{39.60 \times 70.9249 \, \text{u}}{100} = 69.7173832 \, \text{u} ; 69.72 \, \text{u with SF} \]
The atomic weight listed for gallium in the periodic table is 69.72 u. The two values are the same.

2.40 \[ 69.09\% \times 62.9298 \, \text{u} + 30.91\% \times 64.9278 \, \text{u} = \]
\[ 0.6909 \times 62.9298 \, \text{u} + 0.3091 \times 64.9278 \, \text{u} = 63.5473818 \, \text{u} ; 63.55 \, \text{u with SF} \]
The atomic weight listed for copper in the periodic table is 63.55 u. The two values are the same.

AVOGADRO’S NUMBER: THE MOLE (SECTION 2.6)

2.42 \[ 1.60 \times \frac{6.02 \times 10^{23} \text{ atoms O}}{16.00 \text{ g O}} = 6.02 \times 10^{22} \text{ atoms O} \]
\[ 6.02 \times 10^{22} \text{ atoms F} \times \frac{19.0 \text{ g F}}{6.02 \times 10^{23} \text{ atoms F}} = 1.90 \, \text{g F} \]

2.44 \( \text{a. phosphorus} \)
\[ 1 \text{ mol P atoms} = 6.02 \times 10^{23} \text{ P atoms} \]
\[ 6.02 \times 10^{23} \text{ P atoms} = 31.0 \, \text{g P} \]
\[ 1 \text{ mol P atoms} = 31.0 \, \text{g P} \]

\( \text{b. aluminum} \)
\[ 1 \text{ mol Al atoms} = 6.02 \times 10^{23} \text{ Al atoms} \]
\[ 6.02 \times 10^{23} \text{ Al atoms} = 27.0 \, \text{g Al} \]
\[ 1 \text{ mol Al atoms} = 27.0 \, \text{g Al} \]

\( \text{c. krypton} \)
\[ 1 \text{ mol Kr atoms} = 6.02 \times 10^{23} \text{ Kr atoms} \]
\[ 6.02 \times 10^{23} \text{ Kr atoms} = 83.8 \, \text{g Kr} \]
\[ 1 \text{ mol Kr atoms} = 83.8 \, \text{g Kr} \]

2.46 \( \text{a. The mass in grams of one phosphorus atom} \)
\[ 6.02 \times 10^{23} \text{ P atoms} = 31.0 \, \text{g P} ; \frac{31.0 \, \text{g P}}{6.02 \times 10^{23} \, \text{P atoms}} = 5.15 \times 10^{-23} \, \text{g P} \]
(Note: One atom is assumed to be an exact number.)
\[ 1 \text{ atom P} \times \frac{31.0 \, \text{g P}}{6.02 \times 10^{23} \, \text{P atoms}} = 5.15 \times 10^{-23} \, \text{g P} \]

\( \text{b. The number of grams of aluminum in 1.65 mol of aluminum} \)
\[ 1 \text{ mol Al atoms} = 27.0 \, \text{g Al} ; \frac{27.0 \, \text{g Al}}{1 \, \text{mol Al atoms}} = 44.6 \, \text{g Al} \]
\[ 1.65 \text{ mol Al} \times \frac{27.0 \, \text{g Al}}{1 \, \text{mol Al}} = 44.6 \, \text{g Al} \]
c. The total mass in grams of one-fourth Avogadro's number of krypton atoms

\[
1 \text{ mol } \text{Kr} = 83.8 \text{ g Kr; } \frac{83.8 \text{ g Kr}}{1 \text{ mol Kr}} = 20.95 \text{ g Kr}
\]

(Note: One-fourth is assumed to be an exact number.)

THE MOLE AND CHEMICAL FORMULAS (SECTION 2.7)

2.48

\[
\begin{align*}
(1 \times 10.8 \text{ u}) + (3 \times 19.0 \text{ u}) &= 67.8 \text{ u}; \quad 1 \text{ mole BF}_3 = 67.8 \text{ g BF}_3 \\
(2 \times 1.01 \text{ u}) + (1 \times 32.1 \text{ u}) &= 34.1 \text{ u}; \quad 1 \text{ mole H}_2\text{S} = 34.1 \text{ g H}_2\text{S}
\end{align*}
\]

\[
0.34 \text{ g H}_2\text{S} \left( \frac{6.02 \times 10^{23} \text{ molecules H}_2\text{S}}{34.1 \text{ g H}_2\text{S}} \right) = 6.0 \times 10^{21} \text{ molecules H}_2\text{S}
\]

\[
6.0 \times 10^{21} \text{ molecules BF}_3 \left( \frac{67.8 \text{ g BF}_3}{6.02 \times 10^{23} \text{ molecules BF}_3} \right) = 0.68 \text{ g BF}_3
\]

2.50

a. ethyl ether (C\(_4\)H\(_{10}\)O)

1. 2 C\(_4\)H\(_{10}\)O molecules contain 8 C atoms, 20 H atoms, and 2 O atoms.
2. 10 C\(_4\)H\(_{10}\)O molecules contain 40 C atoms, 100 H atoms, and 10 O atoms.
3. 100 C\(_4\)H\(_{10}\)O molecules contain 400 C atoms, 1000 H atoms, and 100 O atoms.
4. \(6.02 \times 10^{23}\) C\(_4\)H\(_{10}\)O molecules contain \(24.08 \times 10^{23}\) C atoms, \(60.2 \times 10^{23}\) H atoms, and \(6.02 \times 10^{23}\) O atoms.
5. 1 mol of C\(_4\)H\(_{10}\)O molecules contain 4 moles of C atoms, 10 moles of H atoms, and 1 mole O atoms.
6. 74.1 g of ethyl ether contains 48.0 g of C, 10.1 g of H, and 16.0 g of O.

b. fluoroacetic acid (C\(_3\)H\(_2\)O\(_2\)F)

1. 2 C\(_3\)H\(_2\)O\(_2\)F molecules contain 4 C atoms, 6 H atoms, 4 O atoms, and 2 F atoms.
2. 10 C\(_3\)H\(_2\)O\(_2\)F molecules contain 20 C atoms, 30 H atoms, 20 O atoms, and 10 F atoms.
3. 100 C\(_3\)H\(_2\)O\(_2\)F molecules contain 200 C atoms, 300 H atoms, 200 O atoms, and 100 F atoms.
4. \(6.02 \times 10^{23}\) C\(_3\)H\(_2\)O\(_2\)F molecules contain \(12.04 \times 10^{23}\) C atoms, \(18.06 \times 10^{23}\) H atoms, \(12.04 \times 10^{23}\) O atoms, and \(6.02 \times 10^{23}\) F atoms.
5. 1 mol of C\(_3\)H\(_2\)O\(_2\)F molecules contain 2 moles of C atoms, 3 moles of H atoms, 2 moles of O atoms, and 1 mole of F atoms.
6. 78.0 g of fluoroacetic acid contains 24.0 g of C, 3.03 g of H, 32.0 g of O, and 19.0 g of F.
c. aniline \((C_6H_7N)\)

1. 2 \(C_6H_7N\) molecules contain 12 C atoms, 14 H atoms, and 2 N atoms.
2. 10 \(C_6H_7N\) molecules contain 60 C atoms, 70 H atoms, and 10 N atoms.
3. 100 \(C_6H_7N\) molecules contain 600 C atoms, 700 H atoms, and 100 N atoms.
4. \(6.02 \times 10^{23} \ C_6H_7N\) molecules contain \(36.12 \times 10^{23} \) C atoms, \(42.14 \times 10^{23} \) H atoms, and \(6.02 \times 10^{23} \) N atoms.
5. 1 mol of \(C_6H_7N\) molecules contain 6 moles of C atoms, 7 moles of H atoms, and 1 mole N atoms.
6. 93.1 g of aniline contains 72.0 g of C, 7.07 g of H, and 14.0 g of N.

2.52 a. **Statement 5.** 1 mol of \(C_4H_{10}O\) molecules contain 4 moles of C atoms, 10 moles of H atoms, and 1 mole O atoms.

\[
\text{Factor: } \left( \frac{10 \text{ moles H atoms}}{1 \text{ mole } C_4H_{10}O} \right)
\]

\[0.50 \text{ mol } C_4H_{10}O \left( \frac{10 \text{ moles H atoms}}{1 \text{ mole } C_4H_{10}O} \right) = 5.0 \text{ moles H atoms}\]

\[\blackcheck\text{b. Statement 4. } 6.02 \times 10^{23} \ C_2H_2O_F\) molecules contain 12.04 \times 10^{23} \) C atoms, \(18.06 \times 10^{23} \) H atoms, 12.04 \times 10^{23} \) O atoms, and \(6.02 \times 10^{23} \) F atoms.

\[
\text{Factor: } \left( \frac{12.04 \times 10^{23} \text{ C atoms}}{1 \text{ mole } C_2H_2O_F} \right)
\]

\[0.25 \text{ mole } C_2H_2O_F \left( \frac{12.04 \times 10^{23} \text{ C atoms}}{1 \text{ mole } C_2H_2O_F} \right) = 3.0 \times 10^{23} \text{ C atoms}\]

\[\blackcheck\text{c. Statement 6. } 93.1 \text{ g of aniline contains } 72.0 \text{ g of C, } 7.07 \text{ g of H, and } 14.0 \text{ g of N.}

\[
\text{Factor: } \left( \frac{7.07 \text{ g H}}{1 \text{ mole } C_6H_7N} \right)
\]

\[2.00 \text{ mol } C_6H_7N \left( \frac{7.07 \text{ g H}}{1 \text{ mole } C_6H_7N} \right) = 14.1 \text{ g H}\]

2.54

\[0.75 \text{ mole } H_2O \left( \frac{1 \text{ mole O atoms}}{1 \text{ mole } H_2O} \right) \left( \frac{6.02 \times 10^{23} \text{ O atoms}}{1 \text{ mole O atoms}} \right) = 4.515 \times 10^{23} \text{ O atoms}\]

\[4.515 \times 10^{23} \text{ O atoms} \left( \frac{1 \text{ mole O atoms}}{6.02 \times 10^{23} \text{ O atoms}} \right) \left( \frac{1 \text{ mole } C_2H_2O}{1 \text{ mole O atoms}} \right) \left( \frac{46.1 \text{ g } C_2H_2O}{1 \text{ mole } C_2H_2O} \right) \]

\[= 34.575 \text{ g } C_2H_2O \approx 35 \text{ g with SF}\]

2.56

\[
\frac{16.0 \text{ g O}}{28.0 \text{ g CO}} \times 100 = 57.1\% \text{ O in CO}
\]

\[
\frac{32.0 \text{ g O}}{44.0 \text{ g } CO_2} \times 100 = 72.7\% \text{ O in } CO_2
\]
2.58 **Statement 4.** \(6.02 \times 10^{23} \text{C}_6\text{H}_{12}\text{O}_6\) molecules contain \(36.12 \times 10^{23}\) C atoms, \(72.24 \times 10^{23}\) H atoms, and \(36.12 \times 10^{23}\) O atoms.

**Statement 5.** 1 mol \(\text{C}_6\text{H}_{12}\text{O}_6\) molecules contain 6 moles of C atoms, 12 moles of H atoms, and 6 moles of O atoms.

**Statement 6.** 180 g of fructose contains 72.0 g of C, 12.1 g of H, and 96.0 g of O.

a. **Statement 6.** 180 g of fructose contains 72.0 g of C, 12.1 g of H, and 96.0 g of O.

Factor: \(\frac{96.0 \text{ g O}}{180 \text{ g C}_6\text{H}_{12}\text{O}_6}\)

\(\frac{43.5 \text{ g C}_6\text{H}_{12}\text{O}_6}{180 \text{ g C}_6\text{H}_{12}\text{O}_6} \times \frac{96.0 \text{ g O}}{180 \text{ g C}_6\text{H}_{12}\text{O}_6} = 23.2 \text{ g O}\)

b. **Statement 5.** 1 mol \(\text{C}_6\text{H}_{12}\text{O}_6\) molecules contain 6 moles of C atoms, 12 moles of H atoms, and 6 moles of O atoms.

Factor: \(\frac{12 \text{ moles of H atoms}}{1 \text{ mole C}_6\text{H}_{12}\text{O}_6}\)

\(\frac{1.50 \text{ moles C}_6\text{H}_{12}\text{O}_6}{1 \text{ mole C}_6\text{H}_{12}\text{O}_6} \times \frac{12 \text{ moles of H atoms}}{1 \text{ mole C}_6\text{H}_{12}\text{O}_6} = 18.0 \text{ moles of H atoms}\)

c. **Statement 4.** \(6.02 \times 10^{23} \text{C}_6\text{H}_{12}\text{O}_6\) molecules contain \(36.12 \times 10^{23}\) C atoms, \(72.24 \times 10^{23}\) H atoms, and \(36.12 \times 10^{23}\) O atoms.

Factor: \(\frac{36.12 \times 10^{23} \text{C atoms}}{6.02 \times 10^{23} \text{C}_6\text{H}_{12}\text{O}_6 \text{ molecules}}\)

\(\frac{7.50 \times 10^{22} \text{ molecules C}_6\text{H}_{12}\text{O}_6}{6.02 \times 10^{23} \text{C}_6\text{H}_{12}\text{O}_6 \text{ molecules}} \times \frac{36.12 \times 10^{23} \text{C atoms}}{6.02 \times 10^{23} \text{C}_6\text{H}_{12}\text{O}_6 \text{ molecules}} = 4.50 \times 10^{23} \text{C atoms}\)

2.60 **Magnetite (FeO) contains the higher mass percentage of iron as shown in the calculation below:**

\(\frac{167 \text{ g Fe}}{231 \text{ g Fe}_2\text{O}_3} \times 100 = 72.3\% \text{ Fe in Fe}_2\text{O}_3\)

\(\frac{112 \text{ g Fe}}{160 \text{ g Fe}_2\text{O}_3} \times 100 = 70.0\% \text{ Fe in Fe}_2\text{O}_3\)

**ADDITIONAL EXERCISES**

2.62 U-238 contains 3 more neutrons in its nucleus than U-235. U-238 and U-235 have the same volume because the extra neutrons in U-238 do not change the size of the electron cloud. U-238 is 3u heavier than U-235 because of the 3 extra neutrons. Density is a ratio of mass to volume; therefore, U-238 is more dense than U-235 because it has a larger mass divided by the same volume.

2.64 \(\frac{1.99 \times 10^{-23} \text{ g}}{1 \text{ C-12 atom}} \times \frac{1 \text{ C-12 atom}}{12 \text{ protons + neutrons}} \times \frac{14 \text{ protons + neutrons}}{1 \text{C-14 atom}} = 2.32 \times 10^{-23} \text{ g} \)

\(\frac{1 \text{ C-14 atom}}{1 \text{ C-14 atom}} = \frac{14 \text{ protons + neutrons}}{1 \text{C-14 atom}}\)
2.66 In Figure 2.2, the electrons are much closer to the nucleus than they would be in a properly scaled drawing. Consequently, the volume of the atom represented in Figure 2.2 is much less than it should be. Density is calculated as a ratio of mass to volume. The mass of this atom has not changed; however, the volume has decreased. Therefore, the atom in Figure 2.2 is much more dense than an atom that is 99.999% empty.

ALLIED HEALTH EXAM CONNECTION

2.68 (b) Water is a chemical compound. (a) Blood and (d) air are mixtures, while (c) oxygen is an element.

2.70 $^{34}_{17}$Cl has (a) 17 protons, 17 neutrons ($34-17=17$), and 17 electrons (electrons = protons in neutral atom).

2.72 Copper has (b) 29 protons because the atomic number is the number of protons.

2.74 The negative charged particle found within the atom is the (b) electron.

2.76 The major portion of an atom’s mass consists of (a) neutrons and protons.

2.78 (d) $^{32}_{16}S^{2-}$ has 16 protons, 17 neutrons, and 18 electrons.

2.80 The mass number of an atom with 60 protons, 60 electrons, and 75 neutrons is (b) 135.

2.82 (c) 1.0 mol NO$_2$ has the greatest number of atoms ($1.8 \times 10^{24}$ atoms). 1.0 mol N has $6.0 \times 10^{23}$ atoms, 1.0 g N has $4.3 \times 10^{22}$ atoms, and 0.5 mol NH$_3$ has $1.2 \times 10^{24}$ atoms.

2.84 The molar mass of calcium oxide, CaO, is (a) 56 g (40 g Ca + 16 g O).

2.86 (b) 2.0 moles Al are contained in a 54.0 g sample of Al.

\[
54.0 \text{ g Al} \left( \frac{1 \text{ mole Al}}{27.0 \text{ g Al}} \right) = 2.00 \text{ mole Al}
\]

CHEMISTRY FOR THOUGHT

2.88 Aluminum exists as one isotope; therefore, all atoms have the same number of protons and neutrons as well as the same mass. Nickel exists as several isotopes; therefore, the individual atoms do not have the weighted average atomic mass of 58.69 u.

2.90 \[
\frac{\text{dry bean mass}}{\text{jelly bean mass}} = \frac{1}{1.60}
\]

\[
\frac{472 \text{ g jelly beans}}{1.60 \text{ g jelly beans}} = 295 \text{ g dry beans}
\]

\[
\frac{472 \text{ g jelly beans}}{1.18 \text{ g jelly beans}} = 400 \text{ jelly beans} \quad \text{Each jar contains 400 beans.}
\]
2.92 If the atomic mass unit were redefined as being equal to $\frac{1}{24}$th the mass of a carbon-12 atom, then the atomic weight of a carbon-12 atom would be 24 u. Changing the definition for an atomic mass unit does not change the relative mass ratio of carbon to magnesium. Magnesium atoms are approximately 2.024 times as heavy as carbon-12 atoms; therefore, the atomic weight of magnesium would be approximately 48.6 u.

2.94 The value of Avogadro’s number would not change even if the atomic mass unit were redefined. Avogadro’s number is the number of particles in one mole and has a constant value of $6.022 \times 10^{23}$.

ADDITIONAL ACTIVITIES

Section 2.1 Review: The crossword game pieces are chemical symbols combined to spell the name of different substances. The molecular formulas for these named substances (or one of their components) are written to the right of the pieces. Write out the element names for the all of the elemental symbols.

\[
\begin{array}{cccc}
\text{Ca} & \text{F} & \text{Fe} & \text{I} & \text{Ne} \\
\text{As} & \text{P} & \text{Ir} & \text{In} \\
\text{S} & \text{U} & \text{Cr} & \text{O} & \text{Se} \\
\text{W} & \text{At} & \text{Er} \\
\text{C} & \text{Ho} & \text{Co} & \text{La} & \text{Te} \\
\end{array}
\]

$\text{CaH}_2\text{O}_2$, $\text{C}_3\text{H}_8\text{O}_4$, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, $\text{H}_2\text{O}$, $\text{C}_9\text{H}_8\text{N}_4\text{O}_2$ (theobromine – one of the components of chocolate)
Section 2.2 Review: Assume the following picture represents an atom.

(1) Circle the nucleus.
(2) Which particle(s) is(are) found in the nucleus?
(3) Which particle(s) is(are) found outside the nucleus?
(4) What is the charge on the nucleus?
(5) What is the charge on the whole atom?
(6) What is the mass of this atom in amu?
(7) What is the mass of this atom in grams?

Section 2.3 Review:

(1) Add the atomic numbers to each of the game pieces from the Section 2.1 Review.
(2) What is the atomic number for the atom represented in the Section 2.2 Review?
(3) What is the mass number for the atom represented in the Section 2.2 Review?
(4) What are the name and symbol for the isotope represented in the Section 2.2 Review?
(5) Write the symbol for carbon-14.
(6) What is the atomic number for carbon-14?
(7) What is the mass number for carbon-14?
(8) How many protons are in carbon-14?
(9) How many neutrons are in carbon-14?
(10) How many electrons are in carbon-14?
(11) Sketch an atom of carbon-14 (like the drawing in the Section 2.2 Review).

Section 2.4 Review:

(1) Calculate the molecular weights for the crossword game “words” and their molecular formulas from the Section 2.1 Review.

A scientist claims to have discovered a new element, jupiterium. Its atomic mass is 5.994 times the mass of sulfur.
(2) What is the atomic weight of this element?
(3) Add the atomic weight of this element to the box from the periodic table.
(4) Does any known element have this atomic weight? If so, what are the name and symbol for this element?
(5) What information in addition to the atomic mass could confirm the real identity of this element?

Section 2.5 Review:

Gallium has two naturally occurring isotopes as shown in the table below:

<table>
<thead>
<tr>
<th>Isotope symbol</th>
<th>Natural Abundance</th>
<th>Isotope Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{69}$Ga</td>
<td>60.11%</td>
<td>68.925580 amu</td>
</tr>
<tr>
<td>$^{71}$Ga</td>
<td>39.89%</td>
<td>70.9247005 amu</td>
</tr>
</tbody>
</table>

(1) In a sample of 10,000 gallium atoms, how many are gallium-69?
(2) If you were able to pull out individual gallium atoms from sample of 10,000 gallium atom, what is the likelihood of the atom being a gallium-71 isotope?
(3) Calculate the average atomic weight of gallium. Does this match the periodic table?
(4) Will any individual gallium atom have this average atomic weight?
(5) How many atoms are in 5.00 g of gallium?
(6) How many gallium-69 atoms are in a 5.00 g sample of gallium?
Section 2.6 Review:

1. Write Avogadro’s number in expanded form.

This number is enormous! To gain perspective on this number, consider the following information. The surface area of the earth is approximately 196,935,000 square miles. The dimensions of a crossword game box are as follows: 7.5 inches wide, 15.75 inches long, and 1.515 inches deep. The box can hold 1566 game pieces (although each game is sold with only 100 pieces).

2. Write the surface area of the earth in scientific notation.
3. Calculate the surface area (length x width) of the top of the game box in square inches.
4. Convert the surface area of the box into square miles. (12 inches = 1 foot, 144 in$^2$ = 1 ft$^2$, 5280 feet = 1 mile, $2.78784 \times 10^7$ ft$^2 = 1$ mi$^2$)
5. How many boxes could be placed on the earth’s surface?
6. How many game pieces could all of these boxes contain?
7. Divide Avogadro’s number by the number of game pieces in the boxes that would cover the earth’s surface. This will tell you how many game boxes deep each stack would need to be in order to cover the earth with one mole of game pieces.
8. Convert the depth of the stack into miles by multiplying the number of boxes in a stack by the depth of each box in miles.

As a point of comparison of the size of atoms to the game pieces:

9. What is the mass of one mole of silicon atoms?
10. If the density of silicon is 2.33 g/cm$^3$, what is the volume (in cm$^3$) of 1 mole of silicon atoms?
11. Convert this volume to Tablespoons. (15 mL = 1 Tablespoon)
12. Could you hold one mole of silicon atoms in your hand?
13. Assuming the atoms occupy all of the space in the 1 mole sample of silicon*, what is the volume (in cm$^3$) of a silicon atom?
14. How many silicon atoms will fit into the volume of a game piece (0.715 in. x 0.795 in. x 0.175 in.)?

*Note: This assumption is not valid. The solid will contain empty space and the atoms are actually smaller than this calculation implies.

Section 2.7 Review:

1. Calculate the molecular weight for all of the molecular formulas given in the right column of the table in Section 2.1 Review.
2. How many molecules are in 1 mole of each of those compounds?
3. What is the mass in grams for 1 mole of each of those compounds?
4. How many moles of carbon are in 1 mole of each of those compounds?
5. How many atoms of hydrogen are in 1 mole of each of those compounds?
6. How many grams of oxygen are in 1 mole of each of those compounds?
7. What is the mass percentage of nitrogen in each of those compounds?
Tying It All Together with a Laboratory Application:
In 1911 and 1914, Ernest Rutherford published papers in Philosophical Magazine about the structure of the atom. At this time, the charge and mass of an electron were known; however, the proton and the neutron had not been discovered. The experimental setup is shown below:

![setup](image)

The gold foil is 4 $\times$ 10^{-5} cm thick. If the gold foil was 4 $\times$ 10^{-5} cm wide by 4 $\times$ 10^{-5} cm high, the volume of the gold foil would be (1) __________ cm^3. The density of gold is 19.3 g/cm^3; therefore the mass of this gold foil would be (2) __________ g or (3) __________ u. The number of moles of gold atoms in this sample of gold foil would be (4) __________ moles. The number of atoms in this sample of gold foil would be (5) __________ atoms. The gold foil would be approximately (6) __________ atoms thick. The actual width and the height of the gold foil were greater than 4 $\times$ 10^{-5} cm for ease of experimental setup.

The alpha particles are produced by radioactive decay, which is covered in Chapter 10. One of the accepted chemical symbols for an alpha particle is $^4_2\alpha$. The mass number of an alpha particle is (7) __________. The atomic number of an alpha particle is (8) __________. The element with the same atomic number as an alpha particle is (9) __________. The relative mass of gold to an alpha particle is (10) __________. An alpha particle contains (11) __________ protons and (12) __________ neutrons. The alpha particle has a $2^+$ charge, which means it contains (13) __________ electrons. The alpha particles travel at 2.09 $\times$ 10^{8} cm/sec. Light travels at 3.00 $\times$ 10^{8} m/s. The speed of an alpha particle is (14) __________ percentage the speed of light.

The alpha particles were aimed at the gold foil which was surrounded by a circular zinc sulfide (ZnS) screen. ZnS is a phosphor. It emits light after being struck by an energetic material (like an alpha particle). In this experiment, the angle was measured between the initial path of the alpha particle to the gold foil and the location on the screen that the alpha particle struck after interacting with the gold foil. Most of the alpha particles in this experiment went straight through the gold foil (~98%) or were deflected only a small amount (~2%). Approximately 1 in 20,000 alpha particles, though, were turned back through an average angle of 90°. Rutherford’s explanation for this phenomenon was that an atom is mainly empty space with an exceedingly small, dense, positively charged (15) __________ at the center of the atom and (16) __________ distributed around the outside of the nucleus that maintain a neutral atom. If an alpha particle passed close to the nucleus of one of the gold atoms it would be (pick one: attracted or repelled) (17) __________ because the alpha particle is positive and the nucleus is positive.
SOLUTIONS FOR THE ADDITIONAL ACTIVITIES

Section 2.1 Review:
Caffeine – calcium, fluorine, iron, iodine, neon, carbon, hydrogen, nitrogen, oxygen
Aspirin – arsenic, phosphorus, iridium, indium, carbon, hydrogen, oxygen
Sucrose – sulfur, uranium, chromium, oxygen, selenium, carbon, hydrogen, oxygen
Water – tungsten, astatine, erbium, hydrogen, oxygen
Chocolate – carbon, holmium, cobalt, lanthanum, tellurium, carbon, hydrogen, nitrogen, oxygen

Section 2.2 Review:

(1) Caffeine – calcium, fluorine, iron, iodine, neon, carbon, hydrogen, nitrogen, oxygen
Aspirin – arsenic, phosphorus, iridium, indium, carbon, hydrogen, oxygen
Sucrose – sulfur, uranium, chromium, oxygen, selenium, carbon, hydrogen, oxygen
Water – tungsten, astatine, erbium, hydrogen, oxygen
Chocolate – carbon, holmium, cobalt, lanthanum, tellurium, carbon, hydrogen, nitrogen, oxygen

Section 2.4 Review:
(1) Caffeine – 40.08 u + 19.00 u + 55.85 u + 126.90 u + 20.18 u = 262.01 u;
\[
\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 8\left(\frac{12.01\text{u}}{1\text{C}}\right) + 10\text{H}\left(\frac{1.0079\text{u}}{1\text{H}}\right) + 4\text{N}\left(\frac{14.01\text{u}}{1\text{N}}\right) + 2\text{O}\left(\frac{16.00\text{u}}{1\text{O}}\right) = 194.20\text{u};
\]
Aspirin – 74.92 u + 30.97 u + 192.22 u + 114.82 u + 412.93 u = 412.93 u;
\[
\text{C}_9\text{H}_8\text{O}_4 = 9\left(\frac{12.01\text{u}}{1\text{C}}\right) + 8\text{H}\left(\frac{1.0079\text{u}}{1\text{H}}\right) + 4\text{O}\left(\frac{16.00\text{u}}{1\text{O}}\right) = 180.15\text{u};
\]
Sucrose – 32.07 u + 238.03 u + 52.00 u + 16.00 u + 78.96 u + 417.06 u = 417.06 u;
\[
\text{C}_{12}\text{H}_{22}\text{O}_{11} = 12\left(\frac{12.01\text{u}}{1\text{C}}\right) + 22\text{H}\left(\frac{1.0079\text{u}}{1\text{H}}\right) + 11\text{O}\left(\frac{16.00\text{u}}{1\text{O}}\right) = 342.29\text{u};
\]
Water – 183.9 u + 210 u + 167.26 u = 561 u;
\[
\text{H}_2\text{O} - 2\text{H} \left( \frac{1.0079}{1}\text{H} \right) + 1\text{O} \left( \frac{16.00}{1}\text{O} \right) = 18.02 \text{u};
\]
\[
\text{Chocolate} - 12.01 \text{u} + 164.93 \text{u} + 58.93 \text{u} + 138.91 \text{u} + 127.60 \text{u} = 502.38 \text{u};
\]
\[
\text{C}_7\text{H}_8\text{N}_4\text{O}_2 - 7\text{C} \left( \frac{12.01}{1}\text{C} \right) + 8\text{H} \left( \frac{1.0079}{1}\text{H} \right) + 4\text{N} \left( \frac{14.01}{1}\text{N} \right) + 2\text{O} \left( \frac{16.00}{1}\text{O} \right) = 180.17 \text{u};
\]

(2) \(5.994 \times 32.07 \text{u} = 192.2 \text{u}\); (3)

(4) iridium, Ir; (5) If the atomic number of jupiterium is 77, then this element is really iridium. The atomic number is the number of protons in the nucleus of an atom. The atomic number is unique for each element.

**Section 2.5 Review:**

(1) \(60.11\% \times 10,000 = 0.6011 \times 10,000 = 6,011\); (2) \(\frac{3989}{1000} \times 100 = 39.89\%\);

(3) \(60.11\% (68.925580 \text{u}) + 39.89\% (70.9247005 \text{u}) = 0.6011 (68.925580 \text{u}) + 0.3989 (70.9247005 \text{u}) = 69.72 \text{u}\), yes; (4) no; (5) \(5.00 \frac{1 \text{b ox}}{1.661 \times 10^{-24} \text{K}} \left( \frac{1 \text{atom}}{69.72 \text{K}} \right) = 4.32 \times 10^{22} \text{atoms}\);

(6) \(5.00 \frac{1 \text{b ox}}{1.661 \times 10^{-24} \text{K}} \left( \frac{1 \text{atom}}{69.72 \text{K}} \right) 60.11\% = 5.00 \frac{1 \text{b ox}}{1.661 \times 10^{-24} \text{K}} \left( \frac{1 \text{atom}}{69.72 \text{K}} \right) 0.6011 = 2.60 \times 10^{22} \text{gallium} - 69 \text{atoms}\)

**Section 2.6 Review:**

(1) \(602,200,000,000,000,000,000\); (2) \(1.96935 \times 10^8\) square miles;

(3) \(7.5 \text{inches} \times 15.75 \text{inches} = 118.125 \text{in}^2 = 120 \text{in}^2\);

(4) \(118.125 \text{in}^2 \left( \frac{1 \text{mi}}{12 \text{in}} \right)^2 \left( \frac{1 \text{mi}^2}{5280 \text{ft}} \right)^2 = 2.9424662104 \times 10^{-8} \text{mi}^2 = 2.9 \times 10^{-8} \text{mi}^2\);

(5) \(196935000 \text{mi}^2 \frac{1 \text{b ox}}{2.9424662104 \times 10^{-8} \text{mi}^2} = 6.69285510583 \times 10^{15} \text{boxes} = 6.7 \times 10^{15} \text{boxes}\);

(6) \(6.69285510583 \times 10^{15} \text{boxes} \frac{1566 \text{pieces}}{1 \text{b ox}} = 1.04810110957 \times 10^{19} \text{pieces} = 1.0 \times 10^{19} \text{pieces}\);

(7) \(6.022 \times 10^{23} \text{pieces} \frac{1 \text{mi}}{1.04810110957 \times 10^{19} \text{pieces}} = 57456.2888 \text{layers of boxes} = 5.7 \times 10^4 \text{boxes deep}\);

(8) \(57456.2888 \text{layers of boxes} \frac{1.515 \text{inches}}{1 \text{b ox}} \left( \frac{1 \text{foot}}{12 \text{inches}} \right) \left( \frac{1 \text{mile}}{5280 \text{feet}} \right) = 1.37383644996 \text{miles} = 1.4 \text{miles}\);

(9) \(28.09 \text{g} \); (10) \(28.09 \frac{1 \text{cm}^3}{2.33 \text{K}} = 12.0557939914 \text{cm}^3 = 12.1 \text{cm}^3\);

(11) \(12.0557939914 \text{cm}^3 \frac{1 \text{Tablespoon}}{15 \text{mL}} = 0.803719599427 \text{Tablespoons} = 0.80 \text{Tablespoons}\);
Atoms and Molecules 37

(12) yes; (13) \[
\frac{12.0557939914 \text{ cm}^3}{1 \text{ mole of atoms}} = \left( \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mole}} \right) = 2.00195848413 \times 10^{-23} \text{ cm}^3 = 2.0 \times 10^{-23} \text{ cm}^3/\text{ atoms};
\]

(14) 0.715 \(\text{cm} \times 0.795 \text{ cm} \times 0.175 \text{ cm} = \left( \frac{2.54 \text{ cm}}{1 \text{ in}} \right)^3 = \left( \frac{2.33 \text{ g}}{1 \text{ cm}^3} \right)^2 \left( \frac{1 \text{ mole}}{28.09 \text{ g}} \right) \left( \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mole}} \right) = 8.14 \times 10^{22} \text{ atoms.}

Section 2.7 Review:
(1) \(\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 194.20 \text{ u}; \text{C}_8\text{H}_10\text{O}_4 = 180.15 \text{ u}; \text{C}_12\text{H}_22\text{O}_{11} = 342.29 \text{ u}; \text{H}_2\text{O} = 18.02 \text{ u}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 180.17 \text{ u};
\)
(2) 1 mole of any compound contains \(6.022 \times 10^{23}\) molecules; (3) \(\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 194.20 \text{ g}; \text{C}_8\text{H}_10\text{O}_4 = 180.15 \text{ g}; \text{C}_12\text{H}_22\text{O}_{11} = 342.29 \text{ g}; \text{H}_2\text{O} = 18.02 \text{ g}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 180.17 \text{ g};\)
(4) \(\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 8 \text{ moles}; \text{C}_8\text{H}_10\text{O}_4 = 9 \text{ moles}; \text{C}_12\text{H}_22\text{O}_{11} = 12 \text{ moles}; \text{H}_2\text{O} = 0 \text{ moles}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 7 \text{ moles};\)
(5) \(\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 4.818 \times 10^{24} \text{ atoms H}; \text{C}_8\text{H}_10\text{O}_4 = 1.32 \times 10^{23} \text{ atoms H}; \text{H}_2\text{O} = 1.204 \times 10^{24} \text{ atoms H}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 4.818 \times 10^{24} \text{ atoms H} ; \text{C}_8\text{H}_10\text{N}_4\text{O}_2 = 64.00 \text{ g O}; \text{C}_8\text{H}_10\text{O}_4 = 176.00 \text{ g O}; \text{H}_2\text{O} = 16.00 \text{ g O}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 192.00 \text{ g O};\)
(7) \(\text{C}_8\text{H}_10\text{N}_4\text{O}_2 = \frac{56.04 \text{ g N}}{194.20 \text{ g } \text{C}_8\text{H}_10\text{N}_4\text{O}_2} \times 100 = 28.86\% \text{ N}; \text{C}_8\text{H}_10\text{O}_4 = 0\% \text{ N}; \text{C}_12\text{H}_22\text{O}_{11} = 0\% \text{ N}; \text{H}_2\text{O} = 0\% \text{ N}; \text{C}_7\text{H}_8\text{N}_4\text{O}_{12} = 31.10\% \text{ N}.
\)

Tying It All Together with a Laboratory Application:
(1) \(6.4 \times 10^{-14} \text{ cm}^3 = 6 \times 10^{-14} \text{ cm}^3\)
(2) \(1.2352 \times 10^{-12} \text{ g} = 1 \times 10^{-12} \text{ g}\)
(3) \(7.4365 \times 10^{11} \text{ u} = 7 \times 10^{11} \text{ u}\)
(4) \(6.2710 \times 10^{-15} \text{ moles} = 6 \times 10^{-15} \text{ moles}\)
(5) \(3.7764 \times 10^9 \text{ atoms} = 4 \times 10^9 \text{ atoms}\)
(6) \(1557.25 \text{ atoms} = 2000 \text{ atoms} = 2 \times 10^3 \text{ atoms}\)

SELF-TEST QUESTIONS
Multiple Choice
1. Which of the following is an incorrect symbol for an element?
2. Which of the following is an incorrect formula for a compound?
   a. CO \(_2\)  b. CO \(_3\)  c. N\(_2\)O  d. NO\(_2\)
3. Two objects have masses of 3.2 g and 0.80 g. What is the relative mass of the 3.2 g object compared to the other?
   a. 4.0 to 1  b. 2.0 to 1  c. 0.50 to 1  d. 0.25 to 1
4. Suppose the atomic weights of the elements were assigned in such a way that the atomic weight of helium, He, was 1.00 u. What would be the atomic weight of oxygen, O, in u, on this scale?
   a. 16.0  b. 8.00  c. 4.00  d. 0.250
5. What is the molecular weight of phosphoric acid, H₃PO₄, in u?
   a. 48.0  
   b. 50.0  
   c. 96.0  
   d. 98.0

6. How many neutrons are there in the nucleus of a potassium-39 atom?
   a. 1  
   b. 19  
   c. 20  
   d. 39

7. What is the mass in grams of 1.00 mole of chlorine molecules, Cl₂?
   a. 6.02 x 10²³  
   b. 71.0  
   c. 35.5  
   d. 1.18 x 10⁻²²

8. Calculate the weight percent of sulfur, S, in SO₂.
   a. 50.1  
   b. 33.3  
   c. 66.7  
   d. 25.0

Matching

Match the molecules represented on the left with the terms on the right to the correct classification given.

9.  
   a. homoatomic and diatomic
   b. homoatomic and triatomic
   c. homoatomic and polyatomic
   d. heteroatomic and diatomic
   e. heteroatomic and triatomic
   f. heteroatomic and polyatomic
   g. none of the above

10.  
11.  
12.  
13.  

Match the number given as responses to the following:

14. The number of moles of oxygen atoms in 2 moles of NO₂.  
    a. 1

15. The number of moles of NH₃ that contain 3 moles of nitrogen atoms.  
    b. 2

16. The number of moles of nitrogen atoms in one-half mole of N₂O₅.  
    c. 3

17. The number of moles of electrons in one mole of helium atoms.  
    d. 4

18. The number of moles of neutrons in one mole of ³H.  

True-False

19. In some instances, two different elements are represented by the same symbol.

20. The mass of a single atom of silicon, Si, is 28.1 g.

21. All isotopes of a specific element have the same atomic number.

22. All atoms of a specific element have the same number of protons and electrons.

23. One mole of water molecules, H₂O, contain two moles of hydrogen atoms, H.

24. 1.00 mol of sulfur, S, contains the same number of atoms as 14.0 g of nitrogen, N.

25. 6.02 x 10²³ molecules of methane, CH₄, contains 6.02 x 10²³ atoms of hydrogen.
### ANSWERS TO SELF-TEST

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