The Mole

Section 10.1 Measuring Matter
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Practice Problems
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1. Zinc (Zn) is used to form a corrosion-inhibiting surface on galvanized steel. Determine the number of Zn atoms in 2.50 mol of Zn.

$$2.50\ \cancel{\text{mol Zn}} \times \frac{6.02 \times 10^{23}\ \text{atoms Zn}}{1\ \cancel{\text{mol Zn}}}$$
$$= 1.51 \times 10^{24}\ \text{atoms of Zn}$$

2. Calculate the number of molecules in 11.5 mol of water (H_2O).

$$11.5\ \cancel{\text{mol } H_2O} \times \frac{6.02 \times 10^{23}\ \text{molecules } H_2O}{1\ \cancel{\text{mol } H_2O}}$$
$$= 6.92 \times 10^{24}\ \text{molecules of } H_2O$$

3. Silver nitrate ($AgNO_3$) is used to make several different silver halides used in photographic films. How many formula units of $AgNO_3$ are there in 3.25 mol $AgNO_3$?

$$3.25\ \cancel{\text{mol } AgNO_3} \times \frac{6.02 \times 10^{23}\ \text{formula units } AgNO_3}{1\ \cancel{\text{mol } AgNO_3}}$$
$$= 1.96 \times 10^{24}\ \text{formula units of } AgNO_3$$

4. Challenge Calculate the number of oxygen atoms in 5.0 mol of oxygen molecules. Oxygen is a diatomic molecule, O_2.

$$5.00\ \cancel{\text{mol } O_2} \times \frac{6.02 \times 10^{23}\ \cancel{\text{molecules } O^2}}{1\ \cancel{\text{mol } O_2}}$$
$$\times \frac{2\ \text{O atoms}}{\cancel{\text{molecule } O_2}} = 6.02 \times 10^{24}\ \text{atoms O}$$

5. How many moles contain each of the following?

a. 5.75×10^{24} atoms Al

$$5.75 \times 10^{24}\ \cancel{\text{atoms Al}} \times \frac{1\ \text{mol Al}}{6.02 \times 10^{23}\ \cancel{\text{atoms Al}}}$$
$$= 9.55\ \text{mol Al}$$

b. 2.50×10^{20} atoms Fe

$$2.50 \times 10^{20}\ \cancel{\text{atoms Fe}} \times \frac{1\ \text{mol Fe}}{6.02 \times 10^{23}\ \cancel{\text{atoms Fe}}}$$
$$= 4.15 \times 10^{-4}\ \text{mol Fe}$$

6. Challenge Identify the representative particle for each formula and convert the given number of representative particles to moles.

a. $3.75 + 10^{24}$ CO_2

The representative particle is a molecule.

$$3.75 \times 10^{24}\ \cancel{\text{molecules } CO_2}$$
$$\times \frac{1\ \text{mol } CO_2}{6.02 \times 10^{23}\ \cancel{\text{molecules } CO_2}} = 6.23\ \text{mol } CO_2$$

b. 3.58×10^{23} $ZnCl_2$

The representative particle is a formula unit.

$$3.58 \times 10^{23}\ \cancel{\text{formula units } ZnCl_2}$$
$$\times \frac{1\ \text{mol } ZnCl_2}{6.02 \times 10^{23}\ \cancel{\text{formula units } ZnCl_2}}$$
$$= 0.595\ \text{mol } ZnCl_2$$

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7. Explain why chemists use the mole.

Chemists use the mole because it is a convenient way of knowing how many representative particles are in a sample.

8. State the mathematical relationship between Avogadro's number and 1 mol.

One mole contains 6.02×10^{23} representative particles.

9. List the conversion factors used to convert between particles and moles.

$$\frac{6.02 \times 10^{23}\ \text{representative particles}}{1\ \text{mol}}, \quad \frac{1\text{mol}}{6.02 \times 10^{23}\ \text{representative particles}}$$

10. Explain how a mole is similar to a dozen.

The mole is a unit for counting 6.02×10^{23} representative particles. The dozen is used to count 12 items.

11. Apply How does a chemist count the number of particles in a given number of moles of a substance?

They multiply the number moles by Avogadro's number.

12. Calculate the mass in atomic mass units of 0.25 mol of carbon-12 atoms.

$$0.25 \text{ mol carbon-12} \times \frac{6.02 \times 10^{23} \text{ carbon-12 atoms}}{1 \text{ mol carbon-12}} \times \frac{12 \text{ amu}}{1 \text{ carbon-12 atom}} = 1.8 \times 10^{24} \text{ amu}$$

13. Calculate the number of representative particles of each substance.

a. 11.5 mol Ag

$$11.5\ \cancel{\text{mol Ag}} \times \frac{6.02 \times 10^{23} \text{ atoms Ag}}{1\ \cancel{\text{mol Ag}}} = 6.92 \times 10^{24} \text{ atoms Ag}$$

b. 18.0 mol H_2O

$$18.0\ \cancel{\text{mol } H_2O} \times \frac{6.02 \times 10^{23} \text{ molecules } H_2O}{1\ \cancel{\text{mol } H_2O}} = 1.08 \times 10^{25} \text{ molecules } H_2O$$

c. 0.150 mol NaCl

$$0.150\ \cancel{\text{mol NaCl}} \times \frac{6.02 \times 10^{23}\ \cancel{\text{formula}} \text{ units NaCl}}{1\ \cancel{\text{mol NaCl}}} = 9.03 \times 10^{22} \text{ formula units NaCl}$$

d. 1.35×10^{-2} mol CCH_4

$$1.35 \times 10^{-2}\ \cancel{\text{mol } CCH_4} \times \frac{6.02 \times 10^{23} \text{ molecules } CCH_4}{1\ \cancel{\text{mol } CCH_4}} = 8.13 \times 10^{21} \text{ molecules } CCH_4$$

14. Arrange these three samples from smallest to largest in terms of number of representative particles: 1.25×10^{25} atoms of zinc (Zn), 3.56 mol of iron (Fe), and 6.78×10^{22} molecules of glucose ($C_6H_{12}O_6$).

$$3.56\ \cancel{\text{mol Fe}} \times \frac{6.02 \times 10^{23} \text{ atoms Fe}}{1\ \cancel{\text{mol Fe}}} = 2.14 \times 10^{24} \text{ atoms Fe}$$

From smallest to largest: 6.78×10^{22} molecules glucose, 2.14×10^{24} atoms Fe, 1.25×10^{25} atoms Zn.

Section 10.2 Mass and the Mole

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Problem-Solving Lab

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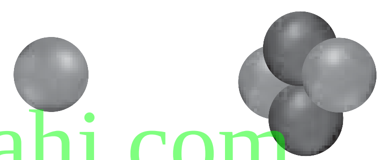

Hydrogen - 1   Helium - 4

1. Apply What is the mass in grams of one helium atom? (The mass of a neutron is approximately the same as the mass of a proton.)

Because neutrons and protons have about the same mass, treat the two neutrons and two protons in the He atom as four protons.

$$\frac{1.672 \times 10^{-24} \text{ g}}{1\ \cancel{\text{proton}}} \times \frac{4\ \cancel{\text{protons}}}{\text{He atom}} = 6.69 \times 10^{-24} \text{ g/He atom}$$

2. Draw Carbon-12 contains six protons and six neutrons. Draw the carbon-12 nucleus and calculate the mass of one atom in amu and g.

A correctly drawn model of the nucleus will have six protons and six neutrons packed in a tight spherical shape. Because neutrons and protons have about the same mass, treat the six neutrons and six protons in the C-12 atom as 12 protons.

$$\frac{1.672 \times 10^{-24} \text{ g}}{1 \text{ proton}} \times \frac{12 \text{ protons}}{\text{C-12 atom}} = 2.01 \times 10^{-23} \text{ g/C-12 atom}$$

3. Apply How many atoms of hydrogen-1 are in a 1.007-g sample? Recall that 1.007 amu is the mass of one atom of hydrogen-1. Round your answer to two significant digits.

$$1.007\ \cancel{g} \times \frac{1\ \text{H-1 atom}}{1.672 \times 10^{-24}\ \cancel{g}}$$
$$= 6.023 \times 10^{23}\ \text{H-1 atoms}$$

4. Apply If you had samples of helium and carbon that contained the same number of atoms as you calculated in Question 1, what would be the mass in grams of each sample?

$$\text{He: } 6.023 \times 10^{23}\ \cancel{\text{He atoms}} \times \frac{6.69 \times 10^{-24}\ \text{g}}{\cancel{\text{He atom}}}$$
$$= 4.03\ \text{g}$$

$$\text{C: } 6.023 \times 10^{23}\ \cancel{\text{C atoms}} \times \frac{2.01 \times 10^{-23}\ \text{g}}{\cancel{\text{C atom}}}$$
$$= 12.1\ \text{g}$$

5. Conclude What can you conclude about the relationship between the number of atoms and the mass of each sample?

The mass of one mole of any atom is the same value in grams as the mass of one atom in amu.

Practice Problems

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15. Determine the mass in grams of each of the following.

a. 3.57 mol Al

$$3.57\ \cancel{\text{mol Al}} \times \frac{26.98\ \text{g Al}}{1\ \cancel{\text{mol Al}}} = 96.3\ \text{g Al}$$

b. 42.6 mol Si

$$42.6\ \cancel{\text{mol Si}} \times \frac{28.09\ \text{g Si}}{1\ \cancel{\text{mol Si}}} = 1.20 \times 10^3\ \text{g Si}$$

16. Challenge Convert each given quantity in scientific notation to mass in grams expressed in scientific notation.

a. 3.45×10^2 mol Co

$$3.45 \times 10^2\ \cancel{\text{mol Co}} \times \frac{58.93\ \text{g Co}}{1\ \cancel{\text{mol Co}}}$$
$$= 2.03 \times 10^4\ \text{g Co}$$

b. 2.45×10^{-2} mol Zn

$$2.45 \times 10^{-2}\ \cancel{\text{mol Zn}} \times \frac{65.38\ \text{g Zn}}{1\ \cancel{\text{mol Zn}}} = 1.60\ \text{g Zn}$$

17. Determine the number of moles in each of the following.

a. 25.5 g Ag

$$25.5\ \cancel{\text{g Ag}} \times \frac{1\ \text{mol Ag}}{107.9\ \cancel{\text{g Ag}}} = 0.236\ \text{mol Ag}$$

b. 300.0 g S

$$300.0\ \cancel{\text{g S}} \times \frac{1\ \text{mol S}}{32.07\ \cancel{\text{g S}}} = 9.355\ \text{mol S}$$

18. Challenge Convert each mass to moles. Express the answer in scientific notation.

a. 1.25×10^3 g Zn

$$1.25 \times 10^3\ \cancel{\text{g Zn}} \times \frac{1\ \text{mol Zn}}{65.38\ \cancel{\text{g Zn}}} = 19.1\ \text{mol Zn}$$
$$= 1.91 \times 10^1\ \text{mol Zn}$$

b. 1.00 kg Fe

$$1.00\ \cancel{\text{kg Fe}} \times \frac{1000\ \cancel{\text{g Fe}}}{1\ \cancel{\text{kg Fe}}} \times \frac{1\ \text{mol Fe}}{55.85\ \cancel{\text{g Fe}}}$$
$$= 17.9\ \text{mol Fe} = 1.79 \times 10^1\ \text{mol Fe}$$

19. How many atoms are in each of the following samples?

a. 55.2 g Li

$$55.2\ \cancel{\text{g Li}} \times \frac{1\ \cancel{\text{mol Li}}}{6.94\ \cancel{\text{g Li}}} \times \frac{6.02 \times 10^{23}\ \text{atoms Li}}{1\ \cancel{\text{mol Li}}}$$
$$= 4.79 \times 10^{24}\ \text{atoms Li}$$

b. 0.230 g Pb

$$0.230\ \cancel{\text{g Pb}} \times \frac{1\ \cancel{\text{mol Pb}}}{207.2\ \cancel{\text{g Pb}}} \times \frac{6.02 \times 10^{23}\ \text{atoms Pb}}{1\ \cancel{\text{mol Pb}}}$$
$$= 6.68 \times 10^{20}\ \text{atoms Pb}$$

c. 11.5 g Hg

$$11.5\ \cancel{\text{g Hg}} \times \frac{1\ \cancel{\text{mol Hg}}}{200.6\ \cancel{\text{g Hg}}} \times \frac{6.02 \times 10^{23}\ \text{atoms Hg}}{1\ \cancel{\text{mol Hg}}}$$
$$= 3.45 \times 10^{22}\ \text{atoms Hg}$$

20. What is the mass in grams of each of the following?

a. 6.02×10^{24} atoms Bi

$$6.02 \times 10^{24}\ \cancel{\text{atoms Bi}} \times \frac{1\ \cancel{\text{mol Bi}}}{6.02 \times 10^{23}\ \cancel{\text{atoms Bi}}} \times \frac{209.0\ \text{g Bi}}{1\ \cancel{\text{mol Bi}}} = 2.09 \times 10^{3}\ \text{g Bi}$$

b. 1.00×10^{24} atoms Mn

$$1.00 \times 10^{24}\ \cancel{\text{atoms}}\ \text{Mn} \times \frac{1\ \cancel{\text{mol}}\ \text{Mn}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} \times \frac{54.94\ \text{g Mn}}{1\ \cancel{\text{mol}}\ \text{Mn}} = 91.3\ \text{g Mn}$$

c. 3.40×10^{22} atoms He

$$3.40 \times 10^{22}\ \cancel{\text{atoms}}\ \text{He} \times \frac{1\ \cancel{\text{mol}}\ \text{He}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} \times \frac{4.003\ \text{g He}}{1\ \cancel{\text{mol}}\ \text{He}} = 0.226\ \text{g He}$$

d. 1.50×10^{15} atoms N

$$1.50 \times 10^{15}\ \cancel{\text{atoms}}\ \text{N} \times \frac{1\ \cancel{\text{mol}}\ \text{N}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} \times \frac{14.01\ \text{g N}}{1\ \cancel{\text{mol}}\ \text{N}} = 3.49 \times 10^{-8}\ \text{g N}$$

e. 1.50×10^{15} atoms U

$$1.50 \times 10^{15}\ \cancel{\text{atoms}}\ \text{U} \times \frac{1\ \cancel{\text{mol}}\ \text{U}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} \times \frac{238.0\ \text{g U}}{1\ \cancel{\text{mol}}\ \text{U}} = 5.93 \times 10^{-7}\ \text{g U}$$

21. Challenge Convert each given mass to number of representative particles. Identify the type of representative particle, and express the number in scientific notation.

a. 4.56×10^{3} g Si

$$4.56 \times 10^{3}\ \cancel{\text{g Si}} \times \frac{1\ \cancel{\text{mol}}\ \text{Si}}{28.09\ \cancel{\text{g}}\ \text{Si}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \cancel{\text{mol}}} = 9.77 \times 10^{25}\ \text{atoms Si}$$

b. 0.120 kg Ti

$$0.120\ \cancel{\text{kg Ti}} \times \frac{1000\ \cancel{\text{g}}\ \text{Ti}}{1\ \cancel{\text{kg Ti}}} \times \frac{1\ \cancel{\text{mol}}\ \text{Ti}}{47.87\ \cancel{\text{g}}\ \text{Ti}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \cancel{\text{mol}}} = 1.51 \times 10^{24}\ \text{atoms Ti}$$

Section 10.2 Assessment

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22. Summarize in terms of particles and mass, one-mole quantities of two different monatomic elements.

Each one-mole quantity has 6.02×10^{23} particles (atoms), but they will have different masses.

23. State the conversion factors needed to convert between mass and moles of the element fluorine.

Mass-to-mole conversions use the conversion factor 1 mol/18.998 g. Moles-to-mass conversions use the conversion factor 18.998 g/1 mol.

24. Explain how molar mass relates the mass of an atom to the mass of a mole of atoms.

Molar mass is the mass in grams of one mole of any pure substance.

25. Describe the steps used to convert the mass of an element to the number of atoms of the element.

Multiply the mass by the inverse of molar mass, and then multiply by Avogadro's number.

26. Arrange these quantities from smallest to largest in terms of mass: 1.0 mol of Ar, 3.0×10^{24} atoms of Ne, and 20 g of Kr.

$$1.0\ \cancel{\text{mol}}\ \text{Ar} \times \frac{39.95\ \text{g Ar}}{1\ \cancel{\text{mol}}\ \text{Ar}} = 39.95\ \text{g Ar}$$

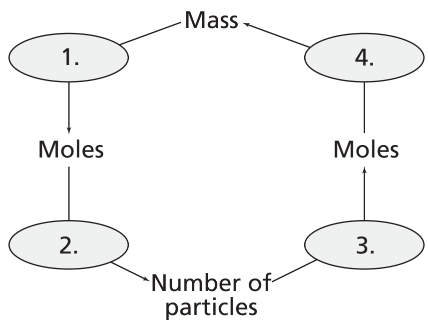
$$3.0 \times 10^{24}\ \cancel{\text{atoms}}\ \text{Ne} \times \frac{1\ \cancel{\text{mol}}\ \text{Ne}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} \times \frac{20.18\ \text{g Ne}}{1\ \cancel{\text{mol}}\ \text{Ne}} = 101\ \text{g Ne}$$

20 g Kr, 1.0 mol Ar, 3.0×10^{24} atoms Ne

27. Identify the quantity calculated by dividing the molar mass of an element by Avogadro's number.

Because the molar mass is a ratio of grams per mole and Avogadro's number is a ratio of particles per mole, dividing the molar mass of an element by Avogadro's number yields the mass of a single representative particle of that element.

28. Design a concept map that shows the conversion factors needed to convert among mass, moles, and number of particles.



Student concept maps will vary, but should show the correct sets of conversion factors needed to convert among mass, moles, and number of particles.

Section 10.3 Moles of Compounds

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Practice Problems

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29. Zinc chloride ($ZnCl_2$) is used in soldering flux, an alloy used to join two metals together. Determine the moles of Cl^- ions in 2.50 mol $ZnCl_2$.

$$2.50\ \cancel{\text{mol } ZnCl_2} \times \frac{2\text{ mol } Cl^-}{1\ \cancel{\text{mol } ZnCl_2}} = 5.00\text{ mol } Cl^-$$

30. Plants and animals depend on glucose ($C_6H_{12}O_6$) as an energy source. Calculate the number of moles of each element in 1.25 mol $C_6H_{12}O_6$.

$$1.25\ \cancel{\text{mol } C_6H_{12}O_6} \times \frac{6\text{ mol C}}{1\ \cancel{\text{mol } C_6H_{12}O_6}} = 7.50\text{ mol C}$$

$$1.25\ \cancel{\text{mol } C_6H_{12}O_6} \times \frac{12\text{ mol H}}{1\ \cancel{\text{mol } C_6H_{12}O_6}} = 15.0\text{ mol H}$$

$$1.25\ \cancel{\text{mol } C_6H_{12}O_6} \times \frac{6\text{ mol O}}{1\ \cancel{\text{mol } C_6H_{12}O_6}} = 7.50\text{ mol O}$$

31. Iron(III) sulfate [$Fe_2(SO_4)_3$] is sometimes used in the water purification process. Determine the number of moles of sulfate ions present in 3.00 mol of $Fe_2(SO_4)_3$.

$$3.00\ \cancel{\text{mol } Fe_2(SO_4)_3} \times \frac{3\text{ mol } SO_4^{2-}}{1\ \cancel{\text{mol } Fe_2(SO_4)_3}}$$

$$= 9.00\text{ mol } SO_4^{2-}$$

32. How many moles of oxygen atoms are present in 5.00 mol diphosphorus pentoxide (P_2O_5)?

$$5.00\ \cancel{\text{mol } P_2O_5} \times \frac{5\text{ mol O}}{1\ \cancel{\text{mol } P_2O_5}} = 25.0\text{ mol O}$$

33. Challenge Calculate the number of moles of hydrogen atoms in 1.15×10^1 mol of water. Express the answer in scientific notation.

$$1.15 \times 10^1\ \cancel{\text{mol } H_2O} \times \frac{2\text{ mol H}}{1\ \cancel{\text{mol } H_2O}} = 23.0\text{ mol H}$$

$$= 2.30 \times 10^1\text{ mol H}$$

34. Determine the molar mass of each ionic compound.

a. NaOH

$$1\ \cancel{\text{mol Na}} \times \frac{22.99\text{ g Na}}{1\text{ mol Na}} = 22.99\text{ g Na}$$

$$1\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = 16.00\text{ g O}$$

$$1\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\text{ mol H}} = 1.008\text{ g H}$$

molar mass NaOH = 40.00 g/mol

b. $CaCl_2$

$$1\ \cancel{\text{mol Ca}} \times \frac{40.08\text{ g Ca}}{1\ \cancel{\text{mol Ca}}} = 40.08\text{ g Ca}$$

$$2\ \cancel{\text{mol Cl}} \times \frac{35.45\text{ g Cl}}{1\ \cancel{\text{mol Cl}}} = \underline{70.90\text{ g Cl}}$$

molar mass $CaCl_2$ = 110.98 g/mol

c. $KC_2H_3O_2$

$$1\ \cancel{\text{mol K}} \times \frac{39.10\text{ g K}}{1\ \cancel{\text{mol K}}} = 39.10\text{ g K}$$

$$2\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 24.02\text{ g C}$$

$$3\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 3.024\text{ g H}$$

$$2\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{32.00\text{ g O}}$$

molar mass $KC_2H_3O_2$ = 98.14 g/mol

35. Calculate the molar mass of each molecular compound.

a. C_2H_5OH

$$2\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 24.02\text{ g C}$$

$$6\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 6.048\text{ g H}$$

$$1\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{16.00\text{ g O}}$$

molar mass C_2H_5OH = 46.07 g/mol

b. HCN

$$1\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 1.008\text{ g H}$$

$$1\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 12.01\text{ g C}$$

$$1\ \cancel{\text{mol N}} \times \frac{14.01\text{ g N}}{1\ \cancel{\text{mol N}}} = \underline{14.01\text{ g N}}$$

molar mass HCN = 27.03 g/mol

c. CCl_4

$$1\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 12.01\text{ g C}$$

$$4\ \cancel{\text{mol Cl}} \times \frac{35.45\text{ g Cl}}{1\ \cancel{\text{mol Cl}}} = \underline{141.80\text{ g Cl}}$$

molar mass CCl_4 = 153.81 g/mol

36. Challenge Identify each substance as a molecular compound or an ionic compound, and then calculate its molar mass.

a. $Sr(NO_3)_2$

ionic compound;

$$1\ \cancel{\text{mol Sr}} \times \frac{87.62\text{ g Sr}}{1\ \cancel{\text{mol Sr}}} = 87.62\text{ g Sr}$$

$$2\ \cancel{\text{mol N}} \times \frac{14.01\text{ g N}}{1\ \cancel{\text{mol N}}} = 28.02\text{ g N}$$

$$6\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{96.00\text{ g O}}$$

molar mass $Sr(NO_3)_2$ = 211.64 g/mol

b. $(NH_4)_3PO_4$

ionic compound;

$$3\ \cancel{\text{mol N}} \times \frac{14.01\text{ g N}}{1\ \cancel{\text{mol N}}} = 42.03\text{ g N}$$

$$12\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 12.096\text{ g H}$$

$$1\ \cancel{\text{mol P}} \times \frac{30.97\text{ g P}}{1\ \cancel{\text{mol P}}} = 30.97\text{ g P}$$

$$4\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{64.00\text{ g O}}$$

molar mass $(NH_4)_3PO_4$ = 149.10 g/mol

c. $C_{12}H_{22}O_{11}$

molecular compound;

$$12\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 144.12\text{ g C}$$

$$22\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 22.176\text{ g H}$$

$$11\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{176.00\text{ g O}}$$

molar mass $C_{12}H_{22}O_{11}$ = 342.30 g/mol

37. The United States chemical industry produces more sulfuric acid (H_2SO_4) in terms of mass, than any other chemical. What is the mass of 3.25 mol of H_2SO_4?

Step 1: Find the molar mass of H_2SO_4.

$$2\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 2.016\text{ g H}$$

$$1\ \cancel{\text{mol S}} \times \frac{32.07\text{ g S}}{1\ \cancel{\text{mol S}}} = 32.07\text{ g S}$$

$$4\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{64.00\text{ g O}}$$

molar mass H_2SO_4 = 98.09 g/mol

Step 2: Make mole → mass conversion.

$$3.25\ \cancel{\text{mol } H_2SO_4} \times \frac{98.09\text{ g } H_2SO_4}{1\ \cancel{\text{mol } H_2SO_4}} = 319\text{ g } H_2SO_4$$

38. What is the mass of 4.35×10^{-2} moles of zinc chloride ($ZnCl_2$)?

Step 1: Find the molar mass of $ZnCl_2$.

$$1\ \cancel{\text{mol Zn}} \times \frac{65.38\ \text{g Zn}}{1\ \cancel{\text{mol Zn}}} = 65.38\ \text{g Zn}$$

$$2\ \cancel{\text{mol Cl}} \times \frac{35.45\ \text{g Cl}}{1\ \cancel{\text{mol Cl}}} = \underline{70.90\ \text{g Cl}}$$

molar mass $ZnCl_2$ = 136.28 g/mol

Step 2: Make mole → mass conversion.

$$4.35 \times 10^{-2}\ \cancel{\text{mol ZnCl}_2} \times \frac{136.28\ \text{g ZnCl}_2}{1\ \cancel{\text{mol ZnCl}_2}}$$

$$= 5.93\ \text{g ZnCl}_2$$

39. Challenge Write the chemical formula for potassium permanganate, and then calculate the mass in grams of 2.55 mol of the compound.

Potassium permanganate has a formula of $KMnO_4$.

Step 1: Find the molar mass of $KMnO_4$.

$$1\ \cancel{\text{mol K}} \times \frac{39.10\ \text{g K}}{1\ \cancel{\text{mol K}}} = 39.10\ \text{g K}$$

$$1\ \cancel{\text{mol Mn}} \times \frac{54.94\ \text{g Mn}}{1\ \cancel{\text{mol Mn}}} = 54.94\ \text{g Mn}$$

$$4\ \cancel{\text{mol O}} \times \frac{16.00\ \text{g O}}{1\ \cancel{\text{mol O}}} = \underline{64.00\ \text{g O}}$$

molar mass $KMnO_4$ = 158.04 g/mol

Step 2: Make mole → mass conversion.

$$2.55\ \cancel{\text{mol KMnO}_4} \times \frac{158.04\ \text{g KmnO}_4}{1\ \cancel{\text{mol KmnO}_4}}$$

$$= 403\ \text{g KMnO}_4$$

40. Determine the number of moles present in each compound.

a. 22.6 g $AgNO_3$

Step 1: Find the molar mass of $AgNO_3$.

$$1\ \cancel{\text{mol Ag}} \times \frac{107.9\ \text{g Ag}}{1\ \cancel{\text{mol Ag}}} = 107.9\ \text{g Ag}$$

$$1\ \cancel{\text{mol N}} \times \frac{14.01\ \text{g N}}{1\ \cancel{\text{mol N}}} = 14.01\ \text{g N}$$

$$3\ \cancel{\text{mol}}\ \text{O} \times \frac{16.00\ \text{g O}}{1\ \cancel{\text{mol}}\ \text{O}} = \underline{48.00\ \text{g O}}$$

molar mass $AgNO_3$ = 169.9 g/mol

Step 2: Make mass → mole conversion.

$$22.6\ \cancel{\text{g AgNO}_3} \times \frac{1\ \text{mol AgNO}_3}{169.9\ \cancel{\text{g AgNO}_3}}$$

$$= 0.133\ \text{mol AgNO}_3$$

b. 6.50 g $ZnSO_4$

Step 1: Find the molar mass of $ZnSO_4$.

$$1\ \cancel{\text{mol Zn}} \times \frac{65.38\ \text{g Zn}}{1\ \cancel{\text{mol Zn}}} = 65.39\ \text{g Zn}$$

$$1\ \cancel{\text{mol S}} \times \frac{32.07\ \text{g S}}{1\ \cancel{\text{mol S}}} = 32.07\ \text{g S}$$

$$4\ \cancel{\text{mol O}} \times \frac{16.00\ \text{g O}}{1\ \cancel{\text{mol O}}} = \underline{64.00\ \text{g O}}$$

molar mass $ZnSO_4$ = 161.46 g/mol

Step 2: Make mass → mole conversion.

$$6.50\ \cancel{\text{g ZnSO}_4} \times \frac{1\ \text{mol ZnSO}_4}{161.46\ \cancel{\text{g ZnSO}_4}}$$

$$= 0.0403\ \text{mol ZnSO}_4$$

c. 35.0 g HCl

Step 1: Find the molar mass of HCl.

$$1\ \cancel{\text{mol H}} \times \frac{1.008\ \text{g H}}{1\ \cancel{\text{mol H}}} = 1.008\ \text{g H}$$

$$1\ \text{mol}\ \cancel{\text{Cl}} \times \frac{35.45\ \text{g Cl}}{1\ \cancel{\text{mol Cl}}} = \underline{35.45\ \text{g Cl}}$$

molar mass HCl = 36.46 g/mol

Step 2: Make mass → mole conversion.

$$35.0\ \cancel{\text{g HCl}} \times \frac{1\ \text{mol HCl}}{36.46\ \cancel{\text{g HCl}}} = 0.960\ \text{mol HCl}$$

41. Challenge Identify each as an ionic or molecular compound and convert the given mass to moles. Express your answers in scientific notation.

a. 2.50 kg Fe_2O_3

ionic compound; Step 1: Find the molar mass of Fe_2O_3.

$$2\ \cancel{mol\ Fe} \times \frac{55.85\ g\ Fe}{1\ \cancel{mol\ Fe}} = 111.70\ g\ Fe$$

$$3\ \cancel{mol\ O} \times \frac{16.00\ g\ O}{1\ \cancel{mol\ O}} = \underline{48.00\ g\ O}$$

molar mass Fe_2O_3 = 159.70 g/mol

Step 2: Make mass → mole conversion.

$$2.50\ \cancel{kg\ Fe_2O_3} \times \frac{1000\ \cancel{g}}{1\ \cancel{kg}} \times \frac{1\ mol\ Fe_2O_3}{159.70\ \cancel{g\ Fe_2O_3}}$$

$= 15.7\ mol\ Fe_2O_3 = 1.57 \times 10^1\ mol\ Fe_2O_3$

b. 25.4 mg $PbCl_4$

ionic compound; Step 1: Find the molar mass of $PbCl_4$.

$$1\ \cancel{mol\ Pb} \times \frac{207.2\ g\ Pb}{1\ \cancel{mol\ Pb}} = 207.2\ g\ Pb$$

$$4\ \cancel{mol\ Cl} \times \frac{35.45\ g\ Cl}{1\ \cancel{mol\ Cl}} = \underline{141.80\ g\ Cl}$$

molar mass $PbCl_4$ = 349.0 g/mol

Step 2: Make mass → mole conversion.

$$25.4\ \cancel{mg\ PbCl_4} \times \frac{1\ \cancel{g}}{1000\ \cancel{mg}} \times \frac{1\ mol\ PbCl_4}{349.0\ \cancel{g\ PbCl_4}}$$

$= 7.28 \times 10^{-5}\ mol\ PbCl_4$

42. Ethanol (C_2H_5OH), a domestically produced fuel source, is often blended with gasoline. A sample of ethanol has a mass of 45.6 g.

a. How many carbon atoms does the sample contain?

Step 1: Find the molar mass of C_2H_5OH.

$$2\ \cancel{mol\ C} \times \frac{12.01\ g\ C}{1\ \cancel{mol\ C}} = 24.02\ g$$

$$6\ \cancel{mol\ H} \times \frac{1.008\ g\ H}{1\ \cancel{mol\ H}} = 6.048\ g$$

$$1\ \cancel{mol\ O} \times \frac{16.00\ g\ O}{1\ \cancel{mol\ O}} = \underline{16.00\ g}$$

molar mass C_2H_5OH = 46.07 g/mol

Step 2: Make mass → mole conversion.

$$45.6\ \cancel{g\ C_2H_5OH} \times \frac{1\ mol\ C_2H_5OH}{46.07\ \cancel{g\ C_2H_5OH}}$$

$= 0.990\ mol\ C_2H_5OH$

Step 3: Make mole → molecule conversion.

$$0.990\ \cancel{mol}\ C_2H_5OH \times \frac{6.02 \times 10^{23}\ molecules}{1\ \cancel{mol}}$$

$= 5.96 \times 10^{23}\ molecules\ C_2H_5OH$

Step 4: Determine the number of carbon atoms.

$$5.96 \times 10^{23}\ \cancel{molecules\ C_2H_5OH} \times \frac{2\ C\ atoms}{1\ \cancel{molecule\ C_2H_5OH}} = 1.19 \times 10^{24}\ C\ atoms$$

b. How many hydrogen atoms are present?

$$5.96 \times 10^{23}\ \cancel{molecules\ C_2H_5OH} \times \frac{6\ H\ atoms}{1\ \cancel{molecule\ C_2H_5OH}} = 3.58 \times 10^{24}\ H\ atoms$$

c. How many oxygen atoms are present?

$$5.96 \times 10^{23}\ \cancel{molecules\ C_2H_5OH} \times \frac{1\ O\ atoms}{1\ \cancel{molecule\ C_2H_5OH}} = 5.96 \times 10^{23}\ O\ atoms$$

43. A sample of sodium sulfite (Na_2SO_3) has a mass of 2.25 g.

a. How many Na^+ ions are present?

Step 1: Find the molar mass of Na_2SO_3

$$2\ \cancel{mol\ Na} \times \frac{22.99\ g\ Na}{1\ \cancel{mol\ Na}} = 45.98\ g$$

$$1\ \cancel{mol\ S} \times \frac{32.07\ g\ S}{1\ \cancel{mol\ S}} = 32.07\ g$$

$$3\ \cancel{mol\ O} \times \frac{16.00\ g\ O}{1\ \cancel{mol\ O}} = \underline{48.00\ g}$$

molar mass Na_2SO_3 = 126.05 g/mol

Step 2: Make mass → mole conversion

$$2.25\ \cancel{g\ Na_2SO_3} \times \frac{1\ mol\ Na_2SO_3}{126.05\ \cancel{g\ Na_2SO_3}}$$

$= 0.0179\ mol\ Na_2SO_3$

Step 3: Make mole → formula unit conversion

$$0.0179\ \cancel{mol}\ Na_2SO_3 \times \frac{6.02 \times 10^{23}\ formula\ units}{1\ \cancel{mol}}$$

$= 1.08 \times 10^{22}$ formula units Na_2SO_3

Step 4: Determine the number of Na^+ ions.

$$1.08 \times 10^{22} \cancel{\text{formula units } Na_2SO_3} \times \frac{2\ Na^+ \text{ ions}}{1 \cancel{\text{formula unit } Na_2SO_3}} = 2.16 \times 10^{22}\ Na^+ \text{ ions}$$

b. How many SO_3^{2-} ions are present?

$$1.08 \times 10^{22} \cancel{\text{formula units } Na_2SO_3} \times \frac{2\ SO_3^{2-} \text{ ions}}{1 \cancel{\text{formula unit } Na_2SO_3}} = 1.08 \times 10^{22}\ SO_3^{2-} \text{ ions}$$

c. What is the mass in grams of one formula unit of Na_2SO_3?

$$\frac{126.08 \text{ g } Na_2SO_3}{1 \cancel{\text{mol } Na_2SO_3}} \times \frac{1 \cancel{\text{mol } Na_2SO_3}}{6.02 \times 10^{23} \text{ formula units}}$$

$$= 2.09 \times 10^{-22} \text{ g } Na_2SO_3\text{/formula unit}$$

44. A sample of carbon dioxide (CO_2) has a mass of 52.0 g.

a. How many carbon atoms are present?

Step 1: Find the molar mass of CO_2.

$$1 \cancel{\text{mol C}} \times \frac{12.01 \text{ g C}}{1 \cancel{\text{mol C}}} = 12.01 \text{ g}$$

$$2 \cancel{\text{mol O}} \times \frac{16.00 \text{ g O}}{1 \cancel{\text{mol O}}} = \underline{32.00 \text{ g}}$$

molar mass CO_2 = 44.01 g/mol

Step 2: Make mass → mole conversion.

$$52.0 \cancel{\text{g } CO_2} \times \frac{1 \text{ mol } CO_2}{44.01 \cancel{\text{g } CO_2}} = 1.18 \text{ mol } CO_2$$

Step 3: Make mole → molecule conversion.

$$1.18 \cancel{\text{mol}}\ CO_2 \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mol}}}$$

$$= 7.11 \times 10^{23} \text{ molecules } CO_2$$

Step 4: Determine the number of carbon atoms.

$$7.11 \times 10^{23} \cancel{\text{molecules } CO_2} \times \frac{1 \text{ C atom}}{1 \cancel{\text{molecule } CO_2}}$$

$$= 7.11 \times 10^{23} \text{ C atoms}$$

b. How many oxygen atoms are present?

$$7.11 \times 10^{23} \cancel{\text{molecules } CO_2} \times \frac{2 \text{ O atoms}}{1 \cancel{\text{molecule } CO_2}}$$

$$= 1.42 \times 10^{24} \text{ O atoms}$$

c. What is the mass in grams of one molecule of CO_2?

$$\frac{44.01 \text{ g } CO_2}{1 \cancel{\text{mol}}\ CO_2} \times \frac{1 \cancel{\text{mol}}}{6.02 \times 10^{23} \text{ molecules}}$$

$$= 7.31 \times 10^{-23} \text{ g } CO_2\text{/molecule}$$

45. What mass of sodium chloride (NaCl) contains 4.59×10^{24} formula units?

Step 1: Find the number of moles of NaCl.

$$4.59 \times 10^{24} \cancel{\text{formula units}} \text{ NaCl} \times \frac{1 \text{ mol NaCl}}{6.02 \times 10^{23} \cancel{\text{formula units}}} = 7.62 \text{ mol NaCl}$$

Step 2: Find the molar mass of NaCl.

$$1 \cancel{\text{mol Na}} \times \frac{22.99 \text{ g Na}}{1 \cancel{\text{mol Na}}} = 22.99 \text{ g}$$

$$1 \cancel{\text{mol Cl}} \times \frac{35.45 \text{ g Cl}}{1 \cancel{\text{mol Cl}}} = \underline{35.45 \text{ g}}$$

molar mass NaCl = 58.44 g/mol

Step 3: Make mole → mass conversion.

$$7.62 \cancel{\text{mol NaCl}} \times \frac{58.44 \text{ g NaCl}}{1 \cancel{\text{mol NaCl}}} = 445 \text{ g NaCl}$$

46. Challenge A sample of silver chromate has a mass of 25.8 g.

a. Write the formula for silver chromate.

The formula for silver chromate is Ag_2CrO_4.

b. How many cations are present in the sample?

Step 1: Find the molar mass of Ag_2CrO_4.

$$2 \cancel{\text{mol Ag}} \times \frac{107.9 \text{ g Ag}}{1 \cancel{\text{mol Ag}}} = 215.8 \text{ g}$$

$$1 \cancel{\text{mol Cr}} \times \frac{52.00 \text{ g Cr}}{1 \cancel{\text{mol Cr}}} = 52.00 \text{ g}$$

$$4 \cancel{\text{mol O}} \times \frac{16.00 \text{ g O}}{1 \cancel{\text{mol O}}} = \underline{64.00 \text{ g}}$$

molar mass Ag_2CrO_4 = 331.8 g/mol

Step 2: Make mass → mole conversion.

$$25.8\ \cancel{g\ Ag_2CrO_4} \times \frac{1\ mol\ Ag_2CrO_4}{331.8\ \cancel{g\ Ag_2CrO_4}}$$

$= 0.0778\ mol\ Ag_2CrO_4$

Step 3: Make mole → formula unit conversion.

$$0.0778\ \cancel{mol}\ Ag_2CrO_4 \times \frac{6.02 \times 10^{23}\ formula\ units}{1\ \cancel{mol}}$$

$= 4.68 \times 10^{22}$ formula units Ag_2CrO_4

Step 4: Determine the number of cations (Ag^+ ions):

$$4.68 \times 10^{22}\ \cancel{formula\ units}\ Ag_2CrO_4 \times \frac{2\ Ag^+\ ions}{1\ formula\ unit\ Ag_2CrO_4} = 9.36 \times 10^{22}\ Ag^+\ ions$$

c. How many anions are present in the sample?

The anions are CrO_4^{2-} ions:

$$4.68 \times 10^{22}\ \cancel{formula\ units}\ Ag_2CrO_4 \times \frac{1\ CrO_4^{2+}\ ions}{1\ \cancel{formula\ unit}\ Ag_2CrO_4}$$

$= 4.68 \times 10^{22}\ CrO_4^{2-}$ ions

d. What is the mass in grams of one formula unit of silver chromate?

$$\frac{331.8\ g\ Ag_2CrO_4}{1\ \cancel{mol\ Ag_2CrO_4}} \times \frac{1\ \cancel{mol\ Ag_2CrO_4}}{6.02 \times 10^{23}\ formula\ units}$$

$= 5.51 \times 10^{-22}\ g\ Ag_2CrO_4$/formula unit

Section 10.3 Assessment

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47. Describe how to determine the molar mass of a compound.

Multiply the mass of one mole of each element by the ratio of that element to one mole of the compound. Add the resulting masses.

48. Identify the conversion factors needed to convert between the number of moles and the mass of a compound.

$$\frac{\text{Number of grams}}{1\ \text{mol}}, \frac{1\ \text{mol}}{\text{number of grams}}$$

49. Explain how you can determine the number of atoms or ions in a given mass of a compound.

Convert the mass to moles, multiply the number of moles by the ratio of the number of atoms or ions to one mole, multiply by Avogadro's number.

50. Apply How many moles of K, C, and O atoms are there in 1 mol of $K_2C_2O_4$?

2 mol K, 2 mol C, 4 mol O

51. Calculate the molar mass of $MgBr_2$.

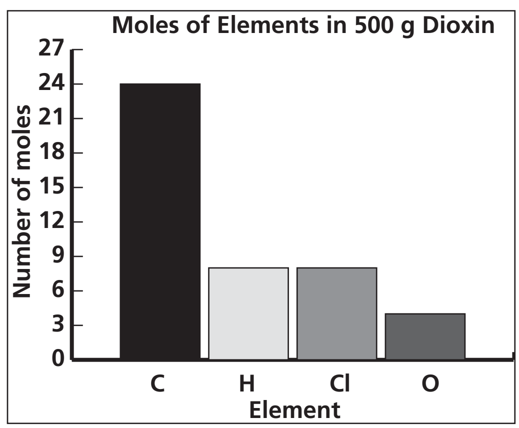
molar mass $MgBr_2$ = 24.305 g/mol × 2(79.904 g/mol) = 184.113 g/mol

52. Calculate Calcium carbonate is the calcium source for many vitamin tablets. The recommended daily allowance of calcium is 1000 mg of Ca^{2+} ions. How many moles of Ca^{2+} does 1000 mg represent?

$$1000\ \cancel{mg\ Ca^{2+}} \times \frac{1\ \cancel{g\ Ca^{2+}}}{10^3\ \cancel{mg\ Ca^{2+}}} \times \frac{1\ mol\ Ca^{2+}}{40.08\ \cancel{g\ Ca^{2+}}}$$

$= 0.02\ mol\ Ca^{2+}$

53. Design a bar graph that will show the number of moles of each element present in 500 g of a particular form of dioxin ($C_{12}H_4C_{14}O_2$), a powerful poison.



$$12\ mol\ C \times \frac{12.01\ g\ C}{1\ mol\ C} = 144.12\ g\ C$$

$$4\ mol\ H \times \frac{1.008\ g\ H}{1\ mol\ H} = 4.032\ g\ H$$

$$4\ mol\ Cl \times \frac{35.45\ g\ Cl}{1\ mol\ Cl} = 141.80\ g\ Cl$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{32.00 \text{ g O}}$$

molar mass = 321.96 g/mol

$$500 \cancel{\text{g } C_{12}H_4Cl_4O_2} \times \frac{1 \text{ mol } C_{12}H_4Cl_4O_2}{321.96 \cancel{\text{g } C_{12}H_4Cl_4O_2}}$$

$$= 2 \text{ mol } C_{12}H_4Cl_4O_2$$

Student bar graphs should show the following molar quantities:

$$2 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2 \times \frac{12 \text{ mol C}}{1 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2} = 24 \text{ mol C}$$

$$2 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2 \times \frac{4 \text{ mol H}}{1 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2} = 8 \text{ mol H}$$

$$2 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2 \times \frac{4 \text{ mol Cl}}{1 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2} = 8 \text{ mol Cl}$$

$$2 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2 \times \frac{2 \text{ mol O}}{1 \cancel{\text{mol}} \ C_{12}H_4Cl_4O_2} = 4 \text{ mol O}$$

Section 10.4 Emperical and Molecular Formulas

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Practice Problems

pages 344–350

54. What is the percent composition of phosphoric acid (H_3PO_4)?

Steps 1 and 2: Assume 1 mole; calculate molar mass of H_3PO_4.

$$3 \cancel{\text{mol}} \text{ H} \times \frac{1.008 \text{ g H}}{1 \cancel{\text{mol}} \text{ H}} = 3.024 \text{ g H}$$

$$1 \cancel{\text{mol}} \text{ P} \times \frac{30.97 \text{ g P}}{1 \cancel{\text{mol}} \text{ P}} = 30.97 \text{ g P}$$

$$4 \cancel{\text{mol}} \text{ O} \times \frac{16.00 \text{ g O}}{1 \cancel{\text{mol}} \text{ O}} = \underline{64.00 \text{ g O}}$$

molar mass H_3PO_4 = 97.99 g/mol

Step 3: Determine percent by mass of each element.

$$\text{percent H} = \frac{3.024 \cancel{\text{g H}}}{97.99 \cancel{\text{g } H_3PO_4}} \times 100 = 3.08\% \text{ H}$$

$$\text{percent P} = \frac{30.97 \cancel{\text{g P}}}{97.99 \cancel{\text{g } H_3PO_4}} \times 100 = 31.61\% \text{ P}$$

$$\text{percent O} = \frac{64.00 \cancel{\text{g O}}}{97.99 \cancel{\text{g } H_3PO_4}} \times 100 = 65.31\% \text{ O}$$

55. Which has the larger percent by mass of sulfur, H_2SO_3 or $H_2S_2O_8$?

Steps 1 and 2: Assume 1 mole; calculate molar mass of H_2SO_3.

$$2 \cancel{\text{mol}} \text{ H} \times \frac{1.008 \text{ g H}}{1 \cancel{\text{mol}} \text{ H}} = 2.016 \text{ g H}$$

$$1 \cancel{\text{mol}} \text{ S} \times \frac{32.06 \text{ g S}}{1 \cancel{\text{mol}} \text{ S}} = 32.06 \text{ g S}$$

$$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \cancel{\text{mol}} \text{ O}} = \underline{48.00 \text{ g O}}$$

molar mass H_2SO_3 = 82.08 g/mol

Step 3: Determine percent by mass of S.

$$\text{percent S} = \frac{32.06 \cancel{\text{g S}}}{82.08 \cancel{\text{g } H_2SO_3}} \times 100 = 39.06\% \text{ S}$$

Repeat steps 1 and 2 for $H_2S_2O_8$. Assume 1 mole; calculate molar mass of $H_2S_2O_8$.

$$2 \cancel{\text{mol}} \text{ H} \times \frac{1.008 \text{ g H}}{1 \cancel{\text{mol}} \text{ H}} = 2.016 \text{ g}$$

$$2 \cancel{\text{mol}} \text{ S} \times \frac{32.06 \text{ g S}}{1 \cancel{\text{mol}} \text{ S}} = 64.12 \text{ g}$$

$$8 \cancel{\text{mol}} \text{ O} \times \frac{16.00 \text{ g O}}{1 \cancel{\text{mol}} \text{ O}} = \underline{128.00 \text{ g}}$$

molar mass $H_2S_2O_8$ = 194.14 g/mol

Step 3: Determine percent by mass of S.

$$\text{percent S} = \frac{64.12 \cancel{\text{g S}}}{194.14 \cancel{\text{g } H_2SO_3}} \times 100$$

$$= 33.03\% \text{ S}$$

H_2SO_3 has a larger percent by mass of S.

56. Calcium chloride ($CaCl_2$) is sometimes used as a de-icer. Calculate the percent by mass of each element in $CaCl_2$.

Steps 1 and 2: Assume 1 mole; calculate molar mass of $CaCl_2$.

$$1 \cancel{\text{mol}} \text{ Ca} \times \frac{40.08 \text{ g Ca}}{1 \cancel{\text{mol}} \text{ Ca}} = 40.08 \text{ g Ca}$$

$$2 \cancel{\text{mol}} \text{ Cl} \times \frac{35.45 \text{ g Cl}}{1 \cancel{\text{mol}} \text{ Cl}} = \underline{70.90 \text{ g Cl}}$$

molar mass $CaCl_2$ = 110.98 g/mol

Step 3: Determine percent by mass of each element.

$$\text{percent Ca} = \frac{40.08\ \cancel{g\ Ca}}{110.98\ \cancel{g\ CaCl_2}} \times 100$$

= 36.11% Ca

$$\text{percent Cl} = \frac{70.90\ \cancel{g\ Cl}}{110.98\ \cancel{g\ CaCl_2}} \times 100$$

= 63.89% Cl

57. Challenge Sodium sulfate is used in the manufacture of detergents.

a. Identify each of the component elements of sodium sulfate, and write the compound's chemical formula.

sodium, sulfur, and oxygen; Na_2SO_4

b. Identify the compound as ionic or covalent.

ionic

c. Calculate the percent by mass of each element in sodium sulfate.

Steps 1 and 2: Assume 1 mole; calculate molar mass of Na_2SO_4.

$$2\ \cancel{mol}\ Na\ 3\times \frac{22.99\ g\ Na}{1\ \cancel{mol}\ Na} = 45.98\ g\ Na$$

$$1\ \cancel{mol}\ S \times \frac{32.07\ g\ S}{1\ \cancel{mol}\ S} = 32.07\ g\ S$$

$$4\ \cancel{mol}\ O \times \frac{16.00\ g\ O}{1\ \cancel{mol}\ O} = \underline{64.00\ g\ O}$$

$$\text{molar mass } Na_2SO_4 = 142.05\ g/mol$$

Step 3: Determine percent by mass of each element.

$$\text{percent Na} = \frac{45.98\ \cancel{g\ Na}}{142.05\ \cancel{g\ NaSO_4}} \times 100$$

= 32.37% Na

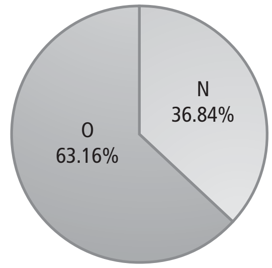
$$\text{percent S} = \frac{32.07\ \cancel{g\ S}}{142.05\ \cancel{g\ NaSO_4}} \times 100$$

= 22.58% S

$$\text{percent O} = \frac{64.00\ \cancel{g\ O}}{142.05\ \cancel{g\ NaSO_4}} \times 100$$

= 45.05% O

58. The circle graph at the right gives the percent composition for a blue solid. What is the empirical formula for this solid?



Step 1: Assume 100 g sample; calculate moles of each element.

$$36.84\ \cancel{g\ N} \times \frac{1\ mol\ N}{14.01\ \cancel{g\ N}} = 2.630\ mol\ N$$

$$63.16\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 3.948\ mol\ O$$

Step 2: Calculate mole ratios.

$$\frac{2.630\ mol\ N}{2.630\ mol\ N} = \frac{1.000\ mol\ N}{1.000\ mol\ N} = \frac{1\ mol\ N}{1\ mol\ N}$$

$$\frac{3.948\ mol\ O}{2.630\ mol\ O} = \frac{1.500\ mol\ O}{1.000\ mol\ N} = \frac{1.5\ mol\ O}{1\ mol\ N}$$

The simplest ratio is 1 mol N: 1.5 mol O.

Step 3: Convert decimal fraction to whole number.

In this case, multiply by 2 because 1.5 × 2 = 3. Therefore, the empirical formula is N_2O_3.

59. Determine the empirical formula for a compound that contains 35.98% aluminum and 64.02% sulfur.

Step 1: Assume 100 g sample; calculate moles of each element.

$$35.98\ \cancel{g\ Al} \times \frac{1\ mol\ Al}{26.98\ \cancel{g\ Al}} = 1.334\ mol\ Al$$

$$64.02\ \cancel{g\ S} \times \frac{1\ mol\ S}{32.06\ \cancel{g\ S}} = 1.996\ mol\ S$$

Step 2: Calculate mole ratios.

$$\frac{1.334\ mol\ Al}{1.334\ mol\ Al} = \frac{1.000\ mol\ Al}{1.000\ mol\ Al} = \frac{1\ mol\ Al}{1\ mol\ Al}$$

$$\frac{1.996\ mol\ S}{1.334\ mol\ Al} = \frac{1.500\ mol\ S}{1.000\ mol\ Al} = \frac{1.5\ mol\ S}{1\ mol\ Al}$$

The simplest ratio is 1 mol Al: 1.5 mol S.

Step 3: Convert decimal fraction to whole number.

In this case, multiply by 2 because 1.5 × 2 = 3. Therefore, the empirical formula is Al_2S_3.

60. Propane is a hydrocarbon, a compound composed only of carbon and hydrogen. It is 81.82% carbon and 18.18% hydrogen. What is the empirical formula?

Step 1: Assume 100 g sample; calculate moles of each element.

$$81.82\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 6.813\ mol\ C$$

$$18.18\ \cancel{g\ H} \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 18.04\ mol\ H$$

Step 2: Calculate mole ratios.

$$\frac{6.183\ mol\ C}{6.183\ mol\ C} = \frac{1.000\ mol\ C}{1.000\ mol\ C} = \frac{1\ mol\ C}{1\ mol\ C}$$

$$\frac{18.04\ mol\ H}{6.183\ mol\ C} = \frac{2.649\ mol\ H}{1.000\ mol\ C} = \frac{2.65\ mol\ H}{1\ mol\ C}$$

The simplest ratio is 1 mol: 2.65 mol H.

Step 3: Convert decimal fraction to whole number.

In this case, multiply by 3 because 2.65 × 3 = 7.95 ≈ 8. Therefore, the empirical formula is C_3H_8.

61. Challenge Aspirin is the world's most-often used medication. The chemical analysis of aspirin indicates that the molecule is 60.00% carbon, 4.44% hydrogen, and 35.56% oxygen. Determine the empirical formula for aspirin.

Step 1: Assume 100 g sample; calculate moles of each element.

$$60.00\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 5.00\ mol\ C$$

$$4.44\ \cancel{g\ H} \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 4.40\ mol\ H$$

$$35.56\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 2.22\ mol\ O$$

Step 2: Calculate mole ratios.

$$\frac{5.00\ mol\ C}{2.22\ mol\ O} = \frac{2.25\ mol\ C}{1.00\ mol\ O} = \frac{2.25\ mol\ C}{1\ mol\ O}$$

$$\frac{4.40\ mol\ C}{2.22\ mol\ O} = \frac{1.98\ mol\ H}{1.00\ mol\ O} = \frac{2\ mol\ H}{1\ mol\ O}$$

$$\frac{2.22\ mol\ O}{2.22\ mol\ O} = \frac{1.00\ mol\ O}{1.00\ mol\ O} = \frac{1\ mol\ O}{1\ mol\ O}$$

The simplest ratio is 2.25 mol C: 2 mol H: 1 mol O.

Step 3: Convert decimal fraction to whole number.

In this case, multiply by 4 because 2.25 × 4 = 9. Therefore, the empirical formula is $C_9H_8O_4$.

62. A compound was found to contain 49.98 g of carbon and 10.47 g of hydrogen. The molar mass of the compound is 58.12 g/mol. Determine the molecular formula.

Step 1: Assume 100 g sample; calculate moles of each element.

$$49.98\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 4.162\ mol\ C$$

$$10.47\ \cancel{g\ H} \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 10.39\ mol\ H$$

Step 2: Calculate mole ratios.

$$\frac{4.162\ mol\ C}{4.162\ mol\ C} = \frac{1.000\ mol\ C}{1.000\ mol\ C} = \frac{1\ mol\ C}{1\ mol\ C}$$

$$\frac{10.39\ mol\ H}{4.162\ mol\ C} = \frac{2.50\ mol\ H}{1.000\ mol\ C} = \frac{2.5\ mol\ H}{1\ mol\ C}$$

The simplest ratio is 1 mol C: 2.5 mol H.

Because 2.5 × 2 = 5, the empirical formula is C_2H_5.

Step 3: Calculate the molar mass of the empirical formula.

$$2\ \cancel{mol\ C} \times \frac{12.01\ g\ C}{1\ \cancel{mol\ C}} = 24.02\ g$$

$$5\ \cancel{mol\ H} \times \frac{1.008\ g\ H}{1\ \cancel{mol\ H}} = \underline{5.040\ g}$$

molar mass C_2H_5 = 29.06 g/mol

Step 4: Determine whole number multiplier.

$$\frac{58.12\ \cancel{g/mol}}{29.06\ \cancel{g/mol}} = 2.000$$

The molecular formula is C_4H_{10}.

63. A colorless liquid composed of 46.68% nitrogen and 53.32% oxygen has a molar mass of 60.01 g/mol. What is the molecular formula?

Step 1: Assume 100 g sample; calculate moles of each element.

$$46.68\ \cancel{\text{g N}} \times \frac{1\text{ mol N}}{14.01\ \cancel{\text{g N}}} = 3.332\text{ mol N}$$

$$53.32\ \cancel{\text{g O}} \times \frac{1\text{ mol O}}{16.00\ \cancel{\text{g O}}} = 3.333\text{ mol O}$$

Step 2: Calculate mole ratios.

$$\frac{3.332\text{ mol N}}{3.332\text{ mol N}} = \frac{1.000\text{ mol N}}{1.000\text{ mol N}} = \frac{1\text{ mol N}}{1\text{ mol N}}$$

$$\frac{3.333\text{ mol O}}{3.332\text{ mol N}} = \frac{1.000\text{ mol O}}{1.000\text{ mol N}} = \frac{1\text{ mol O}}{1\text{ mol N}}$$

The simplest ratio is 1 mol N: 1 mol O.

The empirical formula is NO.

Step 3: Calculate the molar mass of the empirical formula.

$$1\ \cancel{\text{mol N}} \times \frac{14.01\text{ g N}}{1\ \cancel{\text{mol N}}} = 14.01\text{ g}$$

$$1\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{16.00\text{ g}}$$

molar mass NO = 30.01 g/mol

Step 4: Determine whole number multiplier.

$$\frac{60.01\ \cancel{\text{g/mol}}}{30.01\ \cancel{\text{g/mol}}} = 2.000$$

The molecular formula is N_2O_2.

64. When an oxide of potassium is decomposed, 19.55 g K and 4.00 g O are obtained. What is the empirical formula for the compound?

Step 1: Calculate moles of each element.

$$19.55\ \cancel{\text{g K}} \times \frac{1\text{ mol K}}{39.10\ \cancel{\text{g K}}} = 0.5000\text{ mol K}$$

$$4.00\ \cancel{\text{g O}} \times \frac{1\text{ mol O}}{16.00\ \cancel{\text{g O}}} = 0.250\text{ mol O}$$

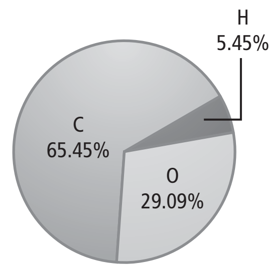
Step 2: Calculate mole ratios.

$$\frac{0.5000\text{ mol K}}{0.250\text{ mol O}} = \frac{2.00\text{ mol K}}{1.00\text{ mol O}} = \frac{2\text{ mol K}}{1\text{ mol O}}$$

$$\frac{0.250\text{ mol O}}{0.250\text{ mol O}} = \frac{1.00\text{ mol O}}{1.00\text{ mol O}} = \frac{1\text{ mol O}}{1\text{ mol O}}$$

The simplest ratio is 2 mol K: 1 mol O.
The empirical formula is K_2O.

65. Challenge Analysis of a chemical used in photographic developing fluid yielded the percent composition data shown in the circle graph to the right. If the chemical's molar mass is 110.0 g/mol, what is its molecular formula?



Step 1: Assume 100 g sample; calculate moles of each element.

$$65.45\ \cancel{\text{g C}} \times \frac{1\text{ mol C}}{12.04\ \cancel{\text{g C}}} = 5.450\text{ mol C}$$

$$5.45\ \cancel{\text{g H}} \times \frac{1\text{ mol H}}{1.008\ \cancel{\text{g H}}} = 5.41\text{ mol H}$$

$$29.09\ \cancel{\text{g O}} \times \frac{1\text{ mol O}}{16.00\ \cancel{\text{g O}}} = 1.818\text{ mol O}$$

Step 2: Calculate mole ratios.

$$\frac{5.450\text{ mol C}}{1.818\text{ mol O}} = \frac{3.000\text{ mol C}}{1.000\text{ mol O}} = \frac{3\text{ mol C}}{1\text{ mol O}}$$

$$\frac{5.41\text{ mol H}}{1.818\text{ mol O}} = \frac{2.97\text{ mol H}}{1.00\text{ mol O}} = \frac{3\text{ mol H}}{1\text{ mol O}}$$

$$\frac{1.818\text{ mol O}}{1.818\text{ mol O}} = \frac{1.000\text{ mol O}}{1.000\text{ mol O}} = \frac{1\text{ mol O}}{1\text{ mol O}}$$

The empirical formula is C_3H_3O.

Step 3: Calculate the molar mass of the empirical formula.

$$3\ \cancel{\text{mol C}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol C}}} = 36.03\text{ g C}$$

$$3\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = 3.024\text{ g H}$$

$$1\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{16.00\text{ g O}}$$

molar mass C_3H_3O = 55.05 g/mol

Step 4: Determine whole number multiplier.

$$\frac{110.0\text{ g/mol}}{55.05\text{ g.nik}} = 1.998\text{, or }2$$

The molecular formula is $C_6H_6O_2$.

66. Challenge Analysis of the pain reliever morphine yielded the data shown in the table. Determine the empirical formula of morphine.

Element	Mass (g)
carbon	17.900
hydrogen	1.680
oxygen	4.225
nitrogen	1.228

Step 1: Calculate moles of each element.

$$17.900\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 1.490\ mol\ C$$

$$1.680\ \cancel{g\ H} \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 1.667\ mol\ H$$

$$4.225\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 0.2641\ mol\ O$$

$$1.228\ \cancel{g\ N} \times \frac{1\ mol\ N}{14.01\ \cancel{g\ N}} = 0.08765\ mol\ N$$

Step 2: Calculate mole ratios.

$$\frac{0.08765\ mol\ N}{0.08765\ mol\ N} = \frac{1.000\ mol\ N}{1.000\ mol\ N} = \frac{1\ mol\ N}{1\ mol\ N}$$

$$\frac{1.490\ mol\ C}{0.08765\ mol\ N} = \frac{17.00\ mol\ C}{1.000\ mol\ N} = \frac{17\ mol\ C}{1\ mol\ N}$$

$$\frac{1.667\ mol\ H}{0.08765\ mol\ N} = \frac{19.02\ mol\ H}{1.000\ mol\ N} = \frac{19\ mol\ H}{1\ mol\ N}$$

$$\frac{0.2641\ mol\ O}{0.08765\ mol\ N} = \frac{3.013\ mol\ O}{1.000\ mol\ N} = \frac{3\ mol\ O}{1\ mol\ N}$$

The simplest ratio is 17 mol C: 19 mol H: 3 mol O: 1 mol N.

The empirical formula is $C_{17}H_{19}O_3N$.

Section 10.4 Assessment

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67. Assess A classmate tells you that experimental data shows a compound's molecular formula to be 2.5 times its empirical formula. Is he correct? Explain.

No, he is in error because the molecular formula must be a whole-number multiple of the empirical formula.

68. Calculate Analysis of a compound composed of iron and oxygen yields 174.86 g of Fe and 75.14 g of O. What is the empirical formula for this compound?

Step 1: Calculate moles of each element

$$174.86\ \cancel{g\ Fe} \times \frac{1\ mol\ Fe}{55.85\ \cancel{g\ Fe}} = 3.131\ mol\ Fe$$

$$75.14\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 4.696\ mol\ O$$

Step 2: Calculate mole ratios.

$$\frac{3.131\ mol\ Fe}{3.131\ mol\ Fe} = \frac{1.000\ mol\ Fe}{1.000\ mol\ Fe} = \frac{1\ mol\ Fe}{1\ mol\ Fe}$$

$$\frac{4.696\ mol\ O}{3.131\ mol\ Fe} = \frac{1.500\ mol\ O}{1.000\ mol\ Fe} = \frac{1.5\ mol\ O}{1\ mol\ Fe}$$

The simplest ratio is 1 mol Fe: 1.5 mol O.

Because 1.5 × 2 = 3, the empirical formula is Fe_2O_3.

69. Calculate An oxide of aluminum contains 0.545 g of Al and 0.485 g of O. Find the empirical formula for the oxide.

Step 1: Calculate moles of each element.

$$0.545\ \cancel{g\ Al} \times \frac{1\ mol\ Al}{26.98\ \cancel{g\ Al}} = 0.0202\ mol\ Al$$

$$0.485\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 0.0303\ mol\ O$$

Step 2: Calculate mole ratios.

$$\frac{0.0202\ mol\ Al}{0.0202\ mol\ Al} = \frac{1.00\ mol\ Al}{1.00\ mol\ Al} = \frac{1\ mol\ Al}{1\ mol\ Al}$$

$$\frac{0.0303\ mol\ O}{0.0202\ mol\ Al} = \frac{1.50\ mol\ O}{1.00\ mol\ Al} = \frac{1.5\ mol\ O}{1\ mol\ Al}$$

The simplest ratio is 1 mol Al: 1.5 mol O.

Because 1.5 × 2 = 3, the empirical formula is Al_2O_3.

70. Explain how percent composition data for a compound are related to the masses of the elements in the compound.

Percent composition is numerically equal to the mass in grams of each element in a 100.0-g sample.

71. Explain how you can find the mole ratio in a chemical compound.

The mole ratio is determined by calculating the moles of each element in the compound and dividing each number of moles by the smallest number of moles. It is sometimes necessary to multiply the ratio by an integer to obtain whole numbers.

72. Apply The molar mass of a compound is twice that of its empirical formula. How are the compound's molecular and empirical formulas related?

The molecular formula is equal to twice the empirical formula.

73. Analyze Hematite (Fe_2O_3) and magnetite (Fe_3O_4) are two ores used as sources of iron. Which ore provides the greater percent of iron per kilogram?

$$2\ \cancel{\text{mol Fe}} \times \frac{55.85\text{ g Fe}}{1\ \cancel{\text{mol Fe}}} = 111.70\text{ g Fe}$$

$$3\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{48.00\text{ g O}}$$

$$\text{molar mass } Fe_2O_3 = 159.70\text{ g/mol}$$

$$3\ \cancel{\text{mol Fe}} \times \frac{55.85\text{ g Fe}}{1\ \cancel{\text{mol Fe}}} = 167.55\text{ g Fe}$$

$$4\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = \underline{64.00\text{ g O}}$$

$$\text{molar mass } Fe_3O_4 = 231.55\text{ g/mol}$$

$$\text{percent by mass} = \frac{111.70\text{ g Fe}}{159.70\text{ g } Fe_2O_3} \times 100$$

$$= 69.94\%\text{ Fe in } Fe_2O_3$$

$$\text{percent by mass} = \frac{167.55\text{ g Fe}}{231.55\text{ g } Fe_2O_4} \times 100$$

$$= 72.36\%\text{ Fe in } Fe_3O_4$$

Hematite is 69.94% Fe, magnetite is 72.36% Fe. Magnetite contains a greater percentage of iron per kilogram than hematite.

Section 10.5 Formulas of Hydrates

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Practice Problems

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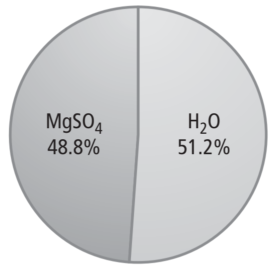
74. The composition of a hydrate is given in the pie chart shown at the right. What is the formula and name for this hydrate?



Step 1: Assume 100 g sample; calculate moles of each component.

$$48.8\ \cancel{\text{g } MgSO_4} \times \frac{1\text{ mol Mg } SO_4}{120.38\ \cancel{\text{g } MgSO_4}}$$

$$= 0.405\text{ mol } MgSO_4$$

$$51.2\ \cancel{\text{g } H_2O} \times \frac{1\text{ mol } H_2O}{18.02\ \cancel{\text{g } H_2O}} = 2.84\text{ mol } H_2O$$

Step 2: Calculate mole ratios.

$$\frac{0.405\text{ mol } MgSO_4}{0.405\text{ mol } MgSO_4} = \frac{1.00\text{ mol } MgSO_4}{1.00\text{ mol } MgSO_4}$$

$$= \frac{1\text{ mol } MgSO_4}{1\text{ mol } MgSO_4}$$

$$\frac{2.84\text{ mol } H_2O}{0.405\text{ mol } MgSO_4} = \frac{7.01\text{ mol } H_2O}{1.00\text{ mol } MgSO_4}$$

$$= \frac{7\text{ mol } H_2O}{1\text{ mol } MgSO_4}$$

The formula of the hydrate is $MgSO_4{\bullet}7H_2O$. Its name is magnesium sulfate heptahydrate.

75. Challenge An 11.75-g sample of a common hydrate of cobalt(II) chloride is heated. After heating, 0.0712 mol of anhydrous cobalt chloride remains. What is the formula and the name for this hydrate?

Step 1: Calculate the mass of $CoCl_2$ remaining.

$$0.0712\text{ mol } CoCl_2 \times \frac{129.83\text{ g } CoCl_2}{1\text{ mol } CoCl_2} = 9.24\text{ g } CoCl_2$$

Step 2: Calculate the mass of water driven off.

mass of hydrated compound – mass of anhydrous compound remaining

$= 11.75\text{ g } CoCl_2 \bullet xH_2O - 9.24\text{ g } CoCl_2 = 2.51\text{ g } H_2O$

Step 3: Calculate moles of each component.

$$9.24\text{ g }\cancel{CoCl_2} \times \frac{1\text{ mol } CoCl_2}{129.83\text{ g }\cancel{CoCl_2}}$$

$$= 0.0712\text{ mol } CoCl_2$$

$$2.50\text{ g }\cancel{H_2O} \times \frac{1\text{ mol } H_2O}{18.02\text{ g }\cancel{H_2O}} = 0.139\text{ mol } H_2O$$

Step 4: Calculate mole ratios.

$$\frac{0.0712\text{ mol } CoCl_2}{0.0712\text{ mol } CoCl_2} = \frac{1.00\text{ mol } CoCl_2}{1.00\text{ mol } CoCl_2} = \frac{1\text{ mol } CoCl_2}{1\text{ mol } CoCl_2}$$

$$\frac{0.139\text{ mol } H_2O}{0.0712\text{ mol } CoCl_2} = \frac{1.95\text{ mol } H_2O}{1.00\text{ mol } CoCl_2} = \frac{2\text{ mol } H_2O}{1\text{ mol } CoCl_2}$$

The formula of the hydrate is $CoCl_2 \bullet 2H_2O$. Its name is cobalt(II) chloride dihydrate.

Section 10.5 Assessment

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76. Summarize the composition of a hydrate.

A hydrate is a solid ionic compound in which water molecules are trapped.

77. Name the compound that has the formula $SrCl_2 \cdot 6H_2O$.

strontium chloride hexahydrate

78. Describe the experimental procedure for determining the formula for a hydrate. Explain the reason for each step.

Mass an empty crucible. Add some hydrate and remass. Heat the crucible to drive out the water. Cool and remass. Determine the moles of the anhydrous com pound. Subtract the mass of the crucible after heating from the mass of the crucible with the hydrate. The difference is the mass of the water lost. Determine the moles of water. Determine the simplest whole-number ratio of moles of water to moles of anhydrous compound, which will yield the formula of the hydrate.

79. Apply A hydrate contains 0.050 mol of H_2O to every 0.00998 mol of ionic compound. Write a generalized formula for the hydrate.

$XY \cdot 5H_2O$, where XY represents the ionic compound

80. Calculate the mass of the water of hydration if a hydrate loses 0.025 mol of H_2O when heated.

$$\text{water of hydration} = 0.025\ \cancel{\text{mol } H_2O} \times \frac{18.02\text{ g } H_2O}{1\ \cancel{\text{mol } H_2O}} = 0.45\text{ g } H_2O$$

81. Arrange these hydrates in order of increasing percent water content: $MgSO_4 \bullet 7H_2O$, $Ba(OH)_2 \bullet 8H_2O$, and $CoCl_2 \bullet 6H_2O$.

$$1\ \cancel{\text{mol Mg}} \times \frac{24.31\text{ g Mg}}{1\ \cancel{\text{mol Mg}}} = 24.31\text{ g Mg}$$

$$1\ \cancel{\text{mol S}} \times \frac{32.07\text{ g S}}{1\ \cancel{\text{mol S}}} = 32.07\text{ g S}$$

$$11\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = 176.00\text{ g O}$$

$$14\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = \underline{14.112\text{ g H}}$$

molar mass $MgSO_4 \bullet 7H_2O$ = 246.49 g

$$1\ \cancel{\text{mol Ba}} \times \frac{137.33\text{ Ba}}{1\ \cancel{\text{mol Ba}}} = 137.33\text{ g Ba}$$

$$10\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = 160.00\text{ g O}$$

$$18\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = \underline{18.144\text{ g H}}$$

molar mass $Ba(OH)_2 \bullet 8H_2O$ = 315.47 g

$$1\ \cancel{\text{mol Co}} \times \frac{58.93\text{ g Co}}{1\ \cancel{\text{mol Co}}} = 58.93\text{ g Co}$$

$$2\ \cancel{\text{mol Cl}} \times \frac{35.45\text{ g Cl}}{1\ \cancel{\text{mol Cl}}} = 70.90\text{ g Cl}$$

$$6\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = 96.00\text{ g O}$$

$$12\ \cancel{\text{mol H}} \times \frac{1.008\text{ g H}}{1\ \cancel{\text{mol H}}} = \underline{12.096\text{ g H}}$$

molar mass $CoCl_2 \bullet 6H_2O$ = 237.93 g

$$1\ \cancel{\text{mol O}} \times \frac{16.00\text{ g O}}{1\ \cancel{\text{mol O}}} = 16.00\text{ g O}$$

$2\ \cancel{mol\ H} \times \frac{1.008\ g\ H}{1\ \cancel{mol\ H}} = \underline{2.016\ g\ H}$

molar mass H_2O = 18.02 g

$\frac{7(18.02\ g\ H_2O)}{246.49\ g\ MgSO_4{\cdot}7H_2O} \times 100$
= 51.17% H_2O in $MgSO_4{\cdot}7H_2O$

$\frac{8(18.02\ g\ H_2O)}{315.47\ g\ Ba(OH)_2{\cdot}8H_2O} \times 100$
= 45.70% H_2O in $Ba(OH)_2{\cdot}8H_2O$

$\frac{6(18.02\ g\ H_2O)}{237.93\ g\ CoCl_2{\cdot}6H_2O} \times 100$
= 45.44% H_2O in $CoCl_2{\cdot}6H_2O$

$CoCl_2{\cdot}6H_2O$; $Ba(OH)_2{\cdot}8H_2O$; $MgSO_4{\cdot}7H_2O$

82. Apply Explain how the hydrate in **Figure 10.17** might be used as a means of roughly determining the probability of rain.

The hydrate is pink in moist air.

Everyday Chemistry

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Writing in Chemistry

Estimating The estimating process used in this article is sometimes called a "back-of-the-envelope" calculation. Use this method to estimate the total mass of all of the students in your school.

Suppose a school has a student body of 500 and that the average mass of each student is about 60 kilograms. The total mass of the students is calculated as follows.

500 students × 60 kilograms/student = 30,000 kg

Chapter 10 Assessment

pages 358–363

Section 10.1

Mastering Concepts

83. What is the numerical value of Avogadro's number?

6.02×10^{23}

84. How many atoms of potassium does 1 mol of potassium contain?

6.02×10^{23} potassium atoms

85. Compare a mole of Ag-108 and a mole of Pt-195 using atoms, protons, electrons, and neutrons.

Since they both contain one mole, you have 6.02×10^{23} particles of silver and 6.02×10^{23} particles of platinum. The difference would be in the number of protons, neutrons, and electrons present because silver contains 47 protons per atom, 47 electrons per atom and 61 neutrons per atom, while platinum contains 78 protons per atom, 78 electrons per atom and 117 neutrons per atom. A mole of platinum would contain more protons, electrons and neutrons but the same number of atoms.

86. Why is the mole an important unit to chemists?

A mole allows a chemist to accurately measure the number of atoms, molecules, or formula units in a substance.

87. Currency Examine the information in **Table 10.2** and explain how rolls used to count pennies and dimes are similar to moles.

Rolled-Coin Values	
Coin	**Value of a Roll of Coins**
Penny	$0.50
Dime	$5.00

One roll of pennies always contains 50 pennies and one roll of dimes always contains 50 dimes. Each roll contains a specific number of coins. A mole also contains a specific number of particles, 6.02×10^{23} particles.

88. Explain how Avogadro's number is used as a conversion factor.

Avogadro's number is the number of particles in one mole of a substance. It can be used to convert particles to moles or moles to particles.

89. Conversion Design a flowchart that could be used to help convert particles to moles or moles to particles.

Flowcharts will vary but should clearly show the use of proper conversion factors.

Mastering Problems

90. Determine the number of representative particles in each substance.

a. 0.250 mol of silver

$$0.250\ \cancel{\text{mol Ag}} \times \frac{6.02 \times 10^{23}\ \text{atoms Ag}}{1\ \cancel{\text{mol Ag}}} = 1.51 \times 10^{23}\ \text{atoms Ag}$$

b. 8.56×10^{-3} mol of sodium chloride

$$8.56 \times 10^{-3}\ \cancel{\text{mol NaCl}} \times \frac{6.02 \times 10^{23}\ \text{formula units NaCl}}{1\ \cancel{\text{mol NaCl}}} = 5.15 \times 10^{21}\ \text{formula units NaCl}$$

c. 35.3 mol of carbon dioxide

$$35.3\ \cancel{\text{mol CO}_2} \times \frac{6.02 \times 10^{23}\ \text{molecules CO}_2}{1\ \cancel{\text{mol CO}_2}} = 2.13 \times 10^{25}\ \text{molecules CO}_2$$

d. 0.425 mol of nitrogen (N_2)

$$0.425\ \cancel{\text{mol N}_2} \times \frac{6.02 \times 10^{23}\ \text{molecules N}_2}{1\ \cancel{\text{mol N}_2}} = 2.56 \times 10^{23}\ \text{molecules N}_2$$

91. Determine the number of representative particles in each substance.

a. 4.45 mol of $C_6H_{12}O_6$

$$4.45\ \text{mol C}_6\text{H}_{12}\text{O}_6 \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} = 2.68 \times 10^{24}\ \text{molecules C}_6\text{H}_{12}\text{O}_6$$

b. 0.250 mol of KNO_3

$$0.250\ \text{mol KNO}_3 \times \frac{6.02 \times 10^{23}\ \text{formula units}}{1\ \text{mol}} = 1.51 \times 10^{23}\ \text{formula units KNO}_3$$

c. 2.24 mol of H_2

$$2.24\ \text{mol H}_2 \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} = 1.35 \times 10^{24}\ \text{molecules of H}_2$$

d. 9.56 mol of Zn

$$9.56\ \text{mol Zn}\ \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = 5.76 \times 10^{24}\ \text{atoms of Zn}$$

92. How many molecules are contained in each compound?

a. 1.35 mol of carbon disulfide (CS_2)

$$1.35\ \cancel{\text{mol CS}_2} \times \frac{6.02 \times 10^{23}\ \text{molecules CS}_2}{1\ \cancel{\text{mol CS}_2}} = 8.13 \times 10^{23}\ \text{molecules CS}_2$$

b. 0.254 mol of diarsenic trioxide (As_2O_3)

$$0.254\ \cancel{\text{mol As}_2\text{O}_3} \times \frac{6.02 \times 10^{23}\ \text{molecules As}_2\text{O}_3}{1\ \cancel{\text{mol As}_2\text{O}_3}} = 1.53 \times 10^{23}\ \text{molecules As}_2\text{O}_3$$

c. 1.25 mol of water

$$1.25\ \cancel{\text{mol H}_2\text{O}} \times \frac{6.02 \times 10^{23}\ \text{molecules H}_2\text{O}}{1\ \cancel{\text{mol H}_2\text{O}}} = 7.53 \times 10^{23}\ \text{molecules H}_2\text{O}$$

d. 150.0 mol of HCl

$$150.0\ \cancel{\text{mol HCl}} \times \frac{6.02 \times 10^{23}\ \text{molecules HCl}}{1\ \cancel{\text{mol HCl}}} = 9.030 \times 10^{25}\ \text{molecules HCl}$$

93. Determine the number of moles in each substance.

a. 3.25×10^{20} atoms of lead

$$3.25 \times 10^{20}\ \cancel{\text{atoms Pb}} \times \frac{1\ \text{mol Pb}}{6.02 \times 10^{23}\ \cancel{\text{atoms Pb}}} = 5.39 \times 10^{-4}\ \text{mol Pb}$$

b. 4.96×10^{24} molecules of glucose

$$4.96 \times 10^{24}\ \cancel{\text{molecules glucose}} \times \frac{1\ \text{mol glucose}}{6.02 \times 10^{23}\ \cancel{\text{molecules glucose}}} = 8.24\ \text{mol of glucose}$$

c. 1.56×10^{23} formula units of sodium hydroxide

$$1.56 \times 10^{23}\ \cancel{\text{formula units NaOH}} \times \frac{1\ \text{mol NaOH}}{6.02 \times 10^{23}\ \cancel{\text{formula units NaOH}}} = 2.59 \times 10^{-1}\ \text{mol NaOH}$$

d. 1.25×10^{25} copper(II) ions

$1.25 \times 10^{25}\ \cancel{Cu^{2+}\ ions} \times \dfrac{1\ mol\ Cu^{2+}}{6.02 \times 10^{23}\ \cancel{Cu^{2+}\ ions}}$

$= 2.08 \times 10^{1}\ mol\ Cu^{2+}\ ions$

94. Perform the following conversions.

a. 1.51×10^{15} atoms of Si to mol of Si

$1.51 \times 10^{15}\ \cancel{atoms\ Si} \times \dfrac{1\ mol\ Si}{6.02 \times 10^{23}\ \cancel{atoms\ Si}}$

$= 2.51 \times 10^{-9}\ mol\ Si$

b. 4.25×10^{-2} mol of H_2SO_4 to molecules of H_2SO_4

$4.25 \times 10^{-2}\ \cancel{mol\ H_2SO_4} \times \dfrac{6.02 \times 10^{23}\ molecules\ H_2SO_4}{1\ \cancel{mol\ H_2SO_4}} = 2.56 \times 10^{22}$ molecules H_2SO_4

c. 8.95×10^{25} molecules of CCl_4 to mol of CCl_4

$8.95 \times 10^{25}\ \cancel{molecules\ CCl_4} \times \dfrac{1\ mol\ CCl_4}{6.02 \times 10^{23}\ \cancel{molecules\ CCl_4}}$

$= 1.49 \times 10^{2}\ mol\ CCl_4$

d. 5.90 mol of Ca to atoms of Ca

$5.90\ \cancel{mol\ Ca} \times \dfrac{6.02 \times 10^{23}\ atoms\ Ca}{1\ \cancel{mol\ Ca}}$

$= 3.55 \times 10^{24}\ atoms\ Ca$

95. How many moles contain the given quantity?

a. 1.25×10^{15} molecules of carbon dioxide

$1.25 \times 10^{15}\ \cancel{molecules\ CO_2} \times \dfrac{1\ mol\ CO_2}{6.02 \times 10^{23}\ \cancel{molecules\ CO_2}}$

$= 2.08 \times 10^{-9}\ mol\ CO_2$

b. 3.59×10^{21} formula units of sodium nitrate

$3.59 \times 10^{21}\ \cancel{formula\ units\ NaNO_3} \times \dfrac{1\ mol\ NaNO_3}{6.02 \times 10^{23}\ \cancel{formula\ units\ NaNO_3}}$

$= 5.96 \times 10^{-3}\ mol\ NaNO_3$

c. 2.89×10^{27} formula units of calcium carbonate

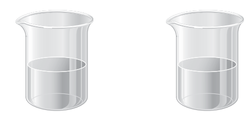
$2.89 \times 10^{27}\ \cancel{formula\ units\ CaCO_3} \times \dfrac{1\ mol\ CaCO_3}{6.02 \times 10^{23}\ \cancel{formula\ units\ CaCO_3}}$

$= 4.80 \times 10^{3}\ mol\ CaCO_3$

96. RDA of Selenium The recommended daily allowance (RDA) of selenium in your diet is 8.87×10^{-4} mol. How many atoms of selenium is this?

$8.87 \times \cancel{10^{-4}\ mol}\ Se \times \dfrac{6.02 \times 10^{23}\ atoms}{\cancel{1\ mol}\ Se}$

$= 5.34 \times 10^{20}\ atoms\ Se$



Solution A
0.250 mol
Cu^{2+} ions

Solution B
0.130 mol
Ca^{2+} ions

97. The two solutions shown in **Figure 10.19** are mixed. What is the total number of metal ions in the mixture?

$0.250\ mol\ Ca^{2+}\ ions + 0.130\ mol\ Ca^{2+}\ ion = 0.380\ mol\ metal\ ions$

$0.380\ \cancel{mol\ metal\ ions} \times \dfrac{6.02 \times 10^{23}\ mol\ metal\ ions}{1\ \cancel{mol\ metal\ ions}}$

$= 2.29 \times 10^{23}\ Cu^{2+}\ and\ Ca^{2+}\ ions$

98. Jewelry A bracelet containing 0.200 mol metal atoms is 75% gold. How many particles of gold atoms are in the bracelet?

$0.200\ mol\ metal\ atoms \times 0.75 = 0.150\ mol\ Au$

$0.150\ \cancel{mol\ Au} \times \dfrac{6.02 \times 10^{23}\ atoms\ Au}{1\ \cancel{mol\ Au}}$

$= 9.03 \times 10^{22}\ atoms\ Au$

99. Snowflakes A snowflake contains 1.9×10^{18} molecules of water. How many moles of water does it contain?

$1.9 \times 10^{18}\ \cancel{molecules\ H_2O} \times \dfrac{1\ mol\ H_2O}{6.02 \times 10^{23}\ \cancel{molecules\ H_2O}}$

$= 3.2 \times 10^{-6}\ mol\ H_2O$

100. If you could count two atoms every second, how long would it take you to count a mole of atoms? Assume that you counted continually for 24 hours every day. How does the time you calculated compare with the age of Earth, which is estimated to be 4.5×10^9 years old?

$$6.02 \times 10^{23} \text{ particles} \times \frac{1 \text{ s}}{2 \text{ particles}} = 3.01 \times 10^{23} \text{ s}$$

$$3.01 \times 10^{23} \text{ s} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1 \text{ day}}{24 \text{ h}} \times \frac{1 \text{ y}}{365 \text{ day}}$$

$= 2.1 \times 10^6$

$= 9.5 \times 10^{15}$ **yr; about 2 million times longer**

101. Chlorophyll The green color of leaves is due to the presence of chlorophyll, $C_{55}H_{72}O_5N_4Mg$. A fresh leaf was found to have 1.5×10^{-5} mol of chlorophyll per cm^2. How many chlorophyll molecules can be found in 1 cm^2?

$$\frac{1.5 \times 10^{-5} \text{ mol chlorophyll}}{1 \text{ cm}^2} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol chlorophyll}}$$

$= 9.03 \times 10^{18}$ **chlorophyll molecules/cm²**

Section 10.2

Mastering Concepts

102. Explain the difference between atomic mass (amu) and molar mass (g).

Atomic mass (amu) is the mass of an individual particle (atom, molecule). Molar mass (g) is the mass of a mole of particles.

103. Which contains more atoms, a mole of silver atoms or a mole of gold atoms? Explain your answer.

They both contain the same number of atoms because a mole of anything contains 6.02×10^{23} representative particles.

104. Which has more mass, a mole of potassium or a mole of sodium? Explain your answer

The molar mass of K is 39.098 g/mol; the molar mass of Na is 22.990 g/mol. Thus, a mole of K has a greater mass.

105. Explain how you would convert from number of atoms of a specific element to its mass.

Convert the number of atoms to moles, then multiply moles by the molar mass of the element.

106. Discuss the relationships that exist between the mole, molar mass, and Avogadro's number.

Molar mass is the mass in grams of one mole of any pure substance. Avogadro's number is the number of representative particles in one mole. The mass of 6.02×10^{23} representative particles of a substance is the molar mass of the substance.

107. Barbed Wire Barbed wire is often made of steel, which is primarily iron, and coated with zinc. Compare the number of particles and the mass of 1 mol of each.

The mole of iron and the mole of zinc both contain 6.02×10^{23} particles but a mole of iron has a mass of 55.85 g/mol and a mole of zinc has a mass of 65.39 g/mol.

Mastering Problems

108. Calculate the mass of each element.

a. 5.22 mol of He

$$5.22 \text{ mol He} \times \frac{4.00 \text{ g He}}{1 \text{ mol He}} = 20.9 \text{ g He}$$

b. 0.0455 mol of Ni

$$0.0455 \text{ mol Ni} \times \frac{58.69 \text{ g Ni}}{1 \text{ mol Ni}} = 2.67 \text{ g Ni}$$

c. 2.22 mol of Ti

$$2.22 \text{ mol Ti} \times \frac{47.87 \text{ g Ti}}{1 \text{ mol Ti}} = 106 \text{ g Ti}$$

d. 0.00566 mol of Ge

$$0.00566 \text{ mol Ge} \times \frac{72.61 \text{ g Ge}}{1 \text{ mol Ge}} = 0.411 \text{ g Ge}$$

109. Perform the following conversions.

a. 3.50 mol of Li to g of Li

$$3.50 \text{ mol Li} \times \frac{6.94 \text{ g Li}}{1 \text{ mol Li}} = 24.3 \text{ g Li}$$

b. 7.65 g of Co to mol of Co

$$7.65 \text{ g Co} \times \frac{1 \text{ mol Co}}{58.93 \text{ g Co}} = 0.130 \text{ mol Co}$$

c. 5.62 g of Kr to mol of Kr

$$5.62 \text{ g Kr} \times \frac{1 \text{ mol Kr}}{83.80 \text{ g Kr}} = 0.0671 \text{ mol Kr}$$

d. 0.0550 mol of As to g of As

$$0.0550 \text{ mol As} \times \frac{74.92 \text{ g As}}{1 \text{ mol As}} = 4.12 \text{ g As}$$

110. Determine the mass in grams of each element.

a. 1.33×10^{22} mol of Sb

$$1.33 \times 10^{22} \text{ mol Sb} \times \frac{121.76 \text{ g Sb}}{1 \text{ mol Sb}} = 1.62 \times 10^{24} \text{ g Sb}$$

b. 4.75×10^{14} mol of Pt

$$4.75 \times 10^{14} \text{ mol Pt} \times \frac{195.08 \text{ g Pt}}{1 \text{ mol Pt}} = 9.27 \times 10^{16} \text{ g Pt}$$

c. 1.22×10^{23} mol of Ag

$$1.22 \times 10^{23} \text{ mol Ag} \times \frac{107.87 \text{ g Ag}}{1 \text{ mol Ag}} = 1.32 \times 10^{25} \text{ g Ag}$$

d. 9.85×10^{24} mol of Cr

$$9.85 \times 10^{24} \text{ mol Cr} \times \frac{52.00 \text{ g Cr}}{1 \text{ mol Cr}} = 5.1\ \ 2 \times 10^{26} \text{ g Cr}$$

111. Complete **Table 10.3.**

Mass, Mole, and Particle Data		
Mass	**Moles**	**Particles**
88.7 g Mg	3.65 mol Mg	2.20 × 1024 atoms Mg
29.54 g Cr	0.5681 mol Cr	3.420 × 1023 atoms Cr
1820 g P	58.8 mol P	3.54×10^{25} atoms P
42.6 g As	0.568 mol As	3.42 × 1023 atoms As

Solutions:

3.65 mol Mg × (24.31 g/1 mol) = 88.7 g mg

3.65 mol mg × (6.02×10^{23} atoms/1 mol) = 2.20×10^{24} atoms Mg

29.54 g Cr × (1 mol/52.00 g) = 0.5681 mol Cr

0.5681 mol Cr × (6.02×10^{23} atoms/1 mol) = 3.420×10^{23} atoms Cr

3.54×10^{25} atoms P × (1 mol /6.02×10^{23} atoms)= 58.8 mol P

58.8 mol P × (30.97 g/1 mol) = 1820 g P

0.568 mol As × (74.92 g/1 mol) = 42.6 g As

0.568 mol As × (6.02×10^{23} atoms/1 mol) = 3.42 × 10^{23} atom As

112. Convert each to mass in grams.

a. 4.22×10^{15} atoms U

$$4.22 \times 10^{15} \text{ atoms U} \times \frac{1 \text{ mol U}}{6.02 \times 10^{23} \text{ atoms U}} \times \frac{283.03 \text{ g U}}{1 \text{ mol U}} = 1.67 \times 10^{-6} \text{ g U}$$

b. 8.65×10^{25} atoms H

$$8.65 \times 10^{25} \text{ atoms H} \times \frac{1 \text{ mol H}}{6.02 \times 10^{23} \text{ atoms H}} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 145 \text{ g H}$$

c. 1.25×10^{22} atoms O

$$1.25 \times 10^{22} \text{ atoms O} \times \frac{1 \text{ mol O}}{6.02 \times 10^{23} \text{ atoms O}} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 0.332 \text{ g O}$$

d. 4.44×10^{23} atoms Pb

$$4.44 \times 10^{23} \text{ atoms Pb} \times \frac{1 \text{ mol Pb}}{6.02 \times 10^{23} \text{ atoms Pb}} \times \frac{207.2 \text{ g Pb}}{1 \text{ mol Pb}} = 153 \text{ g Pb}$$

113. Calculate the number of atoms of each element.

a. 25.8 g of Hg

$$25.8 \text{ g Hg} \times \frac{1 \text{ mol Hg}}{200.59 \text{ g Hg}} \times \frac{6.02 \times 10^{23} \text{ atoms Hg}}{1 \text{ mol Hg}} = 7.74 \times 10^{22} \text{ atoms Hg}$$

b. 0.0340 g of Zn

$$0.0340 \text{ g Zn} \times \frac{1 \text{ mol Zn}}{63.59 \text{ g Zn}} \times \frac{6.02 \times 10^{23} \text{ atoms Zn}}{1 \text{ mol Zn}} = 3.13 \times 10^{20} \text{ atoms Zn}$$

c. 150 g of Ar

$$150 \text{ g Ar} \times \frac{1 \text{ mol Ar}}{39.95 \text{ g Ar}} \times \frac{6.02 \times 10^{23} \text{ atoms Ar}}{1 \text{ mol Ar}} = 2.3 \times 10^{24} \text{ atoms Ar}$$

d. 0.124 g of Mg

$$0.124 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.31 \text{ g Mg}} \times \frac{6.02 \times 10^{23} \text{ atoms Mg}}{1 \text{ mol Mg}} = 3.07 \times 10^{21} \text{ atoms Mg}$$

114. Arrange from least to most in moles: 3.00×10^{24} atoms Ne, 4.25 mole Ar, 2.69×10^{24} atoms Xe, 65.96 g Kr.

Convert atoms Ne, atoms Xe, and g Kr to moles:

Ne: 3.00×10^{24} **atoms**

$$\text{Ne} \times \frac{1 \text{ mol Ne}}{6.02 \times 10^{23} \text{ atoms Ne}} = 4.98 \text{ mol Ne}$$

Xe: 2.69×10^{24} **atoms Xe**

$$\times \frac{1 \text{ mol Xe}}{6.02 \times 10^{23} \text{ atoms Xe}} = 4.47 \text{ mo Xe}$$

$$\text{Kr: } 65.96 \text{ g Kr} \times \frac{1 \text{ mol Kr}}{83.80 \text{ g Kr}} = 0.7871 \text{ mol Kr}$$

0.7871 mol Kr < 4.25 mol Ar < 4.47 mol Xe < 4.98 mol Ne

115. Balance Precision A sensitive electronic balance can detect masses of 1×10^{-8} g. How many atoms of silver would be in a sample having this mass?

$$1 \times 10^{-8} \text{ g Ag} \times \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \times \frac{6.02 \times 10^{23} \text{ atoms Ag}}{1 \text{ mol Ag}} = 5 \times 10^{13} \text{ atoms Ag}$$

116. A sample of a compound contains 3.86 g of sulfur and 4.08 g of vanadium. How many atoms of sulfur and vanadium does the compound contain?

$$3.86 \text{ g S} \times \frac{1 \text{ mol}}{32.07 \text{ g S}} \times \frac{6.02 \times 10^{23} \text{ atoms S}}{1 \text{ mol S}} = 7.25 \times 10^{22} \text{ atoms S}$$

$$4.08 \text{ g V} \times \frac{1 \text{ mol}}{50.94 \text{ g V}} \times \frac{6.02 \times 10^{23} \text{ atoms V}}{1 \text{ mol V}} = 4.82 \times 10^{22} \text{ atoms V}$$

117. Which has more atoms, 10.0 g of C or 10.0 g of Ca? How many atoms does each have?

$$10.0 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{6.02 \times 10^{23} \text{ atoms C}}{1 \text{ mol C}} = 5.01 \times 10^{23} \text{ atoms C}$$

$$10.0 \text{ g Ca} \times \frac{1 \text{ mol Ca}}{40.08 \text{ g Ca}} \times \frac{6.02 \times 10^{23} \text{ atoms Ca}}{1 \text{ mol Ca}} = 1.50 \times 10^{23} \text{ atoms Ca}$$

10.0 g C contains more atoms.

118. Which has more atoms, 10.0 mol of C or 10.0 mol of Ca? How many atoms does each have?

One mole of any substance contains 6.02×10^{23} **representative particles. Thus, 10.0 moles of carbon and 10.0 moles of calcium contain the same number or atoms.**

$$10.0 \text{ mol} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 6.02 \times 10^{24} \text{ atoms}$$

119. A mixture contains 0.250 mol of Fe and 1.20 g of C. What is the total number of atoms in the mixture?

$$0.250 \text{ mol Fe} \times \frac{6.02 \times 10^{23} \text{ atoms Fe}}{1 \text{ mol Fe}} = 1.51 \times 10^{23} \text{ atoms Fe}$$

$$1.20 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{6.02 \times 10^{23} \text{ atoms C}}{1 \text{ mol C}} = 0.601 \times 10^{23} \text{ atoms C}$$

$$1.51 \times 10^{23} \text{ atoms Fe} + 0.601 \times 10^{23} \text{ atoms C} = 2.11 \times 10^{23} \text{ total atoms}$$

120. Respiration Air contains several gases. When resting, every breath you take contains approximately 0.600 g of air. If argon makes up 0.934% of the air, calculate the number of argon atoms inhaled with each breath.

$$\frac{0.600 \text{ g air}}{1 \text{ breath}} \times \frac{0.934 \text{ g Ar}}{100 \text{ g air}} \times \frac{1 \text{ mol}}{39.95 \text{ g}} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = \frac{8.44 \times 10^{19} \text{ atoms Ar}}{1 \text{ breath}}$$

Section 10.3

Mastering Concepts

121. What information is provided by the formula for potassium chromate (K_2CrO_4)?

One mole of K_2CrO_4 contains two moles of K^+ ions and one mole of CrO_4^{2-} ions.

122. In the formula for sodium phosphate (Na_3PO_4), how many moles of sodium are represented? How many moles of phosphorus? How many moles of oxygen?

3 mol Na, 1 mol P, 4 mol O

123. Explain how you determine the molar mass of a compound.

Molar mass is determined by multiplying the molar mass of each element present in the compound by its subscript and then adding these values.

124. Insect Repellent Many insect repellents use DEET as the active ingredient. DEET was patented in 1946 and is effective against many biting insects. What must you know to determine the molar mass of DEET?

You must know the chemical formula of the substance to determine the molar mass.

125. Why can molar mass be used as a conversion factor?

Molar mass is the mass of one mole of a compound. It can be used to convert moles of the compound to mass or mass of the compound to moles.

126. List three conversion factors used in molar conversions.

$$\frac{1 \text{ mol}}{\text{number of grams}}, \quad \frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mol}}, \quad \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ representative particles}}, \quad \frac{\text{number of grams}}{1 \text{ mol}}$$

127. Which of these contains the most moles of carbon atoms per mole of the compound: ascorbic acid ($C_6H_8O_6$), glycerin ($C_3H_8O_3$), or vanillin ($C_8H_8O_3$)? Explain.

The formula for vanillin ($C_8H_8O_3$) shows there are eight carbon atoms per molecule, more than ascorbic acid or glycerin.

Mastering Problems

128. How many moles of oxygen atoms are contained in each compound?

a. 2.50 mol of $KMnO_4$

$$2.50 \text{ mol } KMnO_4 \times \frac{4 \text{ mol O}}{1 \text{ mol } KMnO_4} = 10.0 \text{ mol O}$$

b. 45.9 mol of CO_2

$$45.9 \text{ mol } CO_2 \times \frac{2 \text{ mol O}}{1 \text{ mol } CO_2} = 91.8 \text{ mol O}$$

c. 1.25×10^{-2} mol of $CuSO_4 \cdot 5H_2O$

$$1.25 \times 10^{-2} \text{ mol } CuSO_4 \cdot 5H_2O \times \frac{9 \text{ mol O}}{1 \text{ mol } CuSO_4 \cdot 5H_2O} = 0.113 \text{ mol O}$$

129. How many carbon tetrachloride (CCl_4) molecules are in 3.00 mol of CCl_4? How many carbon atoms? How many chlorine atoms? How many total atoms?

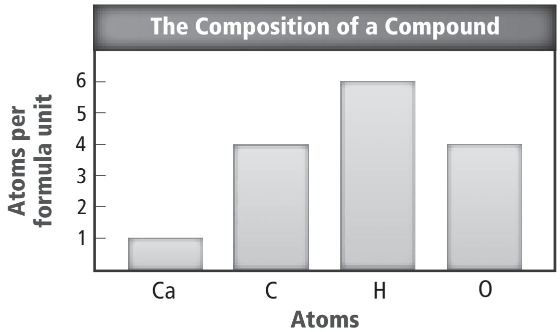
$$3.00 \text{ mol } CCl_4 \times \frac{6.02 \times 10^{23} \text{ molecules } CCl_4}{1 \text{ mol } CCl_4} = 1.81 \times 10^{24} \text{ molecules } CCl_4$$

$$1.81 \times 10^{24} \text{ molecules } CCl_4 \times \frac{1 \text{ mol atoms C}}{1 \text{ molecule } CCl_4} = 1.81 \times 10^{24} \text{ atoms C}$$

1.81×10^{24} molecules $CCl_4 \times \frac{4 \text{ mol atoms Cl}}{1 \text{ molecule } CCl_4}$

$= 7.24 \times 10^{24}$ atoms Cl

1.81×10^{24} atoms C + 7.24×10^{24} atoms Cl = 9.05 $\times 10^{24}$ total atoms



130. The graph in **Figure 10.20** shows the numbers of atoms of each element in a compound. What is the compound's formula? What is its molar mass?

$CaC_4H_6O_4$: $Ca(C_2H_3O_2)_2$ (calcium acetate)

$1 \text{ mol Ca} \times \frac{40.08 \text{ g Ca}}{1 \text{ mol Ca}} = 40.08 \text{ g Ca}$

$4 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 48.04 \text{ g C}$

$6 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 6.048 \text{ g H}$

$4 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{64.00 \text{ g O}}$

molar mass = 158.18 g/mol

131. Determine the molar mass of each compound.

a. nitric acid (HNO_3)

$1 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 1.008 \text{ g H}$

$1 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 14.01 \text{ g N}$

$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{48.00 \text{ g O}}$

molar mass = 63.02 g/mol HNO_3

b. ammonium nitrate (NH_4NO_3)

$2 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 28.02 \text{ g N}$

$4 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 4.032 \text{ g H}$

$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{48.00 \text{ g O}}$

molar mass = 80.05 g/mol NH_4NO_3

c. zinc oxide (ZnO)

$1 \text{ mol Zn} \times \frac{65.39 \text{ g Zn}}{1 \text{ mol Zn}} = 65.39 \text{ g Zn}$

$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{16.00 \text{ g O}}$

molar mass = 81.39 g/mol ZnO

d. cobalt (II) chloride ($CoCl_2$)

$1 \text{ mol Co} \times \frac{58.93 \text{ g Co}}{1 \text{ mol Co}} = 58.93 \text{ g Co}$

$2 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = \underline{70.90 \text{ g Cl}}$

molar mass = 129.83 g/mol $CoCl_2$

132. Garlic Determine the molar mass of allyl sulfide, the compound responsible for the smell of garlic. The chemical formula of allyl sulfide is $(C_3H_5)_2S$.

$6 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 72.06 \text{ g C}$

$10 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 10.080 \text{ g H}$

$1 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = \underline{32.07 \text{ g S}}$

molar mass = 114.21 g/mol $(C_3H_5)_2S$

133. How many moles are in 100.0 g of each compound?

a. dinitrogen oxide (N_2O)

$2 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 28.02 \text{ g N}$

$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{16.00 \text{ g O}}$

molar mass = 44.02 g/mol

$100.0 \text{ g } N_2O \times \frac{1 \text{ mol } N_2O}{44.02 \text{ g } N_2O} = 2.27 \text{ mol } N_2O$

b. methanol (CH_3OH)

$1 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 12.01 \text{ g C}$

$4 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 4.032 \text{ g H}$

$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{16.00 \text{ g O}}$

molar mass = 32.04 g/mol

$100.0 \text{ g } CH_3OH \times \frac{1 \text{ mol } CH_3OH}{32.04 \text{ g } CH_3OH}$
$= 3.12 \text{ mol } CH_3OH$

134. What is the mass of each compound?

a. 4.50×10^{-2} mol of $CuCl_2$

$1 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 63.55 \text{ g Cu}$

$2 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = \underline{70.90 \text{ g Cl}}$

molar mass = 134.45 g/mol

$4.50 \times 10^{-2} \text{ mol } CuCl_2 \times \frac{134.35 \text{ g } CuCl_2}{1 \text{ mol } CuCl_2}$
$= 6.05 \text{ g } CuCl_2$

b. 1.25×10^{2} mol of $Ca(OH)_2$

$1 \text{ mol Ca} \times \frac{40.08 \text{ g Ca}}{1 \text{ mol Ca}} = 40.08 \text{ g Ca}$

$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$

$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = \underline{32.00 \text{ g O}}$

molar mass = 74.10 g/mol

$1.25 \times 10^{2} \text{ mol } Ca(OH)_2 \times \frac{74.10 \text{ g } Ca(OH)_2}{1 \text{ mol } Ca(OH)_2}$
$= 9.26 \times 10^{2} \text{ g } Ca(OH)_2$

135. Acne Benzoyl peroxide ($C_{14}H_{10}O_4$) is a substance used as an acne medicine. What is the mass in grams of 3.50×10^{-2} mol $C_{14}H_{10}O_4$?

$14 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 168.14 \text{ g C}$

$10 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 10.080 \text{ g H}$

$4 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 64.00 \text{ g O}$

molar mass = 168.14 + 10.080 + 64.00
= 242.22 g/mol

$3.50 \times 10^{-2} \text{ mol} \times \frac{242.22 \text{ g}}{1 \text{ mol}} = 8.48$ g benzoyl peroxide

136. Glass Etching Hydrofluoric acid is a substance used to etch glass. Determine the mass of 4.95×10^{25} HF molecules.

$1 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 1.008 \text{ g H}$

$1 \text{ mol F} \times \frac{19.00 \text{ g F}}{1 \text{ mol F}} = 19.00 \text{ g F}$

molar mass = 1.008 + 19.00 = 20.01 g/mol

4.95×10^{25} molecules HF
$\times \frac{1 \text{ mol HF}}{6.02 \times 10^{23} \text{ molecules HF}} \times \frac{20.01 \text{ g HF}}{1 \text{ mol HF}}$
= 1650 g HF

137. What is the mass of a mole of electrons if one electron has a mass of 9.11×10^{-28} g?

$6.02 \times 10^{23} \text{ electrons} \times \frac{9.11 \times 10^{-28} \text{ g}}{1 \text{ electron}}$
$= 5.48 \times 10^{-4}$ g

138. How many moles of ions are in each compound?

a. 0.0200 g of $AgNO_3$

$1 \text{ mol Ag} \times \frac{107.87 \text{ g Ag}}{1 \text{ mol Ag}} = 107.87 \text{ g Ag}$

$1 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 14.01 \text{ g N}$

$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 48.00 \text{ g O}$

molar mass = 107.87 + 14.01 + 48.00
= 169.88 g/mol

$0.0200 \text{ g } AgNO_3 \times \frac{1 \text{ mol } AgNO_3}{169.88 \text{ g } AgNO_3}$
$\times \frac{2 \text{ mol ions}}{1 \text{ mol } AgNO_3} = 2.35 \times 10^{-4}$ mol ions

b. 0.100 mol of K_2CrO_4

$0.100 \text{ mol } K_2CrO_4 \times \frac{3 \text{ mol ions}}{1 \text{ mol } K_2CrO_4} = 0.300$ mol ions

c. 0.500 g of $Ba(OH)_2$

$$1 \text{ mol Ba} \times \frac{137.33 \text{ g Ba}}{1 \text{ mol Ba}} = 137.33 \text{ g Ba}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

$$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$$

molar mass = 137.33 + 32.00 + 2.016
= 171.35 g/mol

$$0.500 \text{ g } Ba(OH)_2 \times \frac{1 \text{ mol } Ba(OH)_2}{171.35 \text{ g } Ba(OH)_2}$$

$$\times \frac{3 \text{ mol ions}}{1 \text{ mol } Ba(OH)_2} = 8.75 \times 10^{-3} \text{ mol ions}$$

d. 1.00×10^{-9} mol of Na_2CO_3

$$1.00 + 10^{-9} \text{ mol } Na_2CO_3 + \frac{3 \text{ mol ions}}{1 \text{ mol } Na_2CO_3}$$

$= 3.00 \times 10^{-9}$ mol ions

139. How many formula units are present in 500.0 g of lead(II) chloride?

$$1 \text{ mol Pb} \times \frac{207.2 \text{ g Pb}}{1 \text{ mol Pb}} = 207.2 \text{ g Pb}$$

$$2 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 70.90 \text{ g Cl}$$

molar mass = 207.2 + 70.90 = 278.1 g/mol

$$500.0 \text{ g } PbCl_2 \times \frac{1 \text{ mol } PbCl_2}{278.1 \text{ g } PbCl_2} = 1.798 \text{ mol } PbCl_2$$

$$1.798 \text{ mol } PbCl_2 \times \frac{6.02 + 10^{23} \text{ formula units}}{1 \text{ mol } PbCl_2}$$

$= 1.082 \times 10^{24}$ formula units $PbCl_2$

140. Determine the number of atoms in 3.50 g of gold.

$$3.50 \text{ g Au} \times \frac{1 \text{ mol Au}}{196.97 \text{ g Au}} \times \frac{6.02 + 10^{23} \text{ atoms Au}}{1 \text{ mol Au}}$$

$= 1.07 \times 10^{22}$ atoms Au

141. Calculate the mass of 3.62×10^{24} molecules of glucose ($C_6H_{12}O_6$).

From a previous solution, the molar mass of glucose equals 180.16 g/mol.

3.62×10^{24} molecules glucose

$$\times \frac{1 \text{ mol glucose}}{6.02 \times 10^{23} \text{ molecules glucose}}$$

$$\times \frac{180.16 \text{ g glucose}}{1 \text{ mol glucose}} = 1080 \text{ g glucose}$$

142. Determine the number of molecules of ethanol (C_2H_5OH) in 47.0 g.

$$2 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 24.02 \text{ g C}$$

$$6 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 6.048 \text{ g H}$$

$$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g O}$$

molar mass = 24.02 + 6.048 + 16.00 = 46.07 g/mol

$$47.0 \text{ g ethanol} \times \frac{1 \text{ mol ethanol}}{46.07 \text{ g ethanol}}$$

$$\times \frac{6.02 \times 10^{23} \text{ molecules ethanol}}{1 \text{ mol ethanol}}$$

$= 6.14 \times 10^{23}$ molecules ethanol

143. What mass of iron(III) chloride contains 2.35×10^{23} chloride ions?

$$1 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 55.85 \text{ g Fe}$$

$$3 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 106.35 \text{ g Cl}$$

molar mass = 55.85 + 106.35 = 162.20 g/mol

2.35×10^{23} chloride ions

$$\times \frac{1 \text{ mol chloride ions}}{6.02 \times 10^{23} \text{ chloride ions}}$$

$$\times \frac{1 \text{ mol } FeCl_3}{3 \text{ mol chloride ions}} \times \frac{162.20 \text{ g } FeCl_3}{1 \text{ mol } FeCl_3}$$

$= 21.1$ g $FeCl_3$

144. How many moles of iron can be recovered from 100.0 kg of Fe_3O_4?

$$3 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 167.55 \text{ g Fe}$$

$$4 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 64.00 \text{ g O}$$

molar mass = 167.55 + 64.00 = 231.55 g/mol

$$100.0 \text{ kg } Fe_3O_4 \times \frac{10^3 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol } Fe^3O_4}{231.55 \text{ g } Fe_3O_4} \times$$

$$\frac{3 \text{ mol Fe}}{1 \text{ mol } Fe_3O_4} = 1296 \text{ mol Fe}$$

145. Cooking A common cooking vinegar is 5.0% acetic acid (CH_3COOH). How many molecules of acetic acid are present in 25.0 g vinegar?

$$2 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 24.02 \text{ g C}$$

$$4 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 4.032 \text{ g H}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

molar mass = 24.02 + 4.032 + 32.00 = 60.05 g/mol

0.050×25.0 g vinegar = 1.25 g CH_3COOH

$$1.25 \text{ g } CH_3COOH \times \frac{1 \text{ mol } CH_3COOH}{60.05 \text{ g } CH_3COOH} \times \frac{6.02 \times 10^{23} \text{ molecules } CH_3COOH}{1 \text{ mol } CH_3COOH} = 1.3 \times 10^{22} \text{ molecules } CH_3COOH$$

146. Calculate the moles of aluminum ions present in 250.0 g of aluminum oxide (Al_2O_3).

$$250.0 \text{ g } Al_2O_3 \times \frac{1 \text{ mol } Al_2O_3}{101.96 \text{ g } Al_2O_3} \times \frac{2 \text{ mol } Al^{3+}}{1 \text{ mol } Al_2O_3} = 4.90 \text{ mol } Al^{3+}$$

147. Determine the number of chloride ions in 10.75 g of magnesium chloride.

$$1 \text{ mol Mg} \times \frac{24.31 \text{ g Mg}}{1 \text{ mol Mg}} = 24.31 \text{ g Mg}$$

$$2 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 70.90 \text{ g Cl}$$

molar mass = 24.31 + 70.90 = 94.31 g/mol

$$10.75 \text{ g } MgCl_2 \times \frac{1 \text{ mol } MgCl_2}{94.31 \text{ g } MgCl_2} \times \frac{2 \text{ mol Cl}}{1 \text{ mol } MgCl_2} \times \frac{6.02 \times 10^{23} \text{ ions}}{1 \text{ mol Cl}} = 1.37 \times 10^{23} \text{ ions } Cl^-$$

148. Pain Relief Acetaminophen, a common aspirin substitute, has the formula $C_8H_9NO_2$. Determine the number of molecules of acetaminophen in a 500-mg tablet.

$$8 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 96.08 \text{ g C}$$

$$9 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 9.072 \text{ g H}$$

$$1 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 14.01 \text{ g N}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

molar mass = 96.08 + 9.072 + 14.01 + 32.00 = 151.16 g/mol

$$500 \text{ mg } C_8H_9NO_2 \times \frac{1 \text{ g}}{10^3 \text{ mg}} \times \frac{1 \text{ mol } C_8H_9NO_2}{151.16 \text{ g } C_8H_9NO_2} = 0.003 \text{ mol } C_8H_9NO_2$$

$$\times \frac{6.02 \times 10^{23} \text{ molecules } C_8H_9NO_2}{1 \text{ mol } C_8H_9NO_2} = 2 \times 10^{21} \text{ molecules } C_8H_9NO_2$$

149. Calculate the number of sodium ions present in 25.0 g of sodium chloride.

25.0 g NaCl × (1 mol NaCl/58.44 g NaCl) × (1mol Na^+/1 mol NaCl) × (6.02 + 10^{23} ions/1 mol Na^+) = 2.58×10^{23} Na^+ ions

150. Determine the number of oxygen atoms present in 25.0 g of carbon dioxide.

$$1 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 12.01 \text{ g C}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

molar mass = 12.01 + 32.00 = 44.01 g/mol

$$25.0 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} = 0.568 \text{ mol } CO_2 \times \frac{2 \text{ mol O}}{1 \text{ mol } CO_2} \times \frac{6.02 \times 10^{23} \text{ atoms O}}{1 \text{ mol O}} = 6.84 \times 10^{23} \text{ atoms O}$$

151. Espresso There is 1.00×10^2 mg of caffeine in a shot of espresso. The chemical formula of caffeine is $C_8H_{10}N_4O_2$. Determine the moles of each element present in one shot of espresso.

molar mass = 194.19 g/mol

$$0.100 \text{ g caffeine} \times \frac{1 \text{ mol caffeine}}{194.19 \text{ g caffeine}} = 5.15 \times 10^{-4} \text{ mol caffeine}$$

C = $8(5.15 \times 10^{-4}$ mol) = 4.12×10^{-3} mol C

H = $10(5.15 \times 10^{-4}$ mol) = 5.15×10^{-3} mol H

N = $4(5.15 \times 10^{-4}$ mol) = 2.06×10^{-3} mol N

O = $2(5.15 \times 10^{-4}$ mol) = 1.03×10^{-3} mol O

152. The density of lead (Pb) is 11.3 g/cm^3. Calculate the volume of 1 mol of Pb.

$$1 \text{ mol Pb} \times \frac{207.2 \text{ g Pb}}{1 \text{ mol Pb}} \times \frac{1 \text{ cm}^3}{11.3 \text{ g Pb}} = 18.3 \text{ cm}^3$$

Section 10.4

Mastering Concepts

153. Explain what is meant by percent composition.

Percent composition is the percent by mass of each element in a compound.

154. What information must a chemist obtain in order to determine the empirical formula of an unknown compound?

the percent composition of the compound

155. What information must a chemist have to determine the molecular formula for a compound?

the percent composition of the compound and the molar mass

156. What is the difference between an empirical formula and a molecular formula? Provide an example.

An empirical formula is the smallest whole-number ratio of elements that make up a compound (CH). A molecular formula specifies the actual number of atoms of each element in one molecule or formula unit of the substance (C_6H_6).

157. When can the empirical formula be the same as the molecular formula?

They are the same when the subscripts for each element present are the same. Na_2O is both the empirical and molecular formula for sodium oxide.

158. Antibacterial Soap Triclosan is an antibacterial agent included in detergents, dish soaps, laundry soaps, deodorants, cosmetics, lotions, creams, toothpastes, and mouthwashes. The chemical formula for triclosan is $C_{12}H_7Cl_3O_2$. What information did the chemist need to determine this formula?

The chemist must have either an analysis of the elements that compose the molecule or the percent composition of the compound to determine the chemical formula.

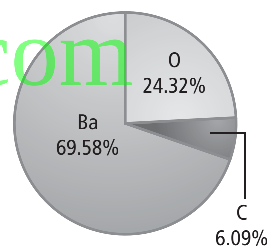
159. Which of the following formulas—NO, N_2O, NO_2, N_2O_4, and N_2O_5—represent the empirical and molecular formulas of the same compound? Explain your answer.

NO_2 is the empirical formula and N_2O_4 is the molecular formula of the same compound. $(NO_2)_2 = N_2O_4$

160. Do all pure samples of a given compound have the same percent composition? Explain.

Yes, for every pure substance, the percent by mass of each element is the same regardless of the size of the sample.

Mastering Problems



161. The circle graph in **Figure 10.21** shows the percent composition of a compound containing barium, carbon, and oxygen. What is the empirical formula of this compound?

$$\frac{69.78 \text{ g Ba}}{137.3 \text{ g/mol}} = \frac{0.5068 \text{ mol Ba}}{0.5068} = 1 \text{ mol Ba}$$

$$\frac{6.09 \text{ g C}}{12.01 \text{ g/mol}} = \frac{0.507 \text{ mol C}}{0.5068} = 1 \text{ mol C}$$

$$\frac{24.34 \text{ g O}}{16.00 \text{ g/mol}} = \frac{1.52 \text{ mol O}}{0.5068} = 3 \text{ mol O}$$

1 mol Ba:1 mol C:3 mol O; empirical formula = $BaCO_3$

162. Iron Three naturally occurring iron compounds are pyrite (FeS_2), hematite (Fe_2O_3), and siderite ($FeCO_3$). Which contains the greatest percentage of iron?

$1 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 55.85 \text{ g Fe}$

$2 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = 64.14 \text{ g S}$

molar mass FeS_2 = 55.85 + 64.14 = 119.99 g/mol

$1 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 111.70 \text{ g Fe}$

$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 48.00 \text{ g O}$

molar mass Fe_2O_3 = 111.70 + 48.00 = 159.70 g/mol

$1 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 55.85 \text{ g Fe}$

$1 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 12.01 \text{ g C}$

$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 96.00 \text{ g O}$

molar mass $FeCO_3$ = 55.85 + 12.01 + 96.00 = 152.95 g/mol

percent mass $= \frac{55.85 \text{ g}}{119.99 \text{ g}} \times 100 = 46.55\%$ in FeS_2

percent mass $= \frac{111.70 \text{ g}}{159.70 \text{ g}} \times 100 = 69.944\%$ in Fe_2O_3

percent mass $= \frac{55.85 \text{ g}}{152.95 \text{ g}} \times 100 = 36.51\%$ in $FeCO_3$

Hematite, with 69.944% Fe, has the greatest percentage of iron.

163. Express the composition of each compound as the mass percent of its elements (percent composition).

a. sucrose ($C_{12}H_{22}O_{11}$)

$12 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 144.12 \text{ g C}$

$22 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 22.18 \text{ g H}$

$11 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 176.00 \text{ g O}$

molar mass = 144.12 + 22.18 + 176.00 = 342.30 g/mol

percent by mass $= \frac{144.12 \text{ g}}{342.30 \text{ g}} \times 100 = 42.10\%$ C

percent by mass $= \frac{22.18 \text{ g}}{342.30 \text{ g}} \times 100 = 6.480\%$ H

percent by mass $= \frac{176.00 \text{ g}}{342.30 \text{ g}} \times 100 = 51.42\%$ O

b. aluminum sulfate ($A_{12}(SO_4)_3$)

$2 \text{ mol Al} \times \frac{26.98 \text{ g Al}}{1 \text{ mol Al}} = 53.96 \text{ g Al}$

$3 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = 96.21 \text{ g S}$

$12 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 192.00 \text{ g O}$

molar mass = 53.96 + 96.21 + 192.00 = 342.17 g/mol

percent by mass $= \frac{53.96 \text{ g}}{342.17 \text{ g}} \times 100 = 15.77\%$ Al

percent by mass $= \frac{96.21 \text{ g}}{342.17 \text{ g}} \times 100 = 28.12\%$ S

percent by mass $= \frac{192.00 \text{ g}}{342.17 \text{ g}} \times 100 = 56.11\%$ O

c. magnetite (Fe_3O_4)

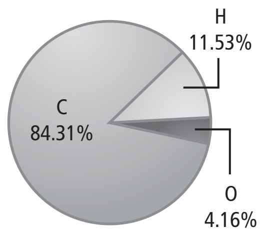
$3 \text{ mol Fe} + \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 167.55 \text{ g Fe}$

$4 \text{ mol O} + \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 64.00 \text{ g O}$

molar mass = 167.55 + 64.00 = 231.55 g/mol

percent by mass $= \frac{167.55 \text{ g}}{231.55 \text{ g}} \times 100$ = 72.360% Fe

percent by mass $= \frac{64.00 \text{ g}}{231.55 \text{ g}} \times 100 = 27.64\%$ O



Molar mass = 384 g/mol

164. Vitamin D_3 Your body's ability to absorb calcium is aided by vitamin D_3. Chemical analysis of vitamin D_3 yields the data shown in **Figure 10.22.** What are the empirical and molecular formulas for vitamin D_3?

$$\frac{84.31\text{ g C}}{12.011\text{ g/mol}} = \frac{7.019\text{ mol C}}{0.260} = 27\text{ mol C}$$

$$\frac{11.53\text{ g H}}{1.008\text{ g/mol}} = \frac{11.44\text{ mol H}}{0.260} = 44\text{ mol H}$$

$$\frac{4.16\text{ g O}}{16.00\text{ g/mol}} = \frac{0.260\text{ mol O}}{0.260} = 1\text{ mol O}$$

27 mol C:44 mol H:1 mol O; empirical formula = $C_{27}H_{44}O$; molar mass is equal to 384 g/mol; 384/384 = 1; the empirical formula is equal to the molecular formula, $C_{27}H_{44}O$

165. When a 30.98-g sample of phosphorus reacts with oxygen, a 71.00-g sample of phosphorus oxide is formed. What is the percent composition of the compound? What is the empirical formula for this compound?

30.98 g P/71.0 g = 43.64 % Phosphorus

40.02 g O/71.0 g = 56.36 % Oxygen

$$\frac{30.98\text{ g P}}{30.97\text{ g/mol}} = \frac{1\text{ mol P}}{1.000} = 1\text{ mol P}$$

$$\frac{40.02\text{ g O}}{16.00\text{ g/mol}} = \frac{2.501\text{ mol O}}{1.000} = 2.5\text{ mol O}$$

2(1 mol P:2.5 mol O) = 2 mol P:5 mol O = P_2O_5

166. Cholesterol Heart disease is linked to high blood cholesterol levels. What is the percent composition of the elements in a molecule of cholesterol ($C_{27}H_{45}OH$)?

(27 mol C)(12.01 g/mol) = 324.3 g C

(46 mol H)(1.008 g/mol) = 46.37 g H

(1 mol O)(16.00 g/mol) = 16.00 g O

total mass = 386.67 g

324.3 g C/386.67 g/mol = 83.9% C

46.37 g H/386.67g/mol = 12.0% H

16.00 g O/386.67g/mol = 4.1% O

167. Determine the empirical formula for each compound.

a. ethylene (C_2H_4)

Both subscripts can be divided by two. The empirical formula is CH_2.

b. ascorbic acid ($C_6H_8O_6$)

All subscripts can be divided by two. The empirical formula is $C_3H_4O_3$.

c. naphthalene ($C_{10}H_8$)

Both subscripts can be divided by two. The empirical formula is C_5H_4.

168. Caffeine The stimulant effect of coffee is due to caffeine, $C_8H_{10}N_4O_2$. Calculate the molar mass of caffeine. Determine its percent composition.

$$8\text{ mol C} \times \frac{12.01\text{ g C}}{1\text{ mol C}} = 96.08\text{ g C}$$

$$10\text{ mol H} \times \frac{1.008\text{ g H}}{1\text{ mol H}} = 10.080\text{ g H}$$

$$4\text{ mol N} \times \frac{14.01\text{ g N}}{1\text{ mol N}} = 56.04\text{ g N}$$

$$2\text{ mol O} \times \frac{16.00\text{ g O}}{1\text{ mol O}} = 32.00\text{ g O}$$

molar mass = 96.08 + 10.080 + 56.04 + 32.00 = 194.20 g/mol

$$\text{percent by mass} = \frac{96.08\text{ g}}{194.20\text{ g}} \times 100 = 49.47\%\text{ C}$$

$$\text{percent by mass} = \frac{10.08\text{ g}}{194.20\text{ g}} \times 100 = 5.191\%\text{ H}$$

$$\text{percent by mass} = \frac{56.04\text{ g}}{194.20\text{ g}} \times 100 = 28.86\%\text{ N}$$

$$\text{percent by mass} = \frac{32.00\text{ g}}{194.20\text{ g}} \times 100 = 16.48\%\text{ O}$$

169. Which of the titanium-containing minerals, rutile (TiO_2) or ilmenite ($FeTiO_3$), has the larger percentage of titanium?

$$1 \text{ mol Ti} \times \frac{47.87 \text{ g Ti}}{1 \text{ mol Ti}} = 47.87 \text{ g Ti}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

molar mass TiO_2 = 47.87 + 32.00 = 79.87 g/mol

$$1 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 55.85 \text{ g Fe}$$

$$1 \text{ mol Ti} \times \frac{47.87 \text{ g Ti}}{1 \text{ mol Ti}} = 47.87 \text{ g Ti}$$

$$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 48.00 \text{ g O}$$

molar mass $FeTiO_3$ = 55.85 + 47.87 + 48.00 = 151.72 g/mol

$$\text{percent by mass} = \frac{47.87 \text{ g}}{79.87 \text{ g}} \times 100$$
= 59.93% Ti in TiO_2

$$\text{percent by mass} = \frac{47.87 \text{ g}}{151.72 \text{ g}} \times 100$$
= 31.55% Ti in $FeTiO_3$

TiO_2 has the greater percent by mass of titanium.

170. Vitamin E Many plants contain vitamin E ($C_{29}H_{50}O_2$), a substance that some think slows the aging process in humans. What is the percent composition of vitamin E?

$$29 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 348.29 \text{ g C}$$

$$50 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 50.400 \text{ g H}$$

$$2 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 32.00 \text{ g O}$$

molar mass = 348.29 + 50.400 + 32.00 = 430.69 g/mol

$$\text{percent by mass} = \frac{348.29 \text{ g}}{430.69 \text{ g}} \times 100 = 80.87\% \text{ C}$$

$$\text{percent by mass} = \frac{50.400 \text{ g}}{430.69 \text{ g}} \times 100 = 11.70\% \text{ H}$$

$$\text{percent by mass} = \frac{32.00 \text{ g}}{430.69 \text{ g}} \times 100 = 7.430\% \text{ O}$$

171. Artificial Sweetener Determine the percent composition of aspartame ($C_{14}H_{18}N_2O_5$), an artificial sweetener.

$$14 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 168.14 \text{ g C}$$

$$18 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 18.144 \text{ g H}$$

$$2 \text{ mol N} \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 28.02 \text{ g N}$$

$$5 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 80.00 \text{ g O}$$

molar mass = 168.14 + 18.144 + 28.02 + 80.00 = 294.30 g/mol

$$\text{percent by mass} = \frac{168.14 \text{ g}}{294.30 \text{ g}} \times 100 = 57.13\% \text{ C}$$

$$\text{percent by mass} = \frac{18.144 \text{ g}}{294.30 \text{ g}} \times 100 = 6.165\% \text{ H}$$

$$\text{percent by mass} = \frac{28.02 \text{ g}}{294.30 \text{ g}} \times 100 = 9.521\% \text{ N}$$

$$\text{percent by mass} = \frac{80.00 \text{ g}}{294.30 \text{ g}} \times 100 = 27.18\% \text{ O}$$

172. MSG Monosodium glutamate, known as MSG, is sometimes added to food to enhance flavor. Analysis determined this compound to be 35.5% C, 4.77% H, 8.29% N, 13.6% Na, and 37.9% O. What is its empirical formula?

$$35.5 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 2.96 \text{ mol C}$$

$$4.77 \text{ g H} \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 4.73 \text{ mol H}$$

$$8.29 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 0.592 \text{ mol N}$$

$$13.6 \text{ g Na} \times \frac{1 \text{ mol Na}}{22.99 \text{ g Na}} = 0.592 \text{ mol Na}$$

$$37.9 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.37 \text{ mol O}$$

$$\frac{2.96 \text{ mol C}}{0.0592} = 5.00 \text{ mol C}$$

$$\frac{4.73 \text{ mol H}}{0.0592} = 8.00 \text{ mol H}$$

$$\frac{.0592 \text{ mol N}}{0.0592} = 1.00 \text{ mol N}$$

$$\frac{0.0592 \text{ mol Na}}{0.0592} = 1.00 \text{ mol Na}$$

$$\frac{2.37 \text{ mol O}}{0.0592} = 4.00 \text{ mol O}$$

The simplest whole-number ratio is 5.00 mol C: 8.00 mol H: 1.00 mol N: 1.00 mol Na: 4.00 mol O. The empirical formula is $C_5H_8NO_4Na$.

173. What is the empirical formula of a compound that contains 10.52 g Ni, 4.38 g C, and 5.10 g N?

$$10.52 \text{ g Ni} \times \frac{1 \text{ mol Ni}}{58.69 \text{ g Ni}} = 0.1792 \text{ mol Ni}$$

$$4.38 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 0.3470 \text{ mol C}$$

$$5.10 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 0.3640 \text{ mol N}$$

$$\frac{0.1792 \text{ mol Ni}}{0.1792} = 1.000 \text{ mol Ni}$$

$$\frac{0.3470 \text{ mol C}}{0.1792} = 1.936 \text{ mol C}$$

$$\frac{0.3640 \text{ mol N}}{0.1792} = 2.031 \text{ mol N}$$

The simplest ratio is 1.00 mol Ni: 1.936 mol C: 2.031 mol N. The empirical formula is $Ni(CN)_2$.

174. Patina The Statue of Liberty has turned green because of the formation of a patina. Two copper compounds, $Cu_3(OH)_4SO_4$ and $Cu_4(OH)_6SO_4$, form this patina. Find the mass percentage of copper in each compound.

$Cu_3(OH)_4SO_4$

$$3 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 190.65 \text{ g Cu}$$

$$8 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 128.00 \text{ g O}$$

$$4 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 4.032 \text{ g H}$$

$$1 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = 32.07 \text{ g S}$$

molar mass $Cu_3(OH)_4SO_4$ = 190.65 + 128.00 + 4.032 + 32.07 = 354.75 g/mol

$$\text{percent by mass} = \frac{190.65 \text{ g}}{354.75} + 100 = 53.74\%$$

$Cu_4(OH)_6SO_4$

$$4 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 254.20 \text{ g Cu}$$

$$10 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 160.00 \text{ g O}$$

$$6 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 6.048 \text{ g H}$$

$$1 \text{ mol S} \times \frac{32.07 \text{ g S}}{1 \text{ mol S}} = 32.07 \text{ g S}$$

molar mass $Cu_4(OH)_6SO_4$ = 254.20 + 160.00 + 6.048 + 32.07 = 452.32 g/mol

$$\text{percent by mass} = \frac{254.20 \text{ g}}{452.32 \text{ g}} \times 100 = 56.20\%$$

Section 10.5

Mastering Concepts

175. What is a hydrated compound? Use an example to illustrate your answer.

A hydrated compound is a compound that has a specific number of water molecules associated with its atoms, for example, $Na_2CO_3 \cdot 10H_2O$ and $CuSO_4 \cdot 5H_2O$.

176. Explain how hydrates are named.

First, name the compound. Then, add a prefix (mono- di- tri-) that indicates how many water molecules are associated with one mole of compound.

177. Desiccants Why are certain electronic devices transported with desiccants?

Desiccants are anhydrous forms of a hydrate that absorbs water from the air and keep it off of electronic devices.

178. In a laboratory setting, how would you determine if a compound was a hydrate?

Mass a sample of the compound before heating. Heat the compound, allow it to cool, and remass the sample. A change in mass might indicate that the compound is a hydrate.

179. Write the formula for the following hydrates.

a. nickel(II) chloride hexahydrate

$NiCl_2 \cdot 6H_2O$

b. cobalt(II) chloride hexahydrate

$CoCl_2 \bullet 6H_2O$

c. magnesium carbonate pentahydrate

$MgCO_3 \bullet 5H_2O$

d. sodium sulfate decahydrate

$Na_2SO_4 \bullet 10H_2O$

Mastering Problems

180. Determine the mass percent of anhydrous sodium carbonate (Na_2CO_3) and water in sodium carbonate decahydrate ($Na_2CO_3{\cdot}10H_2O$).

$$2 \text{ mol Na} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 45.98 \text{ g Na}$$

$$1 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 12.01 \text{ g C}$$

$$13 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 208.00 \text{ g O}$$

$$20 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 20.16 \text{ g H}$$

molar mass $Na_2CO_3 \cdot 10H_2O$ = 45.98 + 12.01 + 208.00 + 20.16 = 286.15 g/mol

$$2 \text{ mol Na} \times \frac{22.99 \text{ g Na}}{\cancel{1 \text{ mol Na}}} = 45.98 \text{ g Na}$$

$$1 \text{ mol C} \times \frac{12.01 \text{ g C}}{\cancel{1 \text{ mol C}}} = 12.01 \text{ g C}$$

$$3 \text{ mol O} \times \frac{16.00 \text{ g O}}{\cancel{1 \text{ mol O}}} = 48.00 \text{ g O}$$

molar mass Na_2CO_3 = 45.98 + 12.01 + 48.00 = 105.99 g/mol

$$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g O}$$

$$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$$\frac{105.99 \text{ g}}{286.15 \text{ g}} \times 100 = 37.03\% \ Na_2CO_3$$

$$\frac{10(18.02 \text{ g})}{286.15 \text{ g}} \times 100 = 62.97\% \ H_2O$$

181. **Table 10.4** shows data from an experiment to determine the formulas of hydrated barium chloride. Determine the formula for the hydrate and its name.

Data for $BaCl_2{\cdot}xH_2O$	
Mass of empty crucible	21.30 g
Mass of hydrate + crucible	31.35 mL
Initial mass of hydrate	
Mass after heating 5 min	29.87 g
Mass of anhydrous solid	

initial mass of hydrate = (mass of hydrate + crucible) − (mass of empty crucible) = 31.35 g − 21.30 g = 10.05 g

mass of anhydrous solid = (mass after heating 5 min) − (mass of empty crucible) = 29.87 g − 21.30 g = 8.57 g

mass of water = (initial mass of hydrate) − (mass of anhydrous solid) = 10.05 g − 8.57 g = 1.48 g

$$1 \text{ mol Ba} \times \frac{137.33 \text{ g Ba}}{1 \text{ mol Ba}} = 137.33 \text{ g Ba}$$

$$2 \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 70.90 \text{ g Cl}$$

molar mass $BaCl_2$ = 137.33 + 70.90 = 208.23 g/mol

$$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g O}$$

$$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$$8.57 \text{ g } BaCl_2 \times \frac{1 \text{ mol } BaCl_2}{208.23 \text{ g } BaCl_2} = 0.0412 \text{ mol } BaCl_2$$

$$1.48 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.0821 \text{ mol } H_2O$$

$$n = \frac{0.0821 \text{ mol}}{0.0412 \text{ mol}} = 2.00$$

$BaCl_2 \cdot 2H_2O$, barium chloride dihydrate

182. Chromium(III) nitrate forms a hydrate that is 40.50% water by mass. What is its chemical formula?

100.0% − 40.5% = 59.5% $Cr(NO_3)_3$

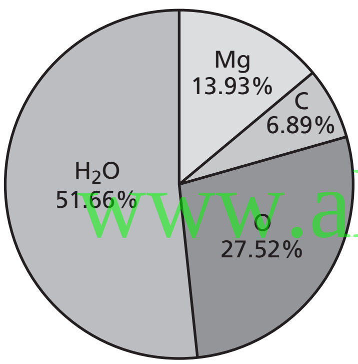
$$\frac{59.5\text{ g }Cr(NO_3)_3}{238\text{ g/mol}} = \frac{0.250\text{ mol }Cr(NO_3)_3}{0.250\text{ mol}}$$

= 1 mol $Cr(NO_3)_3$

$$\frac{40.80\text{ g }H_2O}{18.02\text{ g/mol}} = \frac{2.26\text{ mol }H_2O}{0.250\text{ mol}} = 9\text{ mol }H_2O$$

formula = $Cr(NO_3)_3 \bullet 9\ H_2O$

183. Determine the percent composition of $MgCO_3 \bullet 5H_2O$ and draw a pie graph to represent the hydrate.



Circle graph should show the following percentages (if addition of molar mass takes place to one-hundredths spot): 13.93% Mg, 6.89% C, 27.52% O, 51.66% H_2O

Molar mass = 174.41 g/mol

$$1\text{ mol Mg} \times \frac{24.30\text{ g/mol}}{174.41\text{ g/mol}} \times 100 = 13.93\%\text{ Mg}$$

$$1\text{ mol C} \times \frac{12.01\text{ g/mol}}{174.41\text{ g/mol}} \times 100 = 6.89\%\text{ C}$$

$$3\text{ mol O} \times \frac{16.00\text{ g/mol}}{174.41\text{ g/mol}} \times 100 = 27.52\%\text{ O}$$

$$5\text{ mol }H_2O \times \frac{18.02\text{ g}}{\text{mol/174.41 g/mol}} \times 100$$

= 51.66% H_2O

184. What is the formula and name of a hydrate that is 85.3% barium chloride and 14.7% water?

$$1\text{ mol Ba} \times \frac{137.33\text{ g Ba}}{1\text{ mol Bas}} = 137.33\text{ g Ba}$$

$$2\text{ mol Cl} \times \frac{35.45\text{ g Cl}}{1\text{ mol Cl}} = 70.90\text{ g Cl}$$

molar mass $BaCl_2$ = 137.33 + 70.90 = 208.23 g/mol

$$1\text{ mol O} \times \frac{16.00\text{ g O}}{1\text{ mol O}} = 16.00\text{ g O}$$

$$2\text{ mol H} \times \frac{1.008\text{ g H}}{1\text{ mol H}} = 2.016\text{ g H}$$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$$85.3\text{ g }BaCl_2 \times \frac{1\text{ mol }BaCl_2}{208.23\text{ g }BaCl_2} = 0.410\text{ mol }BaCl_2$$

$$14.7\text{ g }H_2O \times \frac{1\text{ mol }H_2O}{18.02\text{ g }H_2O} = 0.816\text{ mol }H_2O$$

$$n = \frac{0.816\text{ mol}}{0.410\text{ mol}} = 2.00$$

$BaCl_2 \bullet 2H_2O$, barium chloride dihydrate

185. Gypsum is hydrated calcium sulfate. A 4.89-g sample of this hydrate was heated. After the water was removed, 3.87 g anhydrous calcium sulfate remained. Determine the formula for this hydrate and name the compound.

mass of hydrated $CaSO_4$ = mass of $CaSO_4$ + mass of H_2O

mass of H_2O = mass of hydrated $CaSO_4$ − mass of H_2O = 4.89 g − 3.87 g = 1.02 g

$$1\text{ mol Ca} \times \frac{40.08\text{ g Ca}}{1\text{ mol Ca}} = 40.08\text{ g Ca}$$

$$1\text{ mol S} \times \frac{32.07\text{ g S}}{1\text{ mol S}} = 32.07\text{ g S}$$

$$4\text{ mol O} \times \frac{16.00\text{ g O}}{1\text{ mol O}} = 64.00\text{ g O}$$

molar mass $CaSO_4$ = 40.08 + 32.07 + 64.00 = 136.15 g/mol

$$1\text{ mol O} \times \frac{16.00\text{ g O}}{1\text{ mol O}} = 16.00\text{ g O}$$

$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$3.87 \text{ g } CaSO_4 \times \frac{1 \text{ mol } CaSO_4}{134.15 \text{ g } CaSO_4} = 0.0284 \text{ mol}$ $CaSO_4$

$1.02 \text{ g } H_2O + \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.0566 \text{ mol } H_2O$

$n = \frac{0.0566 \text{ mol}}{0.0284 \text{ mol}} = 2.00$

$CaSO_4 \bullet 2H_2O$, calcium sulfate dihydrate

186. A 1.628−g sample of a hydrate of magnesium iodide is heated until its mass is reduced to 1.072 g and all water has been removed. What is the formula of the hydrate?

mass of water = mass of hydrate − mass of anhydrous solid = 1.628 g − 1.072 g = 0.556 g

$1 \text{ mol Mg} \times \frac{24.31 \text{ g Mg}}{1 \text{ mol Mg}} = 24.31 \text{ g Mg}$

$2 \text{ mol I} \times \frac{126.90 \text{ g I}}{1 \text{ mol I}} = 253.80 \text{ g I}$

molar mass MgI_2 = 24.31 + 253.80 = 278.11 g/mol

$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g O}$

$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$1.072 \text{ g } MgI_2 \times \frac{1 \text{ mol } MgI_2}{278.11 \text{ g } MgI_2}$
$= 0.003855 \text{ mol } MgI_2$

$0.556 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.0309 \text{ mol } H_2O$

$n = \frac{0.0309 \text{ mol}}{0.003855 \text{ mol}} = 8.02$

$MgI_2 \bullet 8H_2O$

187. Borax Hydrated sodium tetraborate ($Na_2B_4O_7{\cdot}xH_2O$) is commonly called borax. Chemical analysis indicates that this hydrate is 52.8% sodium tetraborate and 47.2% water. Determine the formula and name the hydrate.

$2 \text{ mol Na} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 45.98 \text{ g Na}$

$4 \text{ mol B} \times \frac{12.01 \text{ g B}}{1 \text{ mol B}} = 48.04 \text{ g B}$

$7 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 112.00 \text{ g O}$

molar mass $Na_2B_4O_7$ = 45.98 + 48.04 + 112.00 = 206.02 g/mol

$1 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g O}$

$2 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 2.016 \text{ g H}$

molar mass H_2O = 16.00 + 2.016 = 18.02 g/mol

$52.8 \text{ g } Na_2B_4O_7 \times \frac{1 \text{ mol } Na_2B_4O_7}{206.02 \text{ g } Na_2B_4O_7}$
$= 0.256 \text{ mol } Na_2B_4O_7$

$47.2 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 2.61 \text{ mol } H_2O$

$n = \frac{2.61 \text{ mol}}{0.256 \text{ mol}} = 10.2$

$Na_2B_4O_7 \bullet 10H_2O$, sodium tetraborate decahydrate

Mixed Review

188. Rank samples A–D from least number of atoms to greatest number of atoms. A: 1.0 mol of H_2, B: 0.75 mol of H_2O, C: 1.5 mol of NaCl, D: 0.50 mol of Ag_2S

A: H2 has two atoms per mole, thus 2(1.0 mol) = 2 mol atoms

$2.0 \text{ mol} \times \frac{6.02 + 10^{23} \text{ atoms}}{1 \text{ mol H}} = 1.20 + 10^{24}$ atoms

B: H_2O has three atoms per mole, thus 3 (0.75 mol) = 2.25 mol atoms

$2.25 \text{ mol} \times \frac{6.02 + 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.35 + 10^{24}$ atoms

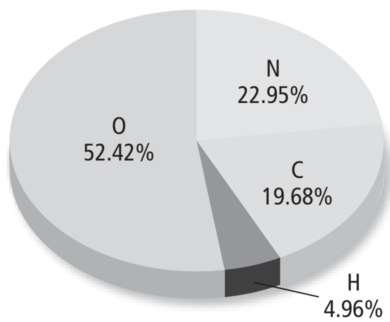
C: NaCl has two atoms per mole, thus (1.5 mol) = 3.0 mol atoms

$3.0 \text{ mol} \times \frac{6.02 + 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.81 + 10^{24}$ atoms

D: Ag_2S has three atoms per mole, thus 3(0.50 mol) = 1.5 mol atoms

$1.5 \text{ mol} \times \frac{6.02 + 10^{23} \text{ atoms}}{1 \text{ mol}} = 9.03 + 10^{23}$ atoms

D < A < B < C



189. The graph in **Figure 10.23** shows the percent composition of a compound containing carbon, hydrogen, oxygen, and nitrogen. How many grams of each element are present in 100 g of the compound?

Because the percentages are 100-based values, and the masses per 100-g are desired, simply change each percent to grams.

52.42 g O, 22.95 g N, 19.68 g C, 4.96 g H

190. How many grams of $CoCl_2$•6 H_2O must you measure out in a container to have exactly Avogadro's number of particles?

Avogadro's number is the number of particles in one mole. You must measure 237.8 g of $CoCl_2 \cdot 6\ H_2O$ to have one mole of particles of this compound.

191. One atom of an unknown element has a mass of 6.66 1 10^{-23} g. What is the identity of this element?

$\frac{6.66 + 10^{-23} \text{ g}}{1 \text{ atom}} \times \frac{6.02 + 10^{23} \text{ atoms}}{1 \text{ mol}}$
= 40.09 g/mol

This is closest to the molar mass of calcium.

192. Skunks Analysis of skunk spray yields a molecule with 44.77% C, 7.46% H and 47.76% S. What is the chemical formula for this molecule found in the spray from skunks that scientists think is partly responsible for the foul odor?

$$\frac{44.77 \text{ g C}}{12.01 \text{ g/mol}} = \frac{3.73 \text{ mol C}}{1.49 \text{ mol}} = 2.5 \text{ mol C}$$

$$\frac{7.46 \text{ g H}}{1.008 \text{ g/mol}} = \frac{7.40 \text{ mol H}}{1.49 \text{ mol}} = 5 \text{ mol H}$$

$$\frac{47.776 \text{ g S}}{32.07 \text{ g/mol}} = \frac{1.49 \text{ mol S}}{1.49 \text{ mol}} = 1 \text{ mol S}$$

$$\frac{3.73 \text{ mol C}}{1.49 \text{ mol}} : \frac{7.40 \text{ mol H}}{1.49 \text{ mol}} : \frac{1.49 \text{ mol S}}{1.49 \text{ mol}}$$

(2.5 mol C:5.0 mol H:1 mol S)2 = 5.0 mol C:10.0 mol H:2.0 mol S = $C_5H_{10}S_2$

193. How many moles are present in 1.00 g of each compound?

a. L-tryptophan ($C_{11}H_{12}N_2O_2$), an essential amino acid

$C_{11}H_{12}N_2O_2$: molar mass = 204 g/mol

1.00 g/204 g/mol = 0.00490 mol $C_{11}H_{12}N_2O_2$

b. magnesium sulfate heptahydrate, also known as Epsom salts

$MgSO_4 \cdot 7\ H_2O$: molar mass = 246.4 g/mol

1.00 g/246.4 g/mol =
0.00406 mol $MgSO_4 \cdot 7\ H_2O$

c. propane (C_5H_8), a fuel

C_5H_8: molar mass = 68.1 g/mol

1.00 g/68.1 g/mol = 0.0147 mol C_5H_8

194. A compound contains 6.0 g of carbon and 1.0 g of hydrogen, and has a molar mass of 42.0 g/mol. What are the compound's percent composition, empirical formula, and molecular formula?

6.0 g C/7.0 g = 85.7 % C

1.0 g H/7.0 g = 14.3 % H

(6.0 g C)/(12.01 g/mol) = 0.50 mol C

(1.0 g H)/(1.008 g/mol) = 1.0 mol H

0.50 mol C/0.50 mol = 1 mol C

1.0 mol H/0.50 mol = 2 mol H

empirical formual: 1 mol C:2 mol H = CH_2

empirical mass = 14.0 g/mol

empirical mass/molar mass = (42.0 g/mol)/(14.0 g/mol) = 3

molecular formula = 3(CH_2) = C_3H_6

195. Which of these compounds has the greatest percent of oxygen by mass: TiO_2, Fe_2O_3, or Al_2O_3?

$$\textbf{1 mol Ti} + \frac{\textbf{47.87 g Ti}}{\textbf{1 mol Ti}} = \textbf{47.87 g Ti}$$

$$\textbf{2 mol O} + \frac{\textbf{16.00 g O}}{\textbf{1 mol O}} = \textbf{32.00 g O}$$

molar mass TiO_2 = 47.87 + 32.00 = 79.87 g/mol

$$\textbf{2 mol Fe} + \frac{\textbf{55.85 g Fe}}{\textbf{1 mol Fe}} = \textbf{111.70 g Fe}$$

$$\textbf{3 mol O} + \frac{\textbf{16.00 g O}}{\textbf{1 mol O}} = \textbf{48.00 g O}$$

molar mass Fe_2O_3 = 111.70 + 48.00 = 159.70 g/mol

$$\textbf{2 mol Al} + \frac{\textbf{26.98 g Al}}{\textbf{1 mol Al}} = \textbf{53.96 g Al}$$

$$\textbf{3 mol O} + \frac{\textbf{16.00 g O}}{\textbf{1 mol O}} = \textbf{48.00 g O}$$

molar mass Al_2O_3 = 53.96 + 48.00 = 54.44 g/mol

$$\textbf{percent by mass} = \frac{\textbf{32.00 g}}{\textbf{79.87 g}} + 100 = \textbf{40.07\% O in } TiO_2$$

$$\textbf{percent by mass} = \frac{\textbf{48.00 g}}{\textbf{159.70 g}} + 100 = \textbf{30.06\% O in } Fe_2O_3$$

$$\textbf{percent by mass} = \frac{\textbf{48.00 g}}{\textbf{54.44 g}} + 100 = \textbf{87.99\% O in } Al_2O_3$$

Al_2O_3 has the greatest percent of oxygen by mass.

196. Mothballs Naphthalene, commonly found in mothballs, is composed of 93.7% carbon and 6.3% hydrogen. The molar mass of naphthalene is 128 g/mol. Determine the empirical and molecular formulas for naphthalene.

$$\textbf{93.7 g C} + \frac{\textbf{1 mol C}}{\textbf{12.01 g C}} = \textbf{7.80 mol C}$$

$$\textbf{6.3 g H} + \frac{\textbf{1 mol H}}{\textbf{1.008 g H}} = \textbf{6.2 mol H}$$

$$\frac{\textbf{7.80 mol C}}{\textbf{6.2}} = \textbf{1.25 mol C}$$

$$\frac{\textbf{6.2 mol H}}{\textbf{6.2}} = \textbf{1.0 mol H}$$

The simplest ratio is 1.25 mol C : 1.0 mol H. Multiply both subscripts by four to obtain the simplest whole-number ratio. The empirical formula is C_5H_4.

$$\textbf{5 mol C} + \frac{\textbf{12.01 g C}}{\textbf{1 mol C}} = \textbf{60.05 g C}$$

$$\textbf{4 mol H} + \frac{\textbf{1.008 g H}}{\textbf{1 mol H}} = \textbf{4.032 g H}$$

molar mass = 60.05 + 4.032 = 64.09 g/mol

$$n = \frac{\textbf{128 g/mol}}{\textbf{64.09 g/mol}} = \textbf{2.00}$$

Molecular formula is $C_{10}H_8$.

197. Which of these molecular formulas are also empirical formulas: ethyl ether ($C_4H_{10}O$), aspirin ($C_9H_8O_4$), butyl dichloride ($C_4H_8Cl_2$), glucose ($C_6H_{12}O_6$)?

$C_4H_{10}O$ and $C_9H_8O_4$; The subscripts in $C_4H_{10}O$ and $C_9H_8O_4$ represent simplest whole-number ratios.

Think Critically

198. Apply Concepts A mining company has two possible sources of copper: chalcopyrite ($CuFeS_2$) and chalcocite (Cu_2S). If the mining conditions and the extraction of copper from the ore were identical for each of the ores, which ore would yield the greater quantity of copper? Explain your answer.

$CuFeS_2$

1 Cu + 63.55 g/mol = 63.55 g

1 Fe + 55.85 g/mol = 55.85

2 S + 32.07 g/mol = 64.14 g

molar mass = 183.54 g/mol

%Cu = (63.55 g/183.54 g/mol) + 100 = 34.62 % Cu

Cu_2S

2 Cu + 63.55 g/mol = 127.10 g

1 S + 32.07 g/mol = 32.07 g

molar mass = 159.17 g/mol

% Cu = (127.10 g/159.17 g/mol) + 100 = 79.9% Cu

Chalcopyrite ($CuFeS_2$) is 34.6% copper by mass (determined from percent composition) and chalcocite (Cu_2S) is 79.9% copper by mass. Chalcocite would yield the greater quantity of copper because the ore has the greater percentage copper by mass.

199. Analyze and Conclude On a field trip, students collected rock samples. Analysis of the rocks revealed that two of the rock samples contained lead and sulfur. **Table 10.5** shows the percent lead and sulfur in each of the rocks. Determine the molecular formula of each rock. What can the students conclude about the rock samples?

Lead and Sulfur Content

Rock Sample	% Lead	% Sulfur
1	86.6 %	13.4%
2	76.4%	23.6%

Rock Sample 1

86.6 % g Pb = 86.6 g Pb; 86.6 g/207.2 g/mol = 0.418 mol Pb

13.4% g S = 13.4 g; 13.4 g/32.07 g/mol = 0.418 mol S

Dividing each quantity by 0.418 mol yields: 1 mol Pb + 1 mol S = PbS

Rock Sample 2

76.4% g Pb = 76.4 g Pb; 76.4 g/207.2 g/mol = 0.369 mol Pb

23.6% g S = 23.6 g S; 23.6 g/32.07 g/mol = 0.736 mol S

Dividing each quantity by 0.369 mol yields:

1 mol Pb + 2 mol S = PbS_2

The rocks contain two different compounds of lead and sulfur. Further analysis will show that Sample 1 has the formula PbS and that Sample 2 has the formula PbS_2.

200. Graph A YAG, or yttrium aluminum garnet ($Y_3Al_5O_{12}$), is a synthetic gemstone which has no counterpart in nature. Design a bar graph to indicate the moles of each element present in a 5.67 carat yttrium aluminum garnet. (1 carat 5 0.20 g)

(5.67 carat $Y_3Al_5O_{12}$)(0.20 g/carat) = 1.13 g $Y_3Al_5O_{12}$

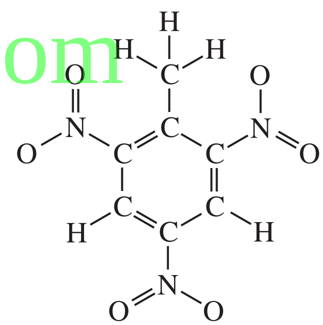
(1.13 $Y_3Al_5O_{12}$)(1 mol/436.75 g) = 0.00260 mol $Y_3Al_5O_{12}$

(0.00260 mol $Y_3Al_5O_{12}$)(3 mol Y/1 mol $Y_3Al_5O_{12}$) = 0.00779 mol Y

(0.00260 mol $Y_3Al_5O_{12}$)(5 mol Al/1 mol $Y_3Al_5O_{12}$) = 0.0130 mol Al

(0.00260 mol $Y_3Al_5O_{12}$)(12 mol O/1 mol $Y_3Al_5O_{12}$) = 0.0312 mol O

The bar graph should show 0.00779 mol Y, 0.0130 mol Al, and 0.0312 mol O.



201. Assess The structure of the TNT molecule is shown in **Figure 10.24.** Critique the statement "Trinitrotoluene, TNT, contains 21 atoms per mole." What is correct about the statement and what is incorrect? Rewrite the statement.

A molecule of TNT contains 21 atoms but a mole of TNT contains 6.02×10^{23} molecules. The statement is false as stated. "Trinitrotoluene, TNT, has the formula $C_7H_5N_3O_6$ which contains 21 atoms but a mole of TNT contains 6.02×10^{23} molecules.

202. Design an Experiment Design an experiment that can be used to determine the amount of water in alum ($KAl(SO_4)_2 \cdot xH_2O$).

Determine and record the mass of an empty evaporating dish. Add about 2 g of the hydrate. Measure and record the mass. Heat the evaporating dish gently for 5 minutes, and strongly for another 5 minutes to evaporate all the water. Allow the dish to cool, and measure and record the mass. Determine the masses of the anhydrous solid and the water lost. Calculate the number of moles of anhydrous compound and water. Determine the ratio of moles of water to moles of anhydrous compound. Use the whole-number ratio of the moles as the coefficient of H_2O in the formula.

203. Design a concept map that illustrates the mole concept. Include the terms *moles, Avogadro's number, molar mass, number of particles, percent composition, empirical formula, and molecular formula.*

Concept maps will vary but should show logical connection between Avogadro's number of particles, a mole, and molar mass, and also show how the molecular formula is a whole-number multiple of the empirical formula.

Challenge Problem

204. Two different compounds are composed of Elements X and Y. The formulas of the compounds are X_2Y_3 and XY. A 0.25 mol sample of XY has a mass of 17.96 g, and a 0.25 mol sample of X_2Y_3 has a mass of 39.92 g.

a. What are the atomic masses of elements X and Y?

b. What are the formulas for the compounds?

Compound XY: $\frac{17.96 \text{ g}}{0.25 \text{ mol}} = 71.84 \text{ g/mol}$

71.84 g/mol = X + Y, Y = 71.84 g/mol = X
Compound X_2Y_3: 39.92 g/0.25 mol = 159.68 g/mol

159.68 g/mol = 2X + 3Y

159.68 g/mol = 2X + 3(71.84 g/mol – X) [substitute for Y and solve for X]

159.68 g/mol = 2X + 215.52 g/mol – 3X

–55.85 g/mol = −X

X = 55.84g/mol

X + Y = 71.84 g/mol

55.84g/mol + Y = 71.84 g/mol

Y = 16 g/mol

X is the element iron (Fe);Y is the element oxygen (O)

Formulas are FeO and Fe_2O_3.

Cumulative Review

205. Express each answer with the correct number of significant figures. *(Chapter 2)*

a. 18.23 − 456.7

−438.5

b. 4.233 ÷ 0.0131

323

c. (82.44 + 4.92) ÷ 0.125

406

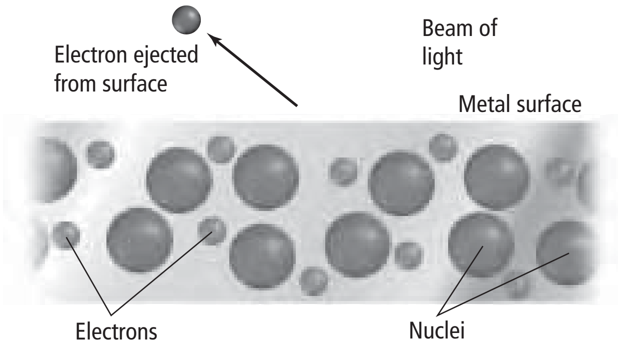
206. Making Candy A recipe for pralines calls for the candy mixture to be heated until it reaches the "soft ball" stage, about 236 °F. Can a Celsius thermometer with a range of –10 to 110 °C be used to determine when the "soft ball" stage is reached? (*Chapter 2*)

$$°C = \frac{°F - 32}{1.8} = \frac{204}{1.8} = 113\ °C.$$

No, the Celsius thermometer could not be used because 113°C is beyond the range of the thermometer.

207. Contrast atomic number and mass number. Compare these numbers for isotopes of an element. *(Chapter 4)*

Atomic number equals the number of protons. Mass number equals the number of protons plus the number of neutrons. Two isotopes of an element will have the same atomic number but different mass numbers.



208. Describe the phenomenon in Figure 10.25. Explain why the electrons are not bound to the nuclei. *(Chapter 5)*

The illustration shows the photoelectric effect; the emission of electrons from a metal surface when light of sufficient energy strikes the metal. The electrons in metals are not bound to nuclei; they are free to move.

209. Given the elements Ar, Cs, Br, and Ra, identify those that form positive ions. Explain your answer. *(Chapter 7)*

Cs and Ra can form positive ions. The configuration of Cs is $[Xe]6s^1$; Cs loses 1 valence electron to form a 1+ ion. The configuration of Ra is $[Rn]7s^2$; Ra loses 2 electrons to form a 2+ ion. Argon is a noble gas and does not lose or gain electrons. Br gains one electron to form a 1− ion.

210. Write the formula and name the compound formed when each pair of elements combine. *(Chapter 7)*

a. barium and chlorine

$BaCl_2$; barium chloride

b. aluminum and selenium

Al_2Se_3; aluminum selenide

c. calcium and phosphorus

Ca_3P_2; calcium phosphide

211. Write balanced equations for each reaction. *(Chapter 9)*

a. Magnesium metal and water combine to form solid magnesium hydroxide and hydrogen gas.

$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$

b. Dinitrogen tetroxide gas decomposes into nitrogen dioxide gas.

$N_2O_4(g) \rightarrow 2NO_2(g)$

c. Aqueous solutions of sulfuric acid and potassium hydroxide undergo a double-replacement reaction.

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

Additional Assessment

Writing in Chemistry

212. Natural Gas Natural gas hydrates are chemical compounds known as clathrate hydrates. Research natural gas hydrates and prepare an educational pamphlet for consumers. The pamphlet should discuss the composition and structure of the compounds, the location of the hydrates, their importance to consumers, and the environmental impact of using the hydrates.

Natural gas hydrates are crystalline solids resembling snow that consist of a water-ice lattice within which light hydrocarbon molecules such as methane, ethane, and propane are trapped in the space between water molecules. They naturally form at moderately high pressures and temperatures near the freezing point of water. These conditions exist in the Arctic permafrost regions of North America and Eurasia and at depth along the world's continental slopes and rises on the sea floor. Natural gas hydrate can be thought of as a "methane concentrator". Gas hydrates may be a new clean energy source. Huge amounts of natural gas are tied up in natural gas hydrates globally. If exploited as a energy source, removal of gas hydrates may destabilize the sea floor, triggering submarine landslides and huge releases of methane. Methane is a very effective greenhouse gas, and large methane releases may explain sudden episodes of climatic warming in the geologic past.

213. Avogadro Research and report on the life of the Italian chemist Amedeo Avogadro (1776–1856) and how his work led scientists to determine the number of particles in a mole.

Students should mention Avogadro's hypothesis. Avogadro formulated his hypothesis as an explanation for earlier works by Gay-Lussac and Ritter. His ideas were rejected by chemists of his day but were revived later by the Italian chemist Stanislao Cannizzaro. Avogadro died before seeing his ideas accepted.

214. Luminol Crime-scene investigators use luminol to visualize blood residue. Research luminol and determine its chemical formula and percent composition.

Luminol($C_8H_7O_2N_3$) reacts with compounds in blood and releases energy in the form of light. When crime scene investigators see the light, they know blood is at the scene. The percent composition of $C_8H_7O_2N_3$ is 54.23% C, 3.98% H, 18.06% O, and 23.72% N.

8 mol C × 12.01 g/mol = 96.08 g C

7 mol H × 1.008g.mol = 7.056 g H

2 mol O × 16.00 g/mol = 32.00 g O

3 mol N × 14.01 g/mol = 42.03 g N

molar mass = 177.17 g/mol

% C = (96.08 g C/177.17 g/mol) × 100 = 54.23% C

% H = (7.056 g H/177.17 g/mol) × 100 = 3.98% H

% O = (32.00 g O/177.17 g/mol) × 100 = 18.06% O

% N = (42.03 g /177.17g/mol) × 100 = 23.72% N

Document-Based Questions

Space Shuttle Propellants At liftoff, the orbiter and an external fuel tank carry 3,164,445 L of the liquid propellants hydrogen, oxygen, hydrazine, monomethylhydrazine and dinitrogen tetroxide. Their total mass is 727,233 kg. Data for the propellants carried at liftoff are given in **Table 10.6.**

Data obtained from: "Space Shuttle Use of Propellants and Fluids." September 2001. *NASA Fact Sheet*

Space Shuttle Liquid Propellants

Propellants	Molecular Formula	Mass (kgs)	Mole	Molecules
Hydrogen	H_2	**1.04 + 10^5**	5.14 + 10^7	**3.09 + 10^{31}**
Oxygen	O_2	**6.18 + 10^5**	**1.93 + 10^7**	1.16 + 10^{31}
Hydrazine	**N_2H_4**	493	**1.54 + 10^4**	**9.27 + 10^{27}**
Monomethyl-hydrazine	CH_3NHNH_2	4,909	**1.07 + 10^5**	**6.44 + 10^{28}**
Dinitrogen tetroxide	N_2O_4	**7950**	8.64 + 10^4	**5.20 + 10^{28}**

215. Hydrazine contains 87.45% nitrogen and 12.55% hydrogen, and has a molar mass of 32.04 g/mol. Determine hydrazine's molecular formula. Record the molecular formula in **Table 10.6.**

87.45% g N = 87.45 g; 87.45 g/14.01 g/mol = 6.24 mol N 12.55% g H = 12.55 g H; 12.55 g/1.008 g/mol = 12.45 mol H

Dividing each quantity by 6.24 mol yields: 1 mol N : 2 mol H

Empirical formula = NH_2

Empirical mass = 14.007 g + 2(1.008 g) = 16.023 g/mol

(32.04 g/mol)/(16.023 g/mol) = 2

molecular formula = 2(NH_2) = N_2H_4

216. Complete **Table 10.6** by calculating the number of moles, mass in kilograms, or molecules for each propellant. Give all answers to three significant figures.

Space Shuttle Liquid Propellants

Propellants	Molecular Formula	Mass (kgs)	Mole	Molecules
Hydrogen	H_2	**$1.04 + 10^5$**	$5.14 + 10^7$	**$3.09 + 10^{31}$**
Oxygen	O_2	**$6.18 + 10^5$**	**$1.93 + 10^7$**	$1.16 + 10^{31}$
Hydrazine	**N_2H_4**	493	**$1.54 + 10^4$**	**$9.27 + 10^{27}$**
Monomethyl-hydrazine	CH_3NHNH_2	4,909	**$1.07 + 10^5$**	**$6.44 + 10^{28}$**
Dinitrogen tetroxide	N_2O_4	**7950**	$8.64 + 10^4$	**$5.20 + 10^{28}$**

5.14×10^7 mol × 2.016 g/mol × 1kg/1000g = 1.04×10^5 kg

5.14×10^7 mol × 6.02×10^{23} particles/mol = 3.09×10^{31}

1.93×10^7 mol × 32.00g/mol × 1kg/1000 g = 6.18×10^5

1.16×10^{31} particles × 1mol/6.02×10^{23} particles = 1.93×10^7 mol

493 kg × 1000g/kg × 1 mol/32.05 g = 1.54×10^4

1.54×10^4 mol × 6.02×10^{23} particles/mol = 9.27×10^{27} particles

4,909 kg × 1000 g/kg × 1 mol/46.08 g = 1.07×10^5

1.07×10^5 mol × 6.02×10^{23} particles/mol = 6.41 × 10^{28} particles

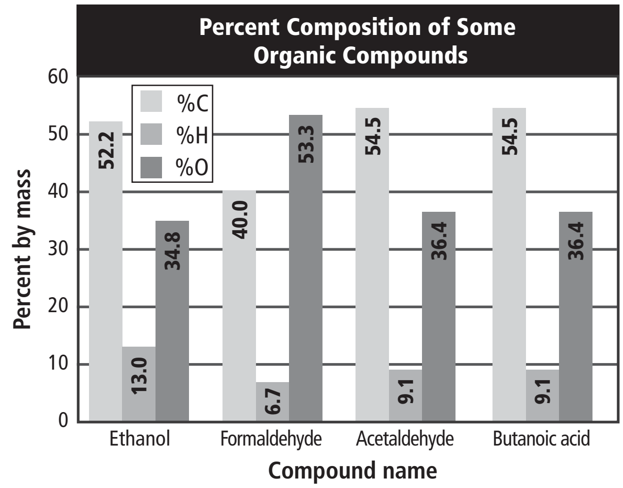
8.64×10^4 mol × 92.02 g/mol × 1 kg/1000 g = 7950 kg

8.64×10^4 mol × 6.02×10^{23} particles/mol = 5.20×10^{28} particles

Standardized Test Practice

pages 364–365

Use the graph below to answer Questions 1 to 4.



1. Acetaldehyde and butanoic acid must have the same

a. molecular formula.
b. empirical formula
c. molar mass.
d. chemical properties.

b

2. If the molar mass of butanoic acid is 88.1 g/mol, what is its molecular formula?

a. $C_3H_4O_3$
b. C_2H_4O
c. $C_5H_{12}O_1$
d. $C_4H_8O_2$

d

Solution:

Determine the empirical formula. Assume a 100.0 g sample.

$$54.5\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 4.54\ mol\ C$$

$$9.1\ g\ H \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 9.03\ mol\ H$$

$$36.4\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}} = 2.28\ mol\ O$$

Determine the mole rations.

$$\frac{4.54 \text{ mol C}}{2.28} = 1.99 = 2 \text{ mol C}$$

$$\frac{9.03 \text{ mol H}}{2.28} = 3.96 = 4 \text{ mol H}$$

$$\frac{2.28 \text{ mol O}}{2.28} = 1.00 = 1 \text{ mol O}$$

The empirical formula for butanoic acid is C2H4O. The mass of the empirical formula is 44.06 g/mol.

$$\frac{88.1 \text{ g/mol}}{44.06 \text{ g/mol}} = 2.00$$

The molecular formula for butanoic acid = $(C_2H_4O)2 = C_4H_8O_2$.

3. What is the empirical formula of ethanol?

a. C_4HO_3
b. C_2H_6O
c. C_2H_6O
d. $C_4H_{13}O_2$

C

Solution:

$$52.2 \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \cancel{\text{g C}}} = 4.35 \text{ mol C}$$

$$13.0 \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.008 \cancel{\text{g H}}} = 12.9 \text{ mol H}$$

$$34.8 \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \cancel{\text{g O}}} = 2.18 \text{ mol O}$$

Determine the mole ratios.

$$\frac{4.35 \text{ mol C}}{2.18} = 2.00 \text{ mol C} = 2 \text{ mol C}$$

$$\frac{12.9 \text{ mol H}}{2.18} = 5.92 \text{ mol H} = 6 \text{ mol H}$$

$$\frac{2.18 \text{ mol O}}{2.18} = 1 \text{ mol O} = 1 \text{ mol O}$$

The empirical formula for ethanol is C_2H_6O.

4. The empirical formula of formaldehyde is the same as its molecular formula. How many grams are in 2.000 mol of formaldehyde?

a. 30.00 g
b. 60.06 g
c. 182.0 g
d. 200.0 g

b

Determine the empirical formula for formaldehyde.

$$40.0 \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \cancel{\text{g C}}} = 3.33 \text{ mol C}$$

$$6.7 \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.008 \cancel{\text{g H}}} = 6.65 \text{ mol H}$$

$$53.3 \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \cancel{\text{g O}}} = 3.33 \text{ mol O}$$

$$\frac{3.33 \text{ mol C}}{3.33} = 1.00 \text{ mol C} = 1 \text{ mol C}$$

$$\frac{6.65 \text{ mol H}}{3.33} = 2.00 \text{ mol H} = 2 \text{ mol H}$$

$$\frac{3.33 \text{ mol O}}{3.33} = 1.00 \text{ mol O} = 1 \text{ mol O}$$

The empirical formula for formaldehyde is CH_2O.

Molar mass of CH_2O = 30.03 g/mol

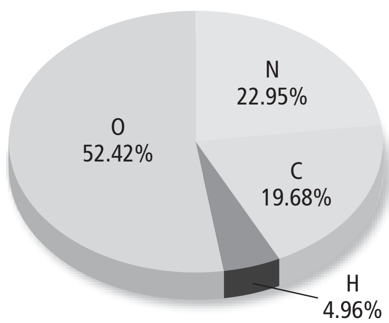
$$\frac{30.03 \text{ g}}{1 \cancel{\text{mol}}} \times 2.00 \cancel{\text{mol}} = 60.06 \text{ g formaldehyde}$$

5. Which does NOT describe a mole?

a. a unit used to count particles directly
b. Avogadro's number of molecules of a compound
c. the number of atoms in exactly 12 g of pure C-12
d. the SI unit for the amount of a substance

a

Use the graph below to answer Question 6.



6. What is the empirical formula for this compound?

a. $C_6H_{12}N_6O_3$
b. $C_4HN_5O_{10}$
c. CH_3NO_2
d. CH_5NO_3

c

Assume a 100.00 g sample.

$$19.68\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}} = 1.639\ mol\ C$$

$$4.96\ \cancel{g\ H} \times \frac{1\ mol\ H}{1.008\ \cancel{g\ H}} = 4.921\ mol\ H$$

$$22.95\ \cancel{g\ N} \times \frac{1\ mol\ N}{14.007\ \cancel{g\ N}} = 1.638\ mol\ N$$

$$52.42\ \cancel{g\ O} \times \frac{1\ mol\ O}{15.999\ \cancel{g\ O}} = 3.276\ mol\ O$$

Determine the mole ratios.

$$\frac{1.639\ mol\ C}{1.638} = 1.001\ mol\ C = 1\ mol\ C$$

$$\frac{4.921\ mol\ H}{1.638\ mol} = 3.004\ mol\ H = 3\ mol\ H$$

$$\frac{1.638\ mol\ N}{1.638} = 1\ mol\ N = 1 mol\ N$$

$$\frac{3.276\ mol\ O}{1.638} = 2\ mol\ O = 2\ mol\ O$$

The empirical formula for this compound is CH_3NO_2.

7. Which is NOT true of molecular compounds?

a. Triple bonds are stronger than single bonds.
b. Electrons are shared in covalent bonds.
c. All atoms have eight valence electrons when they are chemically stable.
d. Lewis structures show the arrangement of electrons in covalent molecules.

c

8. Which type of reaction is shown below?

$$2HI + (NH_4)_2S \rightarrow H_2S + 2NH_4I$$

a. synthesis
b. decomposition
c. single replacement
d. double replacement

d

9. How many atoms are in 0.625 moles of GE (atomic mass = 72.59 amu)?

a. 2.73×10^{25}
b. 6.99×10^{25}
c. 03.76×10^{23}
d. 9.63×10^{23}

c

$$0.625\ \cancel{mol\ Ge} \times \frac{6.02 \times 10^{23}}{1\ \cancel{mol\ Ge}}$$

$$= 3.76 \times 10^{23}\ atoms\ Ge$$

10. What is the mass of one molecule of barium hexafluorosilicate ($BaSiF_6$)?

a. 1.68×10^{26} g
b. 2.16×10^{21} g
c. 4.64×10^{-22}
d. 6.02×10^{-23}

c

Determine the molar mass of $BaSiF_6$.

$$1\ \cancel{mol\ Ba} \times \frac{137.33\ g\ Ba}{1\ \cancel{mol\ Ba}} = 137.33\ g\ Ba$$

$$1\ \cancel{mol\ Si} \times \frac{28.09\ g\ Si}{1\cancel{mol\ Si}} = 28.09\ g\ Si$$

$$6\ \cancel{mol\ F} \times \frac{19.00\ g\ F}{1\ \cancel{mol\ F}} = 114.00\ g\ F$$

$$\text{Molar mass} = 279.42\ g/mol\ BaSiF_6$$

$$\frac{279.42\ g\ BaSiF_6}{1\ \cancel{mol\ BaSiF_6}} \times \frac{1\ \cancel{mol\ BaSiF_6}}{6.02 \times 1023\ g/molecule\ BaSiF_6}$$
$$= 4.64 \times 10^{-22}\ g/molecule\ BaSiF_6$$

Use the table below to answer question 11.

Charges of Some Ions	
Ion	**Formula**
Sulfide	S^{-2}
Sulfite	SO_3^{-2}
Sulfate	SO_4^{-2}
Thiosulfate	$S_2O_3^{-2}$
Copper(I)	Cu^{+}
Copper(II)	Cu^{2+}

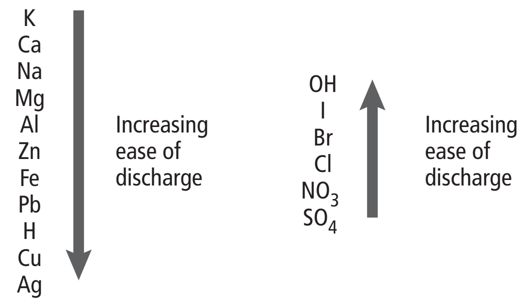
11. How many possible compounds can be made that contain copper, sulfur, and oxygen? Write their names and formulas.

Six compounds are possible.

Copper(I) thiosulfate	$Cu_2S_2O_3$
Copper(II) thisulfate	CuS_2O_3
Copper(I) sulfate	Cu_2SO_4
Copper(II) sulfate	$CuSO_4$
Copper(I) sulfite	Cu_2SO_3
Copper(II) sulfite	$CuSO_3$

Extended Response

Use the figure below to answer Question 12.



12. You have been asked to identify a sample of a metal. It is known to be either zinc, lead, or lithium. You have aqueous solutions of KCl, $AlCl_3$, $FeCl_3$, and $CuCl_2$ available. Explain how you would use these solutions to identify what metal your sample is made of.

You would need to test each sample of metal for a reaction with each of the solutions in turn. If the sample is lithium, it is more reactive than any of the four aqueous chloride solutions, and will display a reaction when placed into any of them. Lead is less reactive than any of the aqueous solutions except for the copper; therefore, if the metal reacts with the copper solution but none of the others, it is likely to be lead. Zinc is more reactive than iron and copper but less reactive than potassium and aluminum, so if the unidentified metal is zinc it will react with the iron and copper solutions but not with the potassium or aluminum solutions.

13. It takes 2 iron atoms and 6 chlorine atoms to make 2 iron (III) chloride particles. How many chlorine atomsare required to make 18 iron (III) chloride particles?

a. 9
b. 18
c. 27
d. 54
e. 72

d

$$\frac{\text{6 chlorine atoms}}{\text{2 iron (III) chloride}} = \frac{x\text{ chlorine atoms}}{\text{18 iron (III) chloride}}$$

x **= 54 chlorine atoms**

14. What is the molar mass of fluorapatite ($Ca_5(PO_4)_3F$)?

a. 314 g/mol
b. 344 g/mol
c. 442 g/mol
d. 504 g/mol
e. 534 g/mol

d

$$5 \text{ mol Ca} \times \frac{40.08 \text{ g Ca}}{1 \text{ mol Ca}} = 200.40 \text{ g Ca}$$

$$3 \text{ mol P} \times \frac{30.97\text{g P}}{1 \text{ mol P}} = 92.91 \text{ g P}$$

$$12 \text{ mol O} \times \frac{16.00 \text{ g O}}{1 \text{ mol P}} = 192.00 \text{ g O}$$

$$1 \text{ mol F} \times \frac{19.00 \text{ g F}}{1 \text{ mol F}} = 19.00 \text{ g F}$$

molar mass = 504.31 g/mol = 504 g/mol

15. Which is not a correct formula for an ionic compound?

a. CaC_{12}
b. Na_2SO_4
c. Al_3S_2
d. $Mg(NO_3)_2$
d. NaCl

c

Use the table below to answer Question 16.

Percent composition of selected hydrocarbons			
Compound	**% C**	**% H**	**% O**
$C_2H_{10}O$	64.81	13.60	21.59
$C_6H_{12}O_4$	48.64	8.108	43.24
$C_7H_{16}O_3$	56.76	10.81	32.43
$C_5H_8O_5$	40.54	5.405	54.05

16. A 25.0-g sample of an unknown hydrocarbon is composed of 12.16 g carbon, 2.027 g hydrogen, and 10.81 g oxygen. If its molecular weight is 148 g/mol, what is the molecular formula for this compound?

a. $C_2H_{10}O$
b. $C_6H_{12}O_4$
c. $C_7H_{16}O_3$
d. $C_5H_8O_5$
e. $C_8H_5O_5$

b

Determine the number of moles.

$$12.16 \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \cancel{\text{g C}}} = 1.012 \text{ mol C}$$

$$2.027 \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \cancel{\text{g H}}} = 2.007 \text{ mol H}$$

$$10.81 \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \cancel{\text{g O}}} = 0.6756 \text{ mol O}$$

Determine the empirical formula.

$$\frac{1.012 \text{ mol C}}{0.6756} = 1.498 = 1.5 \times 2 = 3$$

$$\frac{2.007 \text{ mol H}}{0.6756} = 2.971 = 3 \times 2 = 6$$

$$\frac{6.756 \text{ mol O}}{0.6756} = 1.000 = 1 \times 2 = 2$$

Empirical formula is $C_3H_6O_2$.

Determine the mass of the empirical formula.

$3 \times 12.01 \text{ g/mol} = 36.03 \text{ g/mol}$

$6 \times 1.01 \text{ g/mol} = 6.06 \text{ g/mol}$

$2 \times 16.00 \text{ g/mol} = 32.00 \text{ g/mol}$

The mass of the empirical formula is 74.09 g/mol.

$$\frac{148 \text{ g/mol}}{74.09 \text{ g/}mol} = 2$$

The molecular formula is $C_6H_{12}O_4$.