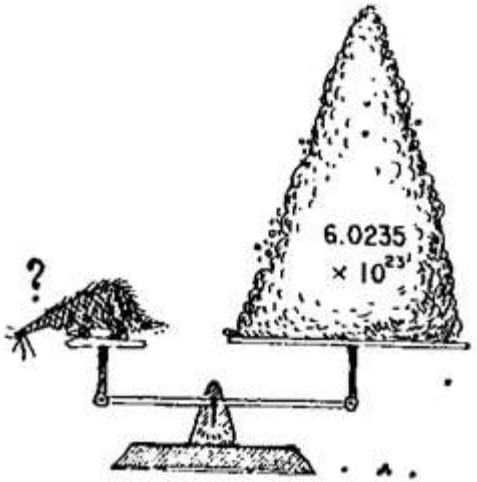
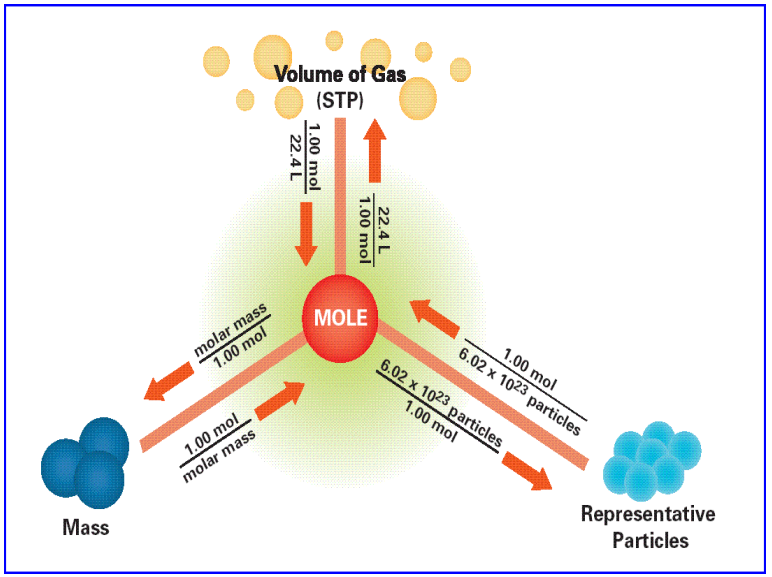
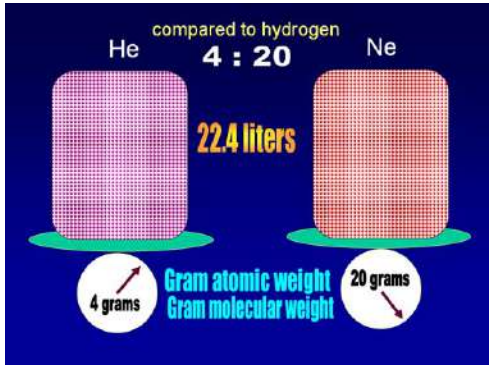




The Mole



Mole = 602,200,000,000,000,000,000,000

Population of the World = 6,000,000,000

Sextillion Quintillion Quadrillion Trillion Billion Million Thousand Hundred

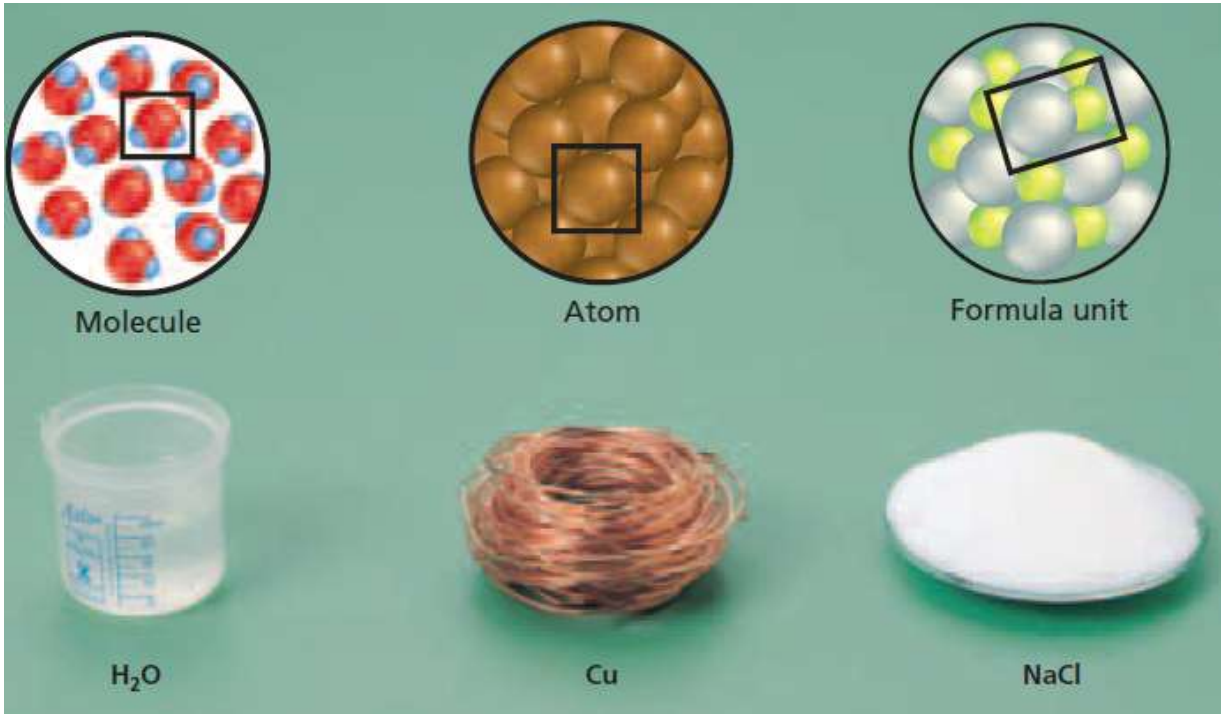
- **Chapter 11: The Mole**
- **____ 11.1 Measuring Matter**
- **____ 11.2 Mass and the Mole**
- **____ 11.3 Moles of Compounds**
- **____ 11.4 Empirical Formulas and Molecular Mass**
- **____ 11.5 The Formula for a Hydrate**

- **11.1 Measuring Matter**

- **Counting Particles**

- **What is a mole (commonly abbreviated mol)**
- **The mole is the SI unit to measure the amount of a substance.**
- **It is the number of representative particles, carbon atoms, in exactly 12g of pure carbon-12.**

- A mole of anything contains **6.02 X 10^{23}** representative particles.
- A representative particle is any kind of particle such as atoms, molecules, formula units, electrons, or ions.



- **Avagadro's Number (6.02×10^{23})**

  602,000,000,000,000,000,000,000

- **Converting Moles to Particles and Particles to Moles**

$$\text{Conversion factor: } \frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mole}}$$

PRACTICE PROBLEMS

1. Determine the number of atoms in 2.50 mol Zn.
2. Given 3.25 mol $AgNO_3$, determine the number of formula units.
3. Calculate the number of molecules in 11.5 mol H_2O.

1. 2.5 mol Zn X $\frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mole}}$

- = 1.51 X 10^{24} atoms Zn

- **2. 3.25 mol $AgNO_3$ X** $\frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mole}}$

- **= 1.96 X 10^{24} formula units $AgNO_3$**

- **3. 11.5 mol H_2O X** $\frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mole}}$

= 6.92 X 10^{24}

- Converting Particles to moles: simply multiply the number of particles by the conversion factor.

$$\text{number of representative particles} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ representative particles}} = \text{number of moles}$$

- Ex: Calculate the number of moles that contain 4.5 X 10^{24} atoms of Zn.

$$\text{number of atoms} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ atoms}} = \text{number of moles}$$

$$4.50 \times 10^{24} \text{ atoms Zn} \times \frac{1 \text{ mol Zn}}{6.02 \times 10^{23} \text{ atoms Zn}} = 7.48 \text{ mol Zn}$$

PRACTICE PROBLEMS

4. How many moles contain each of the following?

a. 5.75×10^{24} atoms Al

b. 3.75×10^{24} molecules CO_2

c. 3.58×10^{23} formula units $ZnCl_2$

d. 2.50×10^{20} atoms Fe

- 4. a. 9.55 mol Al
- b. 6.23 mol CO_3
- c. 0.595 mol $ZnCl_2$
- d. 4.15×10^{-4}

Section 11.1 Assessment

5. How is a mole similar to a dozen?
6. What is the relationship between Avogadro's number and one mole?
7. Explain how you can convert from the number of representative particles of a substance to moles of that substance.
8. Explain why chemists use the mole.
9. **Thinking Critically** Arrange the following from the smallest number of representative particles to the largest number of representative particles: 1.25×10^{25} atoms Zn; 3.56 mol Fe; 6.78×10^{22} molecules glucose ($C_6H_{12}O_6$).
10. **Using Numbers** Determine the number of representative particles in each of the following and identify the representative particle: 11.5 mol Ag; 18.0 mol H_2O; 0.150 mol NaCl.

Section 11.2 Mass and the Mole

Molar mass

The mass in grams of a mole of any pure substance is called its *molar mass.*

The molar mass of any element is equal to its atomic mass and has the units g/mol.

Ex. An atom of manganese has the atomic mass of 54.94 amu. Therefore its molar mass is 54.94 g/mol

Mole to Mass Conversion

Ex. What is the mass of 3.00 moles of Mn.

- **Conversion factor is 1 mole Mn = 54.9g**

$$\text{number of moles} \times \frac{\text{number of grams}}{1 \text{ mole}} = \text{mass}$$

$$3.00 \cancel{\text{ mol Mn}} \times \frac{54.9 \text{ g Mn}}{1 \cancel{\text{ mol Mn}}} = 165 \text{ g Mn}$$

PRACTICE PROBLEMS

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

a. 3.57 mol Al

b. 42.6 mol Si

c. 3.45 mol Co

d. 2.45 mol Zn

- Answers
- 11. a. 96.3 g Al
- b. 1.2×10^3 g Si
- c. 203 g Co
- d. 1.6×10^2 g Zn

Mass to Mole Conversion

Ex. How many moles are there in 525g calcium?

$$\text{mass} \times \frac{1 \text{ mole}}{\text{number of grams}} = \text{number of moles}$$

$$525 \text{ g } \cancel{\text{Ca}} \times \frac{1 \text{ mol Ca}}{40.08 \text{ g } \cancel{\text{Ca}}} = 13.1 \text{ mol Ca}$$

PRACTICE PROBLEMS

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

a. 25.5 g Ag
b. 300.0 g S
c. 125 g Zn
d. 1.00 kg Fe

- Answers
- 12. a. 0.236 mol Ag
- b. 9.355 mol S
- c. 1.91 mol Zn
- d. 17.9 mol Fe

- **Conversions from mass to atoms and atoms to mass (this a two-step process)**

- **Ex. How many atoms are in a 25g sample of pure gold?**

Ex. How many atoms are in a 25g sample of pure gold?

- **Step 1**
- **Multiply the mass of gold by the molar mass conversion factor:**

$$\text{mass Au} \times \frac{1 \text{ mole Au}}{\text{number of grams Au}} = \text{moles Au}$$

$$25.0 \cancel{\text{g Au}} \times \frac{1 \text{ mol Au}}{196.97 \cancel{\text{g Au}}} = 0.127 \text{ mol Au}$$

Ex. How many atoms are in a 25g sample of pure gold?

- Step 2

Multiply the calculated number of moles of gold by Avogadro's number as a conversion factor.

$$\text{moles Au} \times \frac{6.02 \times 10^{23} \text{ atoms Au}}{1 \text{ mole Au}} = \text{atoms Au}$$

$$0.127 \cancel{\text{mol Au}} \times \frac{6.02 \times 10^{23} \text{ atoms Au}}{1 \cancel{\text{mol Au}}} = 7.65 \times 10^{22} \text{ atoms Au}$$

PRACTICE PROBLEMS

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

a. 55.2 g Li

b. 0.230 g Pb

c. 11.5 g Hg

d. 45.6 g Si

e. 0.120 kg Ti

PRACTICE PROBLEMS

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

a. 55.2 g Li

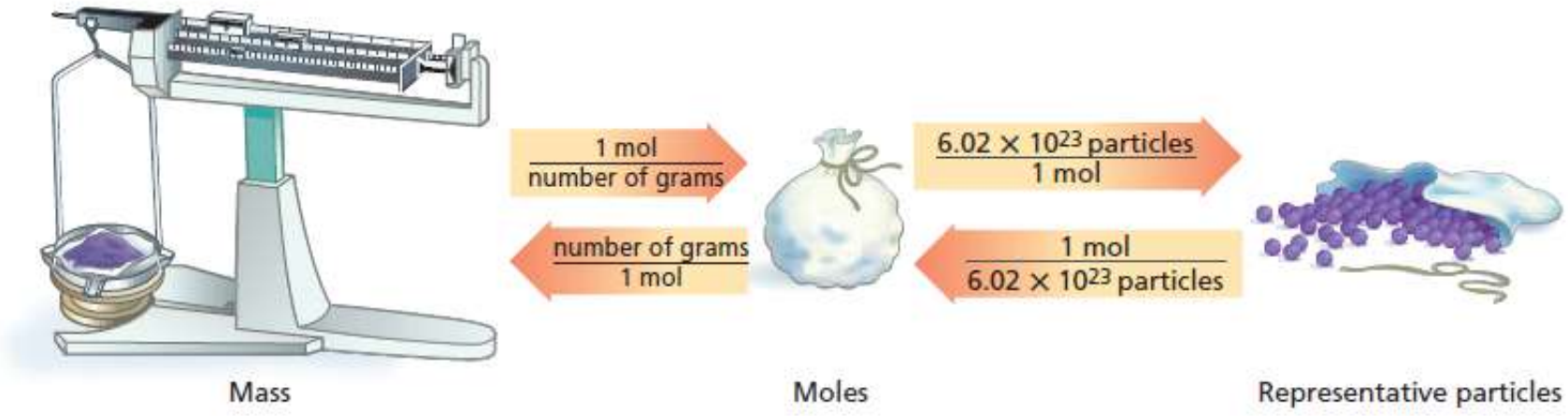
b. 0.230 g Pb

c. 11.5 g Hg

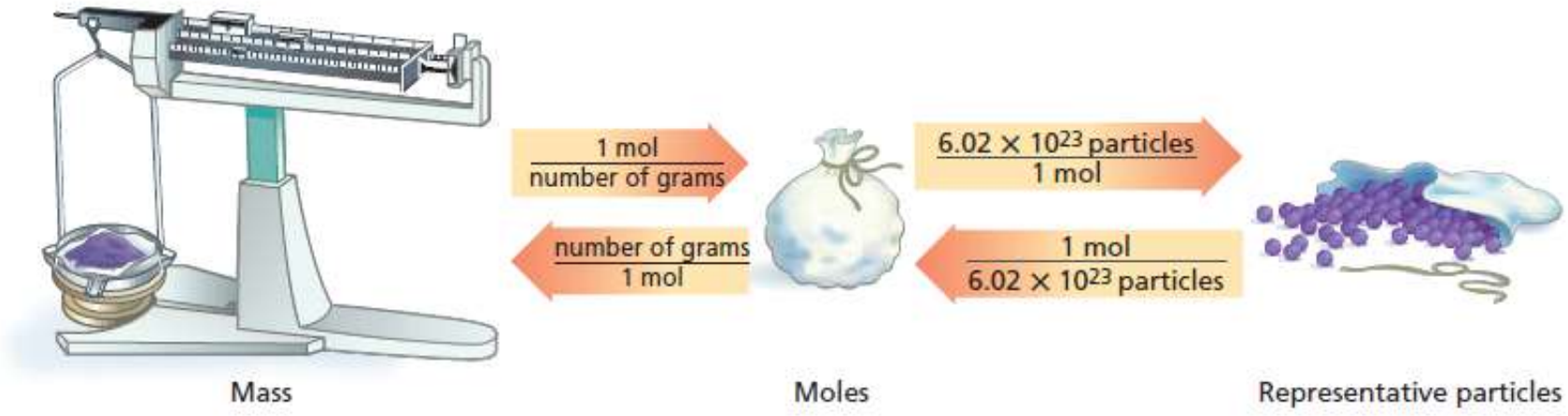
d. 45.6 g Si

e. 0.120 kg Ti

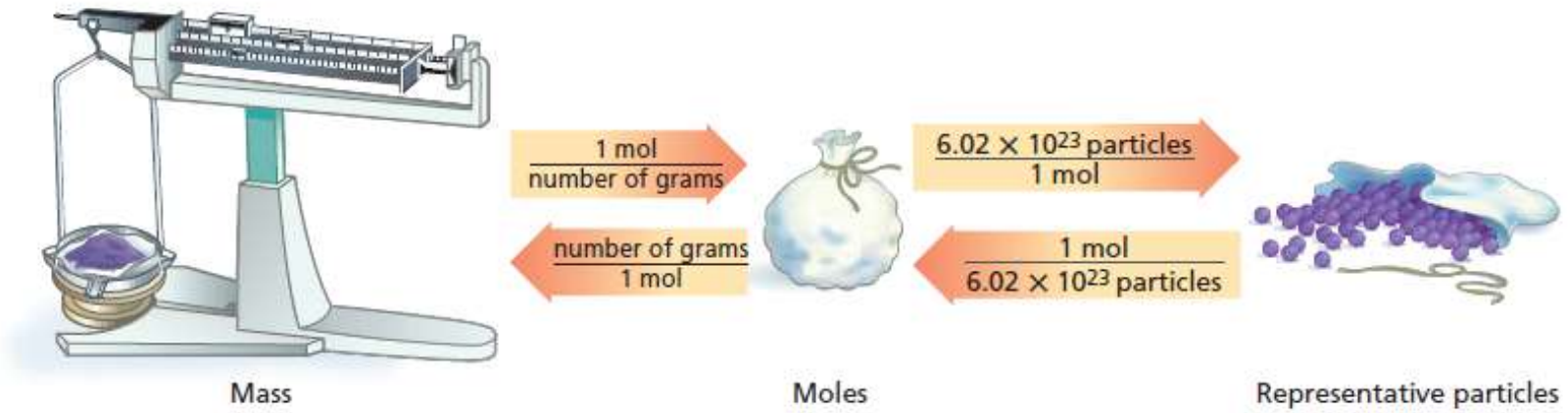
- Answers
- a. 4.79×10^{24} atoms Li
- b. 6.68×10^{20} atoms Pb
- c. 3.45×10^{22} atoms Hg
- d. 9.77×10^{23} atoms Si
- e. 1.51×10^{24} atoms Ti



- Note: Mass must always be converted to moles before being converted to atoms, and atoms must first be converted to moles.



- Although this is a two step process , you can make this conversion in one step.
- Ex. How many molecules are in 1.00 g of H_2O?



- Ex. How many molecules are in 1.00 g of H_2O?
- You can set up the calculation like this:

$$1.00\ \text{g}\ H_2O \times \frac{1\ \text{mol}\ H_2O}{18.02\ \text{g}\ H_2O} \times \frac{6.02 \times 10^{23}\ \text{molecules}\ H_2O}{1\ \text{mol}\ H_2O}$$

$$= 3.34 \times 10^{22}\ \text{molecules}\ H_2O$$

- **The units all cancel to give the answer in molecules of H_2O.**

PRACTICE PROBLEMS

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

a. 6.02×10^{24} atoms Bi
b. 1.00×10^{24} atoms Mn
c. 3.40×10^{22} atoms He
d. 1.50×10^{15} atoms N
e. 1.50×10^{15} atoms U

- Answers
- a. 2.09 X 10^{3} g Bi
- b. 91.3 g Mn
- c. 0.226 g He
- d. 3.49 X 10^{-8} g N
- e. 5.93 X 10^{-7} g U

PRACTICE PROBLEMS

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

a. 6.02×10^{24} atoms Bi

b. 1.00×10^{24} atoms Mn

c. 3.40×10^{22} atoms He

d. 1.50×10^{15} atoms N

e. 1.50×10^{15} atoms U

The Molar Mass of Compounds

A mole of a compound would contain Avagadro's number of molecules of that compound.

- The mass of a mole of a compound equals the sum of the masses of every particle that makes up the compound.

The Molar Mass of Compounds

- Ex. What is the mass of one mole of potassium chromate (K_2CrO_4)?
- Use the periodic table to find the molar mass of each element and multiply it by the subscript.
-
- K 39.1g X 2 = 78.2g
- Cr 52.0g X 1 = 52.0g
- O 16.0g X 4 = <u>64.0g</u>
- Molar mass of K_2CrO_4 = 194.2g

COMPOUNDS are made up of ATOMS.

The **MOLAR MASS** of a compound is the combined **MOLAR MASS** of all the atoms in the compound.

Example: Sodium Hydroxide is NaOH

The **MOLAR MASS** of NaOH is …

Na 22.989770 g/mol x 1 mol = 22.989770 g

O 15.9994 g/mol x 1 mol = 15.9994 g

H 1.00794 g/mol x 1 mol = 1.00794 g

TOTAL MOLAR MASS = 39.99711 g

for 1 mol NaOH or 39.9971 g/mol

PRACTICE PROBLEMS

25. Determine the molar mass of each of the following ionic compounds: $NaOH$, $CaCl_2$, $KC_2H_3O_2$, $Sr(NO_3)_2$, and $(NH_4)_3PO_4$.

26. Calculate the molar mass of each of the following molecular compounds: C_2H_5OH, $C_{12}H_{22}O_{11}$, HCN, CCl_4, and H_2O.

PRACTICE PROBLEMS

25. Determine the molar mass of each of the following ionic compounds: NaOH, $CaCl_2$, $KC_2H_3O_2$, $Sr(NO_3)_2$, and $(NH_4)_3PO_4$.

26. Calculate the molar mass of each of the following molecular compounds: C_2H_5OH, $C_{12}H_{22}O_{11}$, HCN, CCl_4, and H_2O.

- NaOH – 40.00 g
- $CaCl_2$ – 110.98g
- $KC_2H_3O_2$ – 98.14 g
- $Sr(NO_3)_2$ – 211.64g
- $(NH_4)_3PO_4$- 149.10g

PRACTICE PROBLEMS

25. Determine the molar mass of each of the following ionic compounds: NaOH, $CaCl_2$, $KC_2H_3O_2$, $Sr(NO_3)_2$, and $(NH_4)_3PO_4$.

26. Calculate the molar mass of each of the following molecular compounds: C_2H_5OH, $C_{12}H_{22}O_{11}$, HCN, CCl_4, and H_2O.

- C_2H_5OH – 46.07g
- $C_{12}H_{22}O_{11}$- 342.30 g
- HCN – 27.03 g
- CCl_4- 153.81 g
- H_2O – 18.02g

Converting Moles of a gas to volume

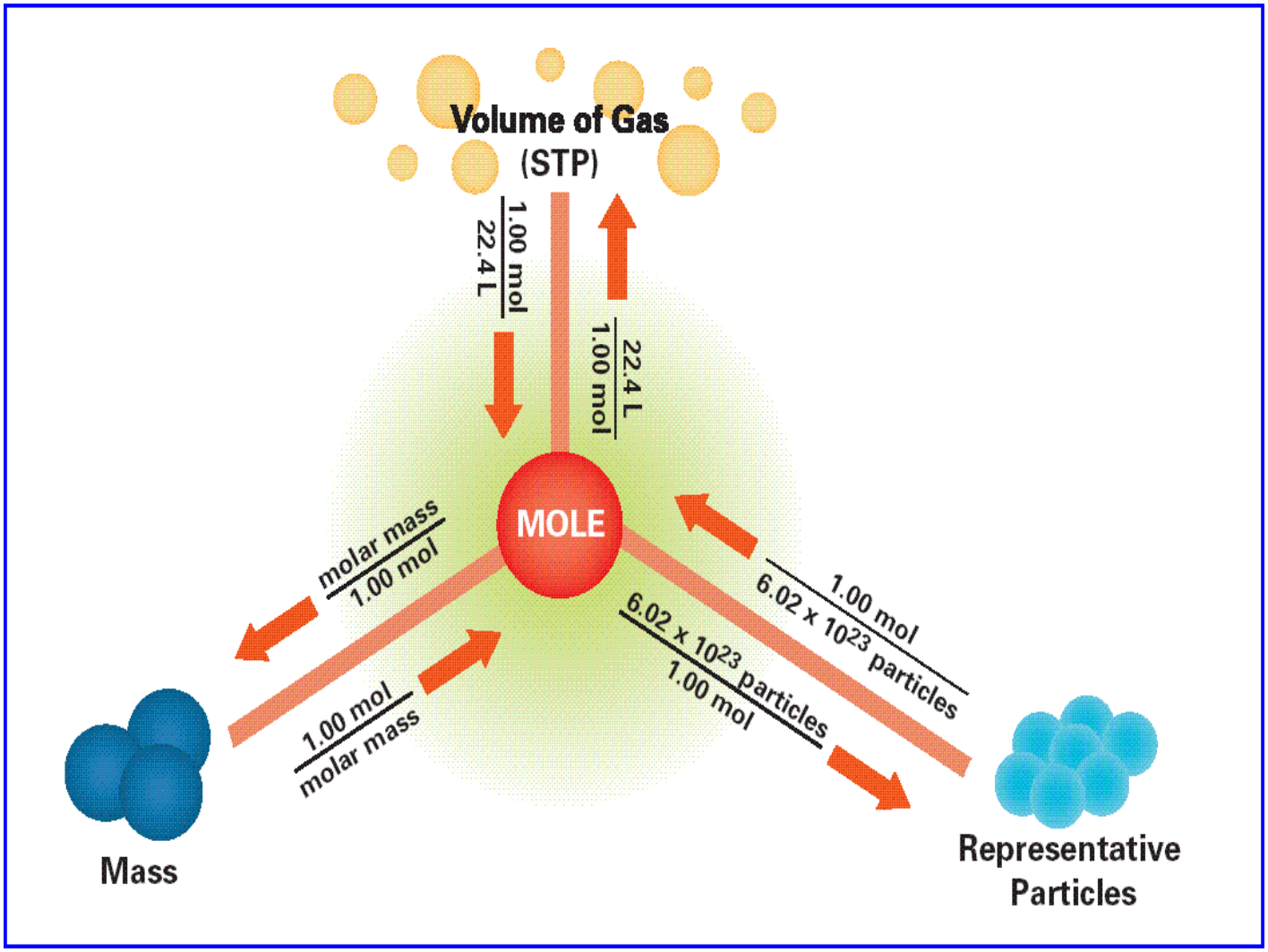
- One mole of any gas at Standard Temperature and Pressure, occupies a volume of ***22.4 Liters***
- STP – Standard Temperature and Pressure ($0^{o}C$) (pressure at sea level 101kPa)

$$\text{Conversion factor: } \frac{22.4\ \text{L}}{1\ \text{mol}}$$

Converting Moles of a gas to volume

- Ex. What is the volume of 2.5 moles of gas at STP?
- 2.5 mol X $\frac{22.4\ \text{L}}{1\ \text{mol}}$ = 61L of Gas

- Ex What is the volume of 2g of H_2 gas at STP?
- First convert mass to moles
- $2\text{g}H_2$ X $\frac{1\ \text{mole}\ H_2}{2\ \text{g}\ H_2}$ X $\frac{22.4\ \text{L}}{1\ \text{mol}}$ **= 22.4L H_2**


Volume of Gas
(STP)
1.00 mol
22.4 L
22.4 L
1.00 mol
MOLE
molar mass
1.00 mol
1.00 mol
molar mass
1.00 mol
6.02 x 10^23 particles
6.02 x 10^23 particles
1.00 mol
Mass
Representative
Particles

Section 11.3 Assessment

36. Describe how you can determine the molar mass of a compound.

37. What three conversion factors are often used in mole conversions?

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

39. If you know the mass in grams of a molecule of a substance, could you obtain the mass of a mole of that substance? Explain.

40. Thinking Critically Design a bar graph that will show the number of moles of each element present in 500 g dioxin ($C_{12}H_4Cl_4O_2$), a powerful poison.

41. Applying Concepts The recommended daily allowance of calcium is 1000 mg of Ca^{2+} ions. Calcium carbonate is used to supply the calcium in vitamin tablets. How many moles of calcium ions does 1000 mg represent? How many moles of calcium carbonate are needed to supply the required amount of calcium ions? What mass of calcium carbonate must each tablet contain?

Section 11.3 Assessment

36. 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.

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

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

$\frac{\text{number of atoms of element}}{1\text{ mol compound}}$

38. 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.

39. Yes, multiply the mass in grams of the molecule by Avogadro's number.

40. The graph should show 24 mol C, 8 mol H, 8 mol Cl, 4 mol O. See Solutions Manual.

41. 0.02 mol Ca^{2+}, 0.02 mol $CaCO_3$, 2 g $CaCO_3$

121. Calculate the values that will complete the table.

Table 11-2

Moles, Mass, and Representative Particles			
Compound	**Number of moles**	**Mass (g)**	**Representative particles**
Silver acetate $Ag(C_2H_3O_2)$	2.50		
Glucose $C_6H_{12}O_6$		324.0	
Benzene C_6H_6			5.65×10^{21}
Lead(II) sulfide PbS		100.0	

121. Calculate the values that will complete the table.

Table 11-2

Moles, Mass, and Representative Particles			
Compound	**Number of moles**	**Mass (g)**	**Representative particles**
Silver acetate $Ag(C_2H_3O_2)$ 173	2.50	471	1.51×10^{24}
Glucose $C_6H_{12}O_6$ 192	1.790	324.0	1.08×10^{24}
Benzene C_6H_6 90	.0094	.733	5.65×10^{21}
Lead(II) sulfide PbS 239	.4178	100.0	2.5×10^{23}

Moles and Mass

Determine the number of moles in each of the quantities below.

1. 25 g of NaCl

.43 mol

2. 125 g of H_2SO_4

1.28 mol

3. 100. g of $KMnO_4$

.633 mol

4. 74 g of KCl

.99 mol

5. 35 g of $CuSO_4 \cdot 5H_2O$

.14 mol

5. 35 g of $CuSO_4 \cdot 5H_2O$ .14 mol

Determine the number of grams in each of the quantities below.

6. 2.5 moles of NaCl 145 g

7. 0.50 moles of H_2SO_4 49 g

8. 1.70 moles of $KMnO_4$ 269 g

9. 0.25 moles of KCl 19 g

10. 3.2 moles of $CuSO_4 \cdot 5H_2O$ 800 g

Gram Formula Mass

Determine the gram formula mass (the mass of one mole) of each compound below.

1. $KMnO_4$ — 158g
2. KCl — 74.55 g
3. Na_2SO_4 — 142 g
4. $Co(NO_3)_2$ — 164 g
5. $Al_2(SO_4)_3$ — 342 g
6. $(NH_4)_3PO_4$ — 149 g
7. $CuSO_4 \cdot 5H_2O$ — 250 g
8. $Mg_3(PO_4)_2$ — 262.86 g
9. $Zn(C_2H_3O_2)_2 \cdot 2H_2O$ — 219 g
10. $Zn_3(PO_4)_2 \cdot 4H_2O$ — 458 g
11. H_2CO_3 — 62 g
12. $Hg_2Cr_2O_7$ — 617 g
13. $Ba(ClO_3)_2$ — 13.304 g
14. $Fe_2(SO_3)_3$ — 352 g
15. $NH_4C_2H_3O_2$ — 15.77 g

The Mole and Volume

For gases at STP (273 K and 1 atm pressure), one mole occupies a volume of 22.4 L. What volume will the following quantities of gases occupy at STP?

1. 1.00 mole of H_2 — 22.4 L
2. 3.20 moles of O_2 — 71.7 L
3. 0.750 mole of N_2 — 16.8 L
4. 1.75 moles of CO_2 — 39.2 L
5. 0.50 mole of NH_3 — 11.2 L
6. 5.0 g of H_2 — 56 L
7. 100. g of O_2 — 70.0 L
8. 28.0 g of N_2 — 22.4 L
9. 60. g of CO_2 — 31 L
10. 10. g of NH_3 — 13 L

Empirical and Molecular Formulas

- **Percent Composition from the chemical formula**

$$\frac{\text{mass of element}}{\text{mass of compound}} \times 100 = \text{percent by mass}$$

- The percent by mass of all the elements of a compound is called the **percent composition** of a compound.

Percent Composition from the Chemical Formula

- Calculate the mass of each element in a compound and divide this value by the molar mass of the compound
- Ex. What is the percent composition of H and O in water H_2O
-
- Mass of H = 2 X 1.01g
-
- Mass of O = 16.00g

Ex. What is the percent composition of H and O in water H_2O

$$\frac{2.02 \text{ g H}}{18.02 \text{ g } H_2O} \times 100 = 11.2\% \text{ H}$$

$$\frac{16.00 \text{ g O}}{18.02 \text{ g } H_2O} \times 100 = 88.80\% \text{ O}$$

PRACTICE PROBLEMS

42. Determine the percent by mass of each element in calcium chloride.

43. Calculate the percent composition of sodium sulfate.

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

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

Empirical Formula

- The empirical formula for a compound is the smallest whole number ratio of the elements.

Molecular Formula

- Molecular Formula specifies the actual number of atoms of each element in one molecule or formula unit of a substance.

PRACTICE PROBLEMS

46. A blue solid is found to contain 36.84% nitrogen and 63.16% oxygen. What is the empirical formula for this solid?

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

48. 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?

49. 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.

50. What is the empirical formula for a compound that contains 10.89% magnesium, 31.77% chlorine, and 57.34% oxygen?

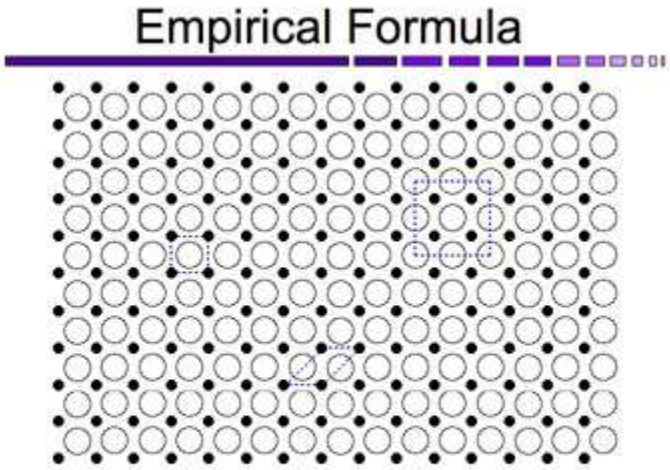
- 42. 36.11% Ca, 63.89%Cl
- 43. 32.37% Na, 22.58% S, 45.05% O
- 44. H_2SO_3
- 45. 3.08% H, 31.61% P, 65.31% O

Empirical Formula

- The ***Empirical Formula*** for a compound is the formula with the smallest whole number mole ratio of the elements.

Empirical formula: Table summary

Name of compound	Empirical formula	Molecular formula
Hydrogen peroxide	HO	H_2O_2
Water	H_2O	H_2O
Glucose	CH_2O	$C_6H_{12}O_6$
Oxalic acid	HCO_2	$H_2C_2O_4$
Ethanol	C_2H_6O	C_2H_6O
Ethane	CH_3	C_2H_6
Ethylene	CH_2	C_2H_4
Caffeine	$C_4H_5N_2O$	$C_8H_{10}N_4O_2$



Calculating Empirical Formula from Percent Composition

- This is a three step process:
- Step 1: Assume that the total mass of the substance is 100g and express the percent of each element in grams.
- Step 2: Convert the mass of each element to moles.
- Step 3: Convert the mole ratios to whole numbers by dividing by the smallest mole value.

Ex: The percent composition of a an oxide of sulfur is 40.05% S and 59.95% O, what is the empirical formula?

- Step 1: Assume that the total mass of the substance is 100g and express the percent of each element in grams. 40.05g S and 59.95g O
- Step 2: Convert the mass of each element to moles.

$$40.05 \text{ g } \cancel{S} \times \frac{1 \text{ mol S}}{32.07 \text{ g } \cancel{S}} = 1.249 \text{ mol S}$$

$$59.95 \text{ g } \cancel{O} \times \frac{1 \text{ mol O}}{16.00 \text{ g } \cancel{O}} = 3.747 \text{ mol O}$$

- Step 3: Convert the mole ratios to whole numbers by dividing by the smallest mole value.

$$\frac{1.249 \text{ mol S}}{1.25} = 1 \text{ mol S}$$

$$\frac{3.747 \text{ mol O}}{1.25} = 3 \text{ mol O}$$

Ex: The percent composition of a an oxide of sulfur is 40.5% S and 59.95% O, what is the empirical formula?

- Step 1: Assume that the total mass of the substance is 100g and express the percent of each element in grams. 40.5g S and 59.95g O
- Step 2: Convert the mass of each element to moles.

$$40.05\ \text{g}\ \cancel{S} \times \frac{1\ \text{mol S}}{32.07\ \text{g}\ \cancel{S}} = 1.249\ \text{mol S}$$

$$59.95\ \text{g}\ \cancel{O} \times \frac{1\ \text{mol O}}{16.00\ \text{g}\ \cancel{O}} = 3.747\ \text{mol O}$$

- Step 3: Convert the mole ratios to whole numbers by dividing by the smallest mole value.

$$\frac{1.249\ \text{mol S}}{1.25} = 1\ \text{mol S}$$

$$\frac{3.747\ \text{mol O}}{1.25} = 3\ \text{mol O}$$

- The simplest whole number mole ratio of S atoms to O atoms is 1:3, so the **empirical formula is SO_3**

EXAMPLE PROBLEM 11-11

Calculating an Empirical Formula from Percent Composition

Methyl acetate is a solvent commonly used in some paints, inks, and adhesives. Determine the empirical formula for methyl acetate, which has the following chemical analysis: 48.64% carbon, 8.16% hydrogen, and 43.20% oxygen.

1. Analyze the Problem

You are given the percent composition of methyl acetate and must find the empirical formula. Because you can assume that each percent by mass represents the mass of the element in a 100.00-g sample, the percent sign can be replaced with the unit grams. Then, you can convert from grams to moles using the molar mass and find the smallest whole-number ratio of moles of the elements.

Known	Unknown
percent by mass = 48.64% C	empirical formula = ?
percent by mass = 8.16% H	
percent by mass = 43.20% O	

2. Solve for the Unknown

The mass of C is 48.64 g, the mass of H is 8.16 g, and the mass of O is 43.20 g. Multiply the mass of each element by the conversion factor that relates moles to grams based on molar mass.

$$48.64\ \cancel{g\ C} \times \frac{1\ \text{mol C}}{12.01\ \cancel{g\ C}} = 4.050\ \text{mol C}$$

$$8.16\ \cancel{g\ H} \times \frac{1\ \text{mol H}}{1.008\ \cancel{g\ H}} = 8.10\ \text{mol H}$$

$$43.20\ \cancel{g\ O} \times \frac{1\ \text{mol O}}{16.00\ \cancel{g\ O}} = 2.700\ \text{mol O}$$

Methyl acetate has a mole ratio of 4.050 mol C : 8.10 mol H : 2.700 mol O.

Calculate the simplest ratio of moles of the elements by dividing each number of moles by the smallest value in the mole ratio.

$$\frac{4.050\ \text{mol C}}{2.700} = 1.500\ \text{mol C} = 1.5\ \text{mol C}$$

$$\frac{8.10\ \text{mol H}}{2.700} = 3.00\ \text{mol H} = 3\ \text{mol H}$$

$$\frac{2.700\ \text{mol O}}{2.700} = 1.000\ \text{mol O} = 1\ \text{mol O}$$

The simplest ratio is 1.5 mol C : 3 mol H : 1 mol O.

Multiply the numbers of moles in the ratio by the smallest number that will produce a ratio of whole numbers.

$2 \times 1.5\ \text{mol C} = 3\ \text{mol C}$

$2 \times 3\ \text{mol H} = 6\ \text{mol H}$

$2 \times 1\ \text{mol O} = 2\ \text{mol O}$

The simplest whole-number ratio of C atoms to H atoms to O atoms is 3 : 6 : 2. The empirical formula is $C_3H_6O_2$.

PRACTICE PROBLEMS

46. A blue solid is found to contain 36.84% nitrogen and 63.16% oxygen. What is the empirical formula for this solid?

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

48. 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?

49. 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.

50. What is the empirical formula for a compound that contains 10.89% magnesium, 31.77% chlorine, and 57.34% oxygen?

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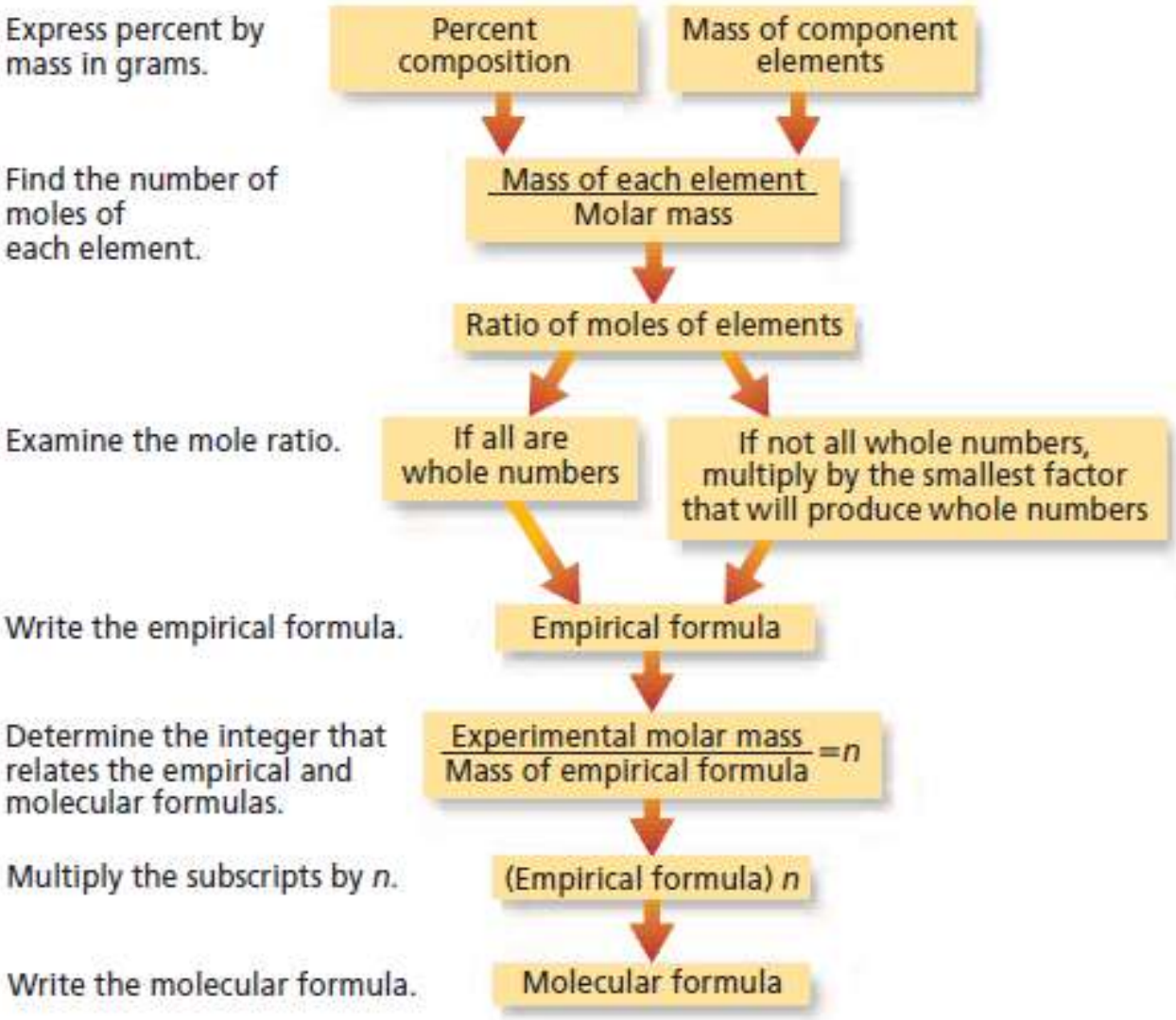
- 46. N_2O_3
- 47. Al_2S_3
- 48. C_3H_8

49. $C_9H_8O_4$

50. $Mg(ClO_4)_2$


Express percent by mass in grams.
Percent composition
Mass of component elements
Find the number of moles of each element.
Mass of each element / Molar mass
Ratio of moles of elements
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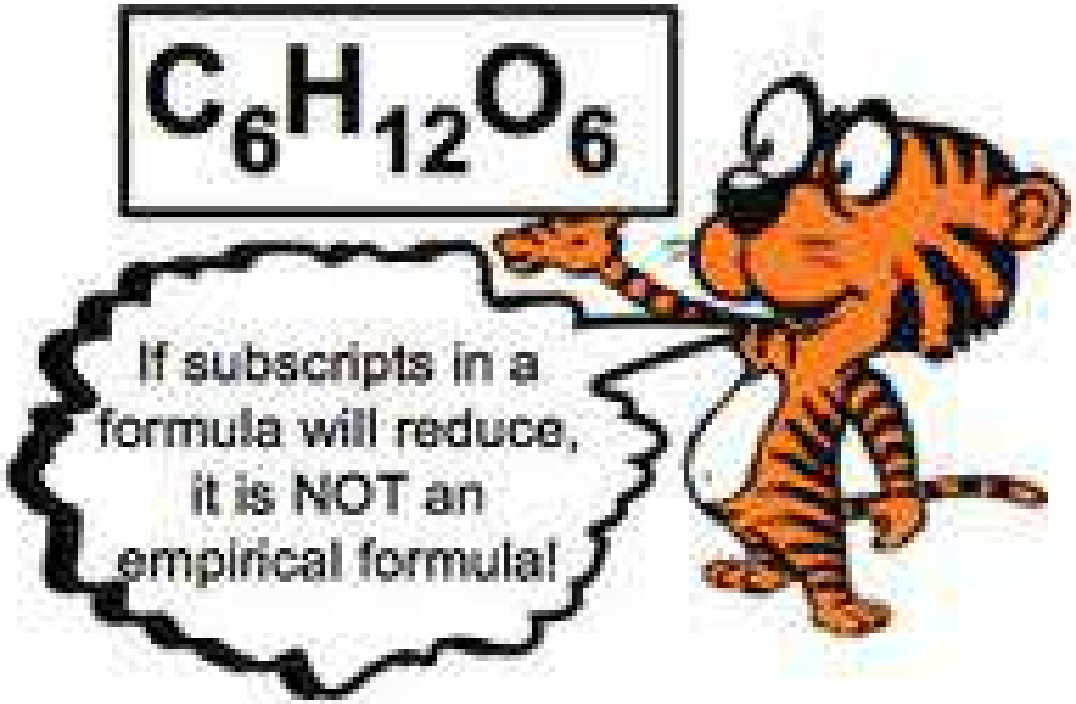
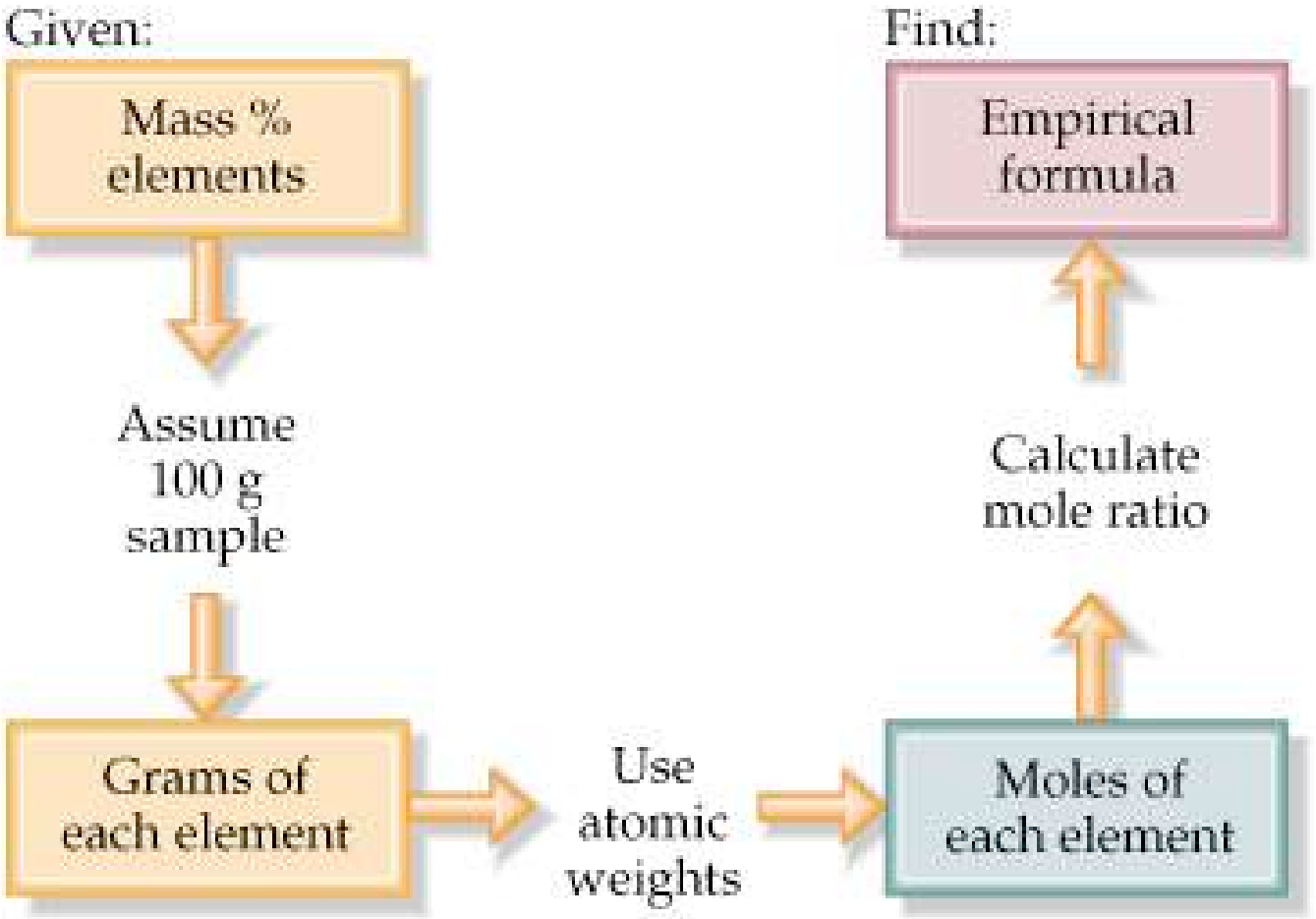
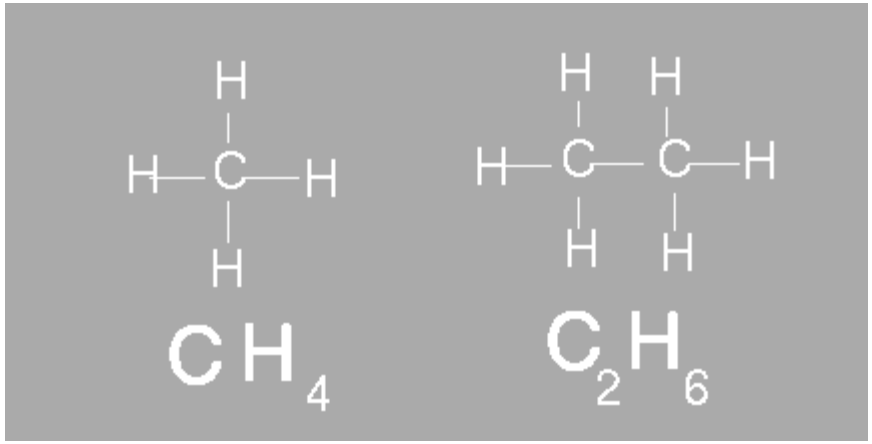
If all are whole numbers
If not all whole numbers, multiply by the smallest factor that will produce whole numbers
Write the empirical formula.
Empirical formula
Determine the integer that relates the empirical and molecular formulas.
Experimental molar mass / Mass of empirical formula = n
Multiply the subscripts by n.
(Empirical formula) n
Write the molecular formula.
Molecular formula


$C_6H_{12}O_6$
If subscripts in a formula will reduce, it is NOT an empirical formula!


Given:
Mass % elements
Assume 100 g sample
Grams of each element
Use atomic weights
Moles of each element
Calculate mole ratio
Find:
Empirical formula


CH4
C2H6

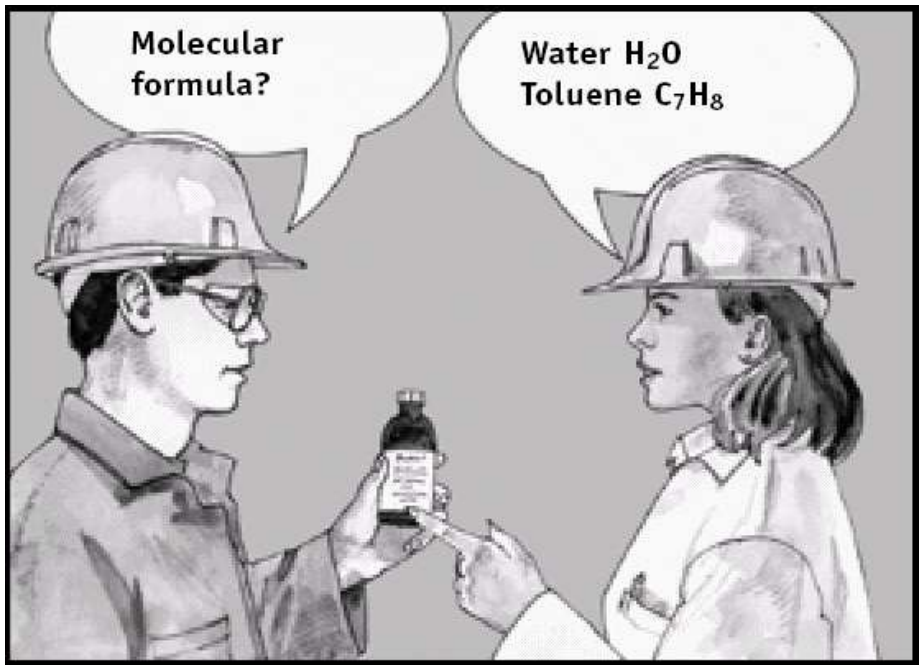

Molecular formula?
Water H2O
Toluene C7H8

TABLE 6.7 Compounds with the same empirical formula but different molecular formulas

Empirical formula	Compound	Molecular formula	Boiling point, °C
CH (92.2% C; 7.8% H)	acetylene	C_2H_2	-84
	benzene	C_6H_6	80
CH_2 (85.6% C; 14.4% H)	ethylene	C_2H_4	-103
	butene	C_4H_8	-6.3
	cyclohexane	C_6H_{12}	80.7
CH_2O (40.0% C; 6.7% H; 53.3% O)	formaldehyde	CH_2O	-21
	acetic acid	C_2H_4O	117
	glyceraldehyde	$C_3H_6O_3$	140

Molecular Formula

- The molecular formula specifies the actual number of atoms of each element in one molecule or formula unit of a substance.
- EX acetylene,C_2H_2, and benzene C_6H_6, nitrogen dioxide NO_2, and dinitrogen tetroxide, N_2O_4

Empirical formula: Table summary

Name of compound	Empirical formula	Molecular formula
Hydrogen peroxide	HO	H_2O_2
Water	H_2O	H_2O
Glucose	CH_2O	$C_6H_{12}O_6$
Oxalic acid	HCO_2	$H_2C_2O_4$
Ethanol	C_2H_6O	C_2H_6O
Ethane	CH_3	C_2H_6
Ethylene	CH_2	C_2H_4
Caffeine	$C_4H_5N_2O$	$C_8H_{10}N_4O_2$

Molecular Formula

- To determine the molecular formula for a compound divide the *actual* molar mass (usually determined experimentally) by the empirical molar mass.

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- Ex. The molar mass of acetylene is 26.04 g/mol, the mass of the empirical formula CH is 13.20g/mol, what is the molecular formula?

$$\frac{\text{experimentally determined molar mass of acetylene}}{\text{mass of empirical formula CH}} =$$

$$\frac{26.04\ \cancel{\text{g/mol}}}{13.02\ \cancel{\text{g/mol}}} = 2.000$$

- The molar mass of acetylene is 2 times that of the empirical formula so the molecular formula is C_2H_2

Similarly, when the experimentally determined molar mass of benzene, 78.12 g/mol, is compared with the mass of the empirical formula, the molar mass of benzene is found to be six times the mass of the empirical formula.

$$\frac{\text{experimentally determined molar mass of benzene}}{\text{mass of empirical formula CH}} = \frac{78.12\ \text{g/mol}}{13.02\ \text{g/mol}} = 6.000$$

So the molecular formula of benzene is C_6H_6, the empirical formula is still CH

A molecular formula can be represented as the empirical formula multiplied by an integer n.

$$\text{molecular formula} = (\text{empirical formula})n$$

PRACTICE PROBLEMS

51. Analysis of a chemical used in photographic developing fluid indicates a chemical composition of 65.45% C, 5.45% H, and 29.09% O. The molar mass is found to be 110.0 g/mol. Determine the molecular formula.

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

53. 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?

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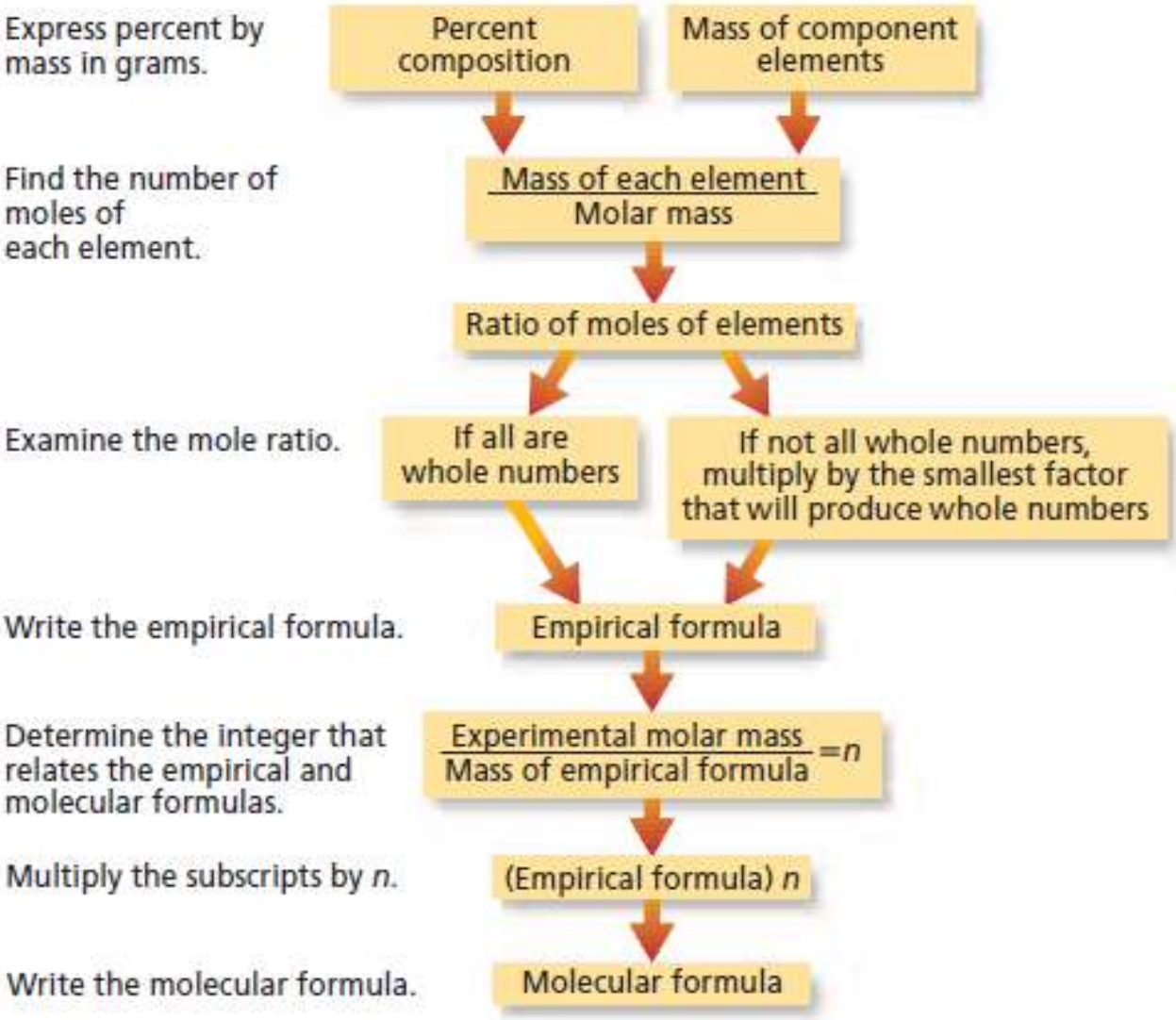
- 51. $C_6H_6O_2$
- 52. C_4H_{10}
- 53. N_2O_2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Molecular formula

Hydrates

- http://www.youtube.com/watch?v=Np_SDsezVXo
- http://www.youtube.com/watch?v=HM2C5FEvR0g
- http://www.youtube.com/watch?v=pM0LWKQpgvI
- http://www.youtube.com/