Chapter 4

Chemical Composition

Chapter 4 Topics

1. **Mole Quantities**
2. **Moles, Masses, and Particles**
3. **Determining Empirical Formulas**
4. **Chemical Composition of Solutions**

4.1 Mole Quantities

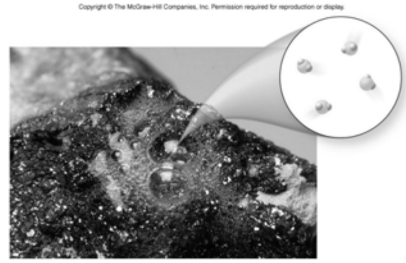
- **When working with amounts of a substance on a macroscopic scale, we cannot simply count atoms or molecules. There are too many. Instead, we use the mole scale, which is scaled up by Avogadro's number:**

1 mole = 6.022×10^{23} particles

- **1 mole C = 6.022×10^{23} carbon atoms**
- **1 mole H_2S = 6.022×10^{23} H_2S molecules**
- **1 mol Cu_2O = 6.022×10^{23} Cu_2O formula units**

H_2S

- **How many sulfur atoms are in 1 mol of H_2S?**
- **How many hydrogen atoms are in 1 mole of H_2S?**



The Mole Scale

- **How many water molecules are in a single drop of water?**
- **The mole scale was developed so we can figure this out.**

Molar Mass
The Mass of 1 Mole

- **Avogadro's number has been defined so that the mass of 1 mol of C-12 has a mass of exactly 12 grams.**
- **This means that the mass of an atom of any substance in amus is the same numerical value as the mass of 1 mole of that substance in grams (molar mass).**
- **The molar mass of carbon is 12.01 g/mol.**
- **The molar mass of CO_2 is:**

12.01 + 2(16.00) = 44.01 g/mol

We'll use 4 sig. figs

Molar Mass

- What is the molar mass of H_2O?
- What is the mass of 1 mole of H_2O?

Molar Mass

- Which contains the greatest number of atoms?
  - 1 mole of copper or 1 mole of gold?
  - 1 gram of copper or 1 gram of gold?

4.2 Moles, Masses, and Particles

- How can we describe the composition of a compound if we know the mass of the elements in the compound?
- A 3.67-g sample of the mineral chalcopyrite was determined to contain 1.27 g Cu, 1.12 g Fe, and 1.28 g S.
  - What is the mass percent of each element in this compound?

Composition of Chalcopyrite

- Would this mass % differ for a different sample of this mineral?
- If you had a 100-gram sample, what mass of copper would it contain?

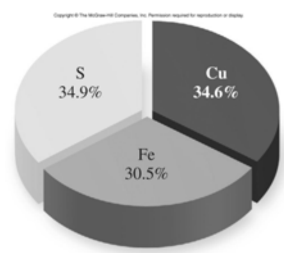


Figure 4.10

Moles from Grams

- How many moles of copper are in 100 grams of chalcopyrite? (molar mass Cu = 63.55 g/mol)

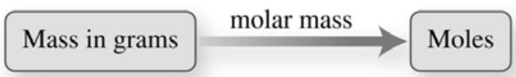
34.6 g Cu ?

Converting Between Grams and Moles

1. Convert 10.0 grams of CO_2 to moles.
2. Convert 0.50 mol CO_2 to grams.

Converting Between Grams and Moles

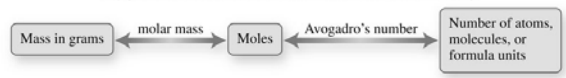
1. Convert 10.0 g O_2 to moles.



Grams ↔ Moles ↔ Particles

- **Once we know the number of moles of a substance, we can use Avogadro's number (6.022×10^{23}) to determine the number of particles described by that substance.**

  1 mole = 6.022×10^{23} particles



Number of Water Molecules in a Drop

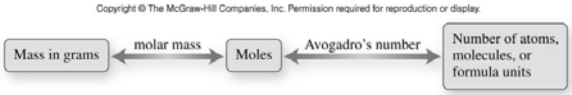
- **Now let's figure out the number of water molecules in 1 drop.**
- **Here is some helpful information:**
  - **There are about 20 drops of water in 1 mL.**
  - **The density of water is 1.0 g/mL**

Determining Number of Particles Group Work

- **How many CO_2 molecules are in a 100-g sample of CO_2?**
- **How many carbon atoms are in a 100-g sample of CO_2?**
- **How many oxygen atoms are in a 100-g sample of CO_2?**

Group Work

- **What mass of $MgCl_2$ contains 6.022×10^{23} Cl^- ions?**

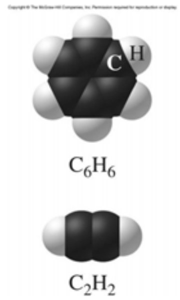


4.3 Empirical and Molecular Formulas

- **The formula for a substance also tells us about the composition of a compound:**
  - **A formula unit for an ionic compound tells us the ratio of ions of different elements in the compound. ($MgCl_2$ has a 1:2 ratio of Mg^{+2} to Cl^-)**
  - **A molecular formula tells the number of atoms of each element in a molecule and the atom ratio.**

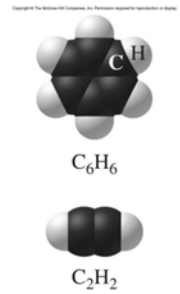
Empirical Formulas

- What is the same about these two compounds?

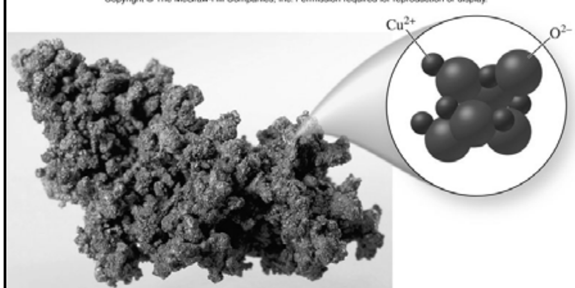


Empirical Formulas

- The empirical formula of a substance is the ratio of atoms of different elements, in terms of the smallest whole numbers.
- What is their empirical formula?



What is the empirical formula for copper(II) oxide?



Determine the Empirical Formula

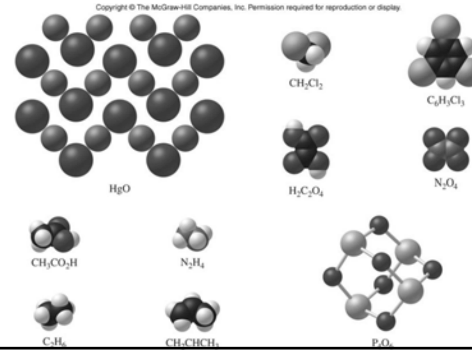
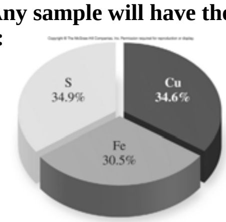


Fig. 4.15

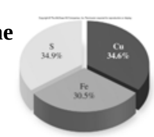
Determining Empirical Formulas from % Composition

- If we know the masses of the elements in a compound, or its percent composition, we can determine its mole ratio, and therefore the compound's empirical formula.
- Consider chalcopyrite. Any sample will have the following % composition:

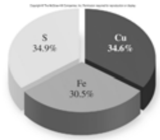


Determining Empirical Formulas

1. Since the percent composition does not change from sample to sample, assume any size sample. The most convenient is 100 grams so % value = mass value.
2. Convert grams to moles for each element.
3. Without changing the relative amounts, change moles to whole numbers. Do this by dividing all by the same smallest value. If all do not convert to whole numbers, multiply to get whole numbers.



Determining Empirical Formulas



1. 100 grams chalcopyrite contains:
   - 30.5 g Fe
   - 34.6 g Cu
   - 34.9 g S
2. Mol Fe = (30.5g Fe)(1mol/55.85 g) = 0.5461 mol Fe
   Mol Cu = (34.6g Cu)(1mol/63.55 g) = 0.5444 mol Cu
   Mol S = (34.9g S)(1mol/32.07 g) = 1.088 mol S
3. (0.5461 mol Fe)/(0. 5444) = 1.003 mol Fe
   (1.063 mol Cu)/(0. 5444) = 1.000 mol Cu
   (1.088 mol S)/(0. 5444) = 1.999 mol S

$\Big\}$ $FeCuS_2$

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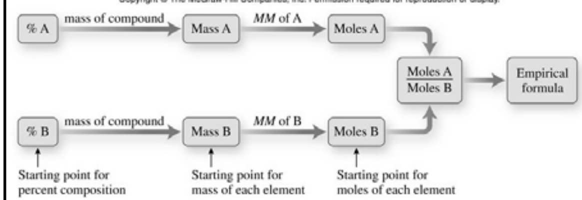
Steps for Determining Empirical Formula



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Group Work

- A compound was determined to have the following percent composition:
  - 50.0% sulfur
  - 50.0% oxygen
- What is the empirical formula for the compound?

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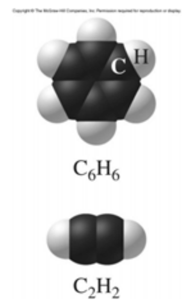
Molecular Formulas from Empirical Formulas

- Benzene and acetylene have the same empirical formulas but different molecular formulas.
- How much greater in mass is benzene than acetylene?
- How much greater in mass is each of these than the empirical formula?



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Empirical and Molecular Formulas

TABLE 4.1 Some Empirical and Molecular Formulas

Substance	Molecular Formula	Empirical Formula
cyclopentane	C_5H_{10}	CH_2
cyclohexane	C_6H_{12}	CH_2
ethylene	C_2H_4	CH_2
hydrogen sulfide	H_2S	H_2S
calcium chloride	There is no molecular formula for an ionic compound.	$CaCl_2$

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Molecular Formulas from Empirical Formulas

- A compound was determined to have an empirical formula of CH_2. Its molar mass was determined to be 42.12 g/mol. What is the molecular formula for this compound?

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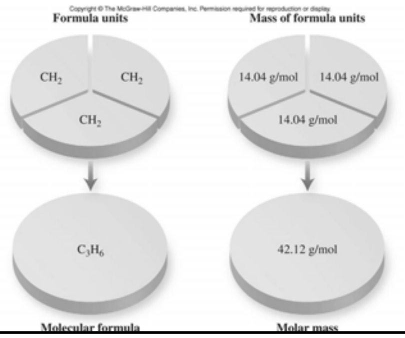
Molecular Formula from Empirical Formula



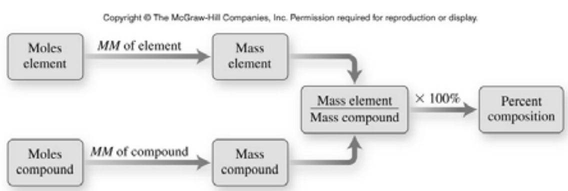
Determining Percent Composition from Empirical or Molecular Formula

- If you know the formula for a compound, you can determine the mass percent composition.
- Assume you have 1 mole of compound, and convert moles of the element and compound to grams.

Mass Percent Composition Mass Ratio	⇄	Empirical or Molecular Formula Atom or Mole Ratio

Determining Percent Composition

- ***Assume 1 mole of compound*, and remember the mass of 1 mole is molar mass.**



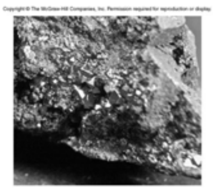
Determining Percent Composition

- **What is the percent sodium in Na_2O?**

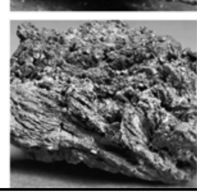
Percent Composition

- **Which has the greatest percentage of Cu?**

Cuprite, Cu_2O



Chalcocite, Cu_2S



4.4 Chemical Composition of Solutions

- **A solution is a homogeneous mixture.**
- **This is a solution being prepared by adding the $CuSO_4$ (solute) to water (solvent).**
- **The composition of the solution depends on the relative amounts of the solute and solvent.**

Concentration

- Which aqueous $CuSO_4$ solution has the greatest concentration (most concentrated)? Which is most dilute?

Percent by Mass of Solute

- Solution concentration is often expressed as the mass percent of solute:

Percent by Mass of Solute

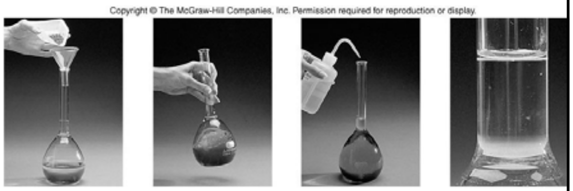
- What is the mass percent of NaCl in a solution that is prepared by adding 10.0 g NaCl to 50.0 g water?

Molarity (*M*)

- Another common way to express the concentration of a solution is in molarity units:

Preparing a $CuSO_4$ Solution

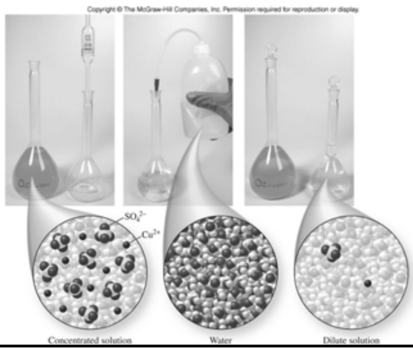
- 6.25 grams (0.0250 mol) of $CuSO_4 \cdot 5H_2O$ is added to a 250-mL volumetric flask.
- Water is added to the mark so that the total volume is 250.0 mL.
- What is the molarity of this solution?



Molarity

- How many moles of NaCl are in 1.85 L of a 0.25 *M* NaCl solution?

Dilution



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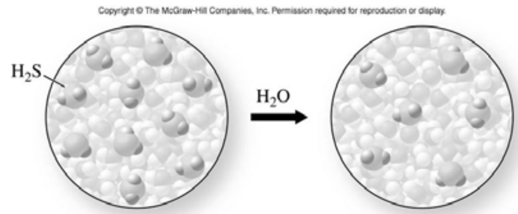
Describe this process



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Dilution

- **Suppose you want to dilute a 0.25 M solution to a concentration of 0.025 M. What are some ways to do this?**

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Dilution

- $\boldsymbol{Moles_{\text{initial}} = Moles_{\text{final}}}$
  - ***Moles = Molarity × Volume***
  - ***Moles = mol/L × L***
- $\boldsymbol{M_{\text{initial}}V_{\text{initial}} = M_{\text{final}}V_{\text{final}}}$

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Dilution

- $\boldsymbol{M_{\text{initial}}V_{\text{initial}} = M_{\text{final}}V_{\text{final}}}$

- **What is the concentration of a solution prepared by adding water to 25.0 mL of 6.00 *M* NaOH to a total volume of 500.0 mL?**

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