

Chapter 3

Compositions of Substances and Solutions



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Atomic mass

- Mass of one atomic element
 - From periodic table.
 - The atomic mass of Na is _____ amu.

Mass of Compounds

- Covalent compounds (H_2O , CH_4 , etc)
 - Molecular mass (MM)
 - Formula mass (FM)
 - Molecular mass is preferred, but either one is used
- Ionic compounds (NaCl , CaCl_2 , etc)
 - Only formula mass (FM) is used

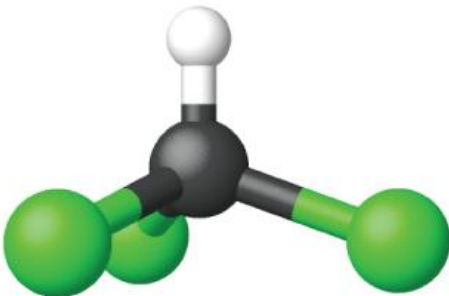
Molecular Mass (MM)

- Mass of a **covalent compound**
- Add up the atomic masses of the atoms from periodic table
- The **molecular mass (formula mass)** of **H₂O** is _____ u.

Molecular Mass (MM)

- CHCl_3

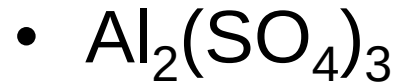
Element	Quantity		Average atomic mass (amu)		Subtotal (amu)
C	1	×	12.01	=	12.01
H	1	×	1.008	=	1.008
Cl	3	×	35.45	=	106.35
Molecular mass					119.37



Formula Mass (FM)

- Mass of one unit of an ionic compound
- Add the atomic masses of all the atoms in the formula
- The formula mass of NaCl is _____ amu.

Formula mass (FM)



How many Al atoms?

How many S atoms?

How many O atoms?

Mole (mol)

Avogadro's number

$$1 \text{ mole} = 6.022 \times 10^{23} \text{ particles(units)}$$

- 1 mole (mol) is the number of atoms in exactly 12 grams of ^{12}C atoms

Mass of one ^{12}C atom = 12 amu

Mass of one mole of ^{12}C atoms = 12 g

Molar mass

- Molar mass of an element or a compound (g/mol)

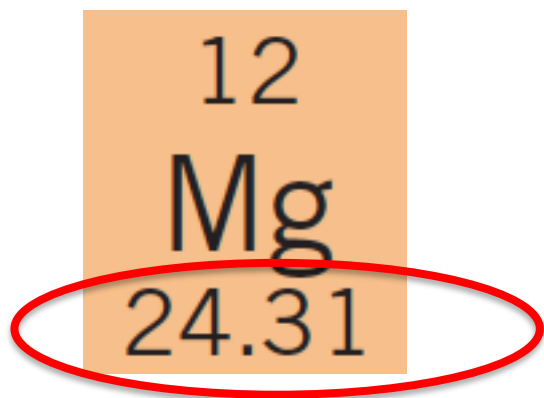
The mass in grams of one mole of the substance

How to calculate molar mass?

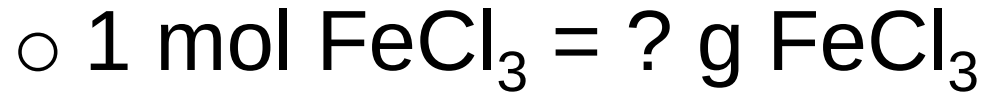
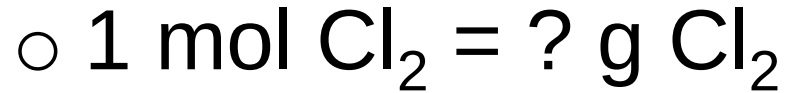
Molar mass of an atom

- The mass of 1 mol of atoms (6×10^{23} atoms)

Simply, change **amu** with **g** from the atomic mass of an element in the periodic table



Molar mass



Molar mass

- The molar mass of Na is _____ g/mol.
- The molar mass of H₂ is _____ g/mol.
- The molar mass of H₂O is _____ g/mol.
- The molar mass of NaCl is _____ g/mol.

Let's make it clear

- | | |
|-----------------------|---|
| ➤ Atomic number | 1.Br |
| ➤ Mass number | 2.Ne |
| ➤ Atomic mass (AM) | 3.O ₃ |
| ➤ Formula mass (FM) | 4.H ₂ O |
| ➤ Molecular mass (MM) | 5.CaCl ₂ |
| ➤ Molar mass | 6.C ₆ H ₁₂ O ₆ |
| ➤ # of moles | |

Mass and # of moles

- Calculate the # of moles of Cu present in a 35.8 g pure Cu wire.



Converting grams to moles

How many moles are in 50.0 g of PbO_2 ?
(AM Pb = 207.2 amu, O = 16.00 amu)

Practice — How many formula units are in 50.0 g of PbO_2 ? (FM $\text{PbO}_2 = 239.2 \text{ amu}$)

Find the number of CO_2 molecules in 10.8 g
of dry ice

Find the number of C atoms in 10.8 g of dry
ice

Find the number of O atoms in 10.8 g of dry
ice

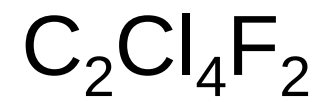
Practice — What is the mass of 4.78×10^{24}
 NO_2 molecules?

Percent Composition

- Percentage of each element in a compound by mass
- Can be determined from
 1. the formula of the compound
 2. the experimental mass analysis of the compound
- The percentages may not always total to 100% due to rounding

$$\text{Percentage} = \frac{\text{part}}{\text{whole}} \times 100\%$$

Find the mass percent of Cl in



Practice — Determine the mass percent composition of the following

- CaCl_2 (AM Ca = 40.08 amu, Cl = 35.45 amu)

Practice — Benzaldehyde is 79.2% carbon. What mass of benzaldehyde contains 19.8 g of C?

Find the mass of hydrogen in 1.00 gal of water

$$d_{\text{H}_2\text{O}} = 1.00 \text{ g/ml}, 3.785 \text{ L} = 1 \text{ gal}$$

How many grams of sodium are in 6.2 g of NaCl? (AM Na = 22.99 amu; Cl = 35.45 amu)

Empirical Formula

- Simplest, whole-number ratio of the atoms of elements in a compound
- NaCl (ratio of Na and Cl = 1:1)
- CH₂O (ratio of C:H:O = 1:2:1)
- Can be determined from elemental analysis (traditional chemical analysis)
 - masses of elements formed when a compound is decompose, or that react together to form a compound
 - combustion analysis
 - percent composition

Finding an Empirical Formula

1. Convert the percentages to grams
 - a) assume you start with 100 g of the compound
 - b) skip if already grams
2. Convert grams to moles
 - a) use molar mass of each element
3. Write a pseudoformula using moles as subscripts
4. Divide all by smallest number of moles
 - a) if result is within 0.1 of whole number, round to whole number
5. Multiply all mole ratios by number to make all whole numbers
 - a) if ratio $\approx .5$, multiply all by 2; if ratio $\approx .33$ or $\approx .67$, multiply all by 3; if ratio 0.25 or 0.75, multiply all by 4; etc.
 - b) skip if already whole numbers

Example (see previous page for procedure)

- Laboratory analysis of aspirin determined the following mass percent composition. Find the empirical formula.

$$\text{C} = 60.00\%$$

$$\text{H} = 4.48\%$$

$$\text{O} = 35.53\%$$

Determine the empirical formula of stannous fluoride, which contains 75.7% Sn (AM: 118.70 amu) and the rest fluorine (AM: 19.00 amu)

Determine the empirical formula of magnetite, which contains 72.4% Fe (AM: 55.85 amu) and the rest oxygen (AM: 16.00 amu)

Molecular Formulas

- Meaningful only molecular compounds
- The molecular formula is a multiple of the empirical formula
- To determine the molecular formula you need to know the empirical formula and the molar mass (molecular weight) of the compound

$$\frac{\text{Molar Mass}_{\text{molecular formula}}}{\text{Molar Mass}_{\text{empirical formula}}} = \text{multiplying factor, } n$$

Find the molecular formula of butanedione

Given: emp. form. = $\text{C}_2\text{H}_3\text{O}$;
MM = 86.03 g/mol

Find: molecular formula

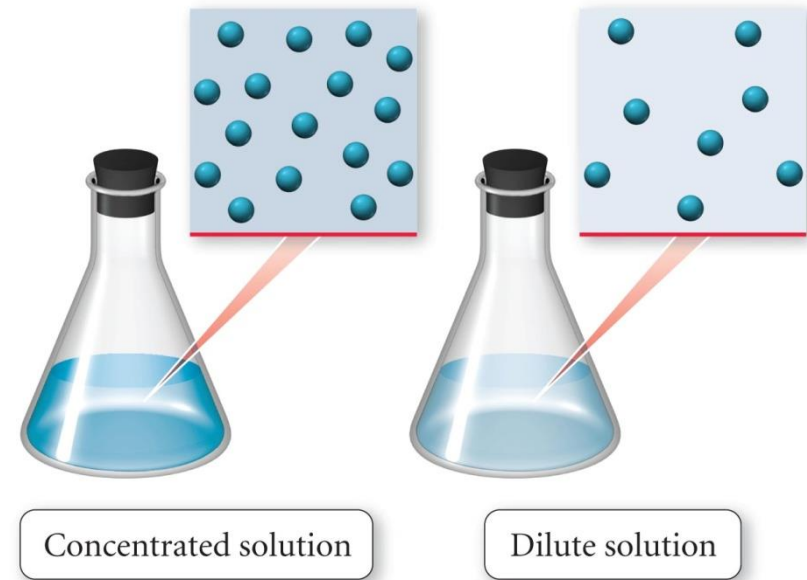
Benzopyrene has a molar mass of 252 g/mol and an empirical formula of C_5H_3 . What is its molecular formula? (AM C = 12.01 amu, H=1.0 amu)

Solution:
Solute (Table Salt) + Solvent (Water)



Solution Concentration

- Qualitatively, solutions are often described as dilute or concentrated
- **Dilute solutions** have a small amount of solute compared to solvent
- **Concentrated solutions** have a large amount of solute compared to solvent



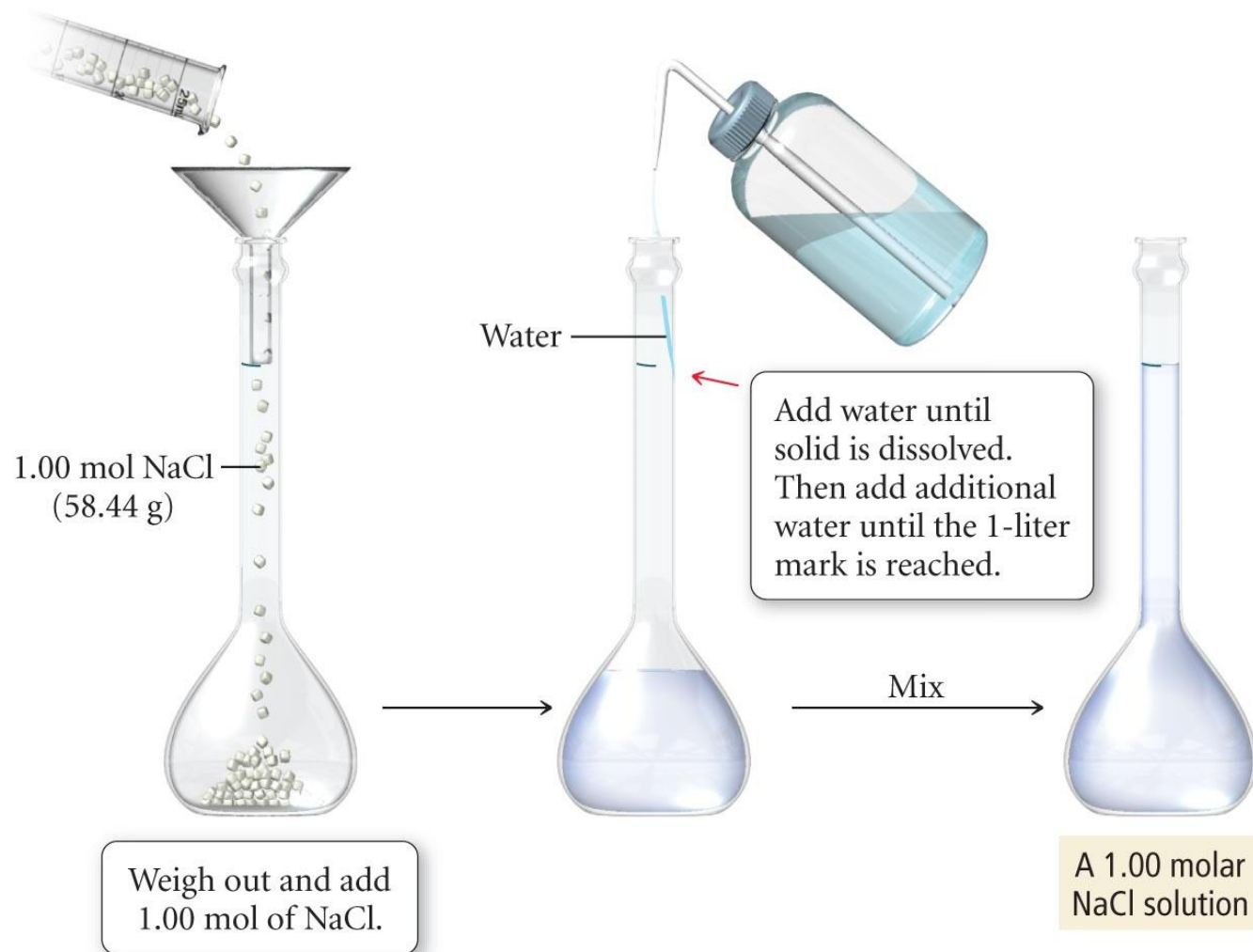
Solution Concentration

Molarity (M)

- Moles of solute per 1 liter of solution
- Used because it describes how many molecules of solute in each liter of solution

$$\text{molarity, } M = \frac{\text{amount of solute (in moles)}}{\text{amount of solution (in L)}}$$

Preparing 1 L of a 1.00 M NaCl Solution



Find the molarity (M) of a solution that has 25.5 g KBr (FM, 119 amu) dissolved in 1.75 L of solution

Practice — What Is the molarity (M) of a solution containing 3.4 g of NH_3 (MM 17.03 amu) in 200.0 mL of solution?

Using Molarity (M) in Calculations

- Molarity shows the relationship between the moles of solute and liters of solution
- If a sugar solution concentration is 2.0 M, then 1 liter of solution contains 2.0 moles of sugar

- 2 liters = 4.0 moles sugar
- 0.5 liters = 1.0 mole sugar

$$\frac{2 \text{ mol sugar}}{1 \text{ L solution}}$$

How many liters (L) of 0.125 M NaOH contain
0.255 mol NaOH?

Determine the mass of CaCl_2
(FM = 110.98 amu) in 1.75 L of 1.50 M solution

Practice – How would you prepare 250.0 mL of 0.150 M CaCl_2 (FM = 110.98 amu)?

Dilution

- To make solutions of lower concentrations from these stock solutions, more solvent is added
 - the amount of solute (mole) doesn't change, just the volume of solution
- The concentrations and volumes of the stock and new solutions are inversely proportional

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

To what volume should you dilute 0.200 L of 15.0 M NaOH to make 3.00 M NaOH?

What is the concentration of a solution prepared by diluting 45.0 mL of 8.25 M HNO_3 to 135.0 mL?

Concentration: percent (%), parts per million (ppm), and parts per billion (ppb)

- Definitions:

$$\text{mass \%} = \frac{\text{mass of component in solution (g)}}{\text{total mass of solution (g)}} \times 100$$

$$\text{ppm of component} = \frac{\text{mass of component in solution (g)}}{\text{total mass of solution (g)}} \times 10^6$$

$$\text{ppb of component} = \frac{\text{mass of component in solution (g)}}{\text{total mass of solution (g)}} \times 10^9$$

% , ppm, ppb

(a) A solution made by dissolving 13.5 g of glucose in 0.1kg of water

(b) A 2.5 g sample of ground water containing 5.4 μg of Zn^{2+}

Example

Sea water is typically 3.5% salt and has a density of 1.03 g mL^{-1} . How many grams of salt is required to fill 62.5 L of aquarium?

Homework

To be announced