- We've been talking about calculations of amounts of products/reactants using a balanced chemical equation:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

The central conversion is mol → mol

Start with 10 mol N_2 + 35 mol H_2. How much NH_3 is made?

$$\frac{10 \text{ mol } N_2}{} \left| \frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2} \right. = 20 \text{ mol } NH_3$$

$$\frac{35 \text{ mol } H_2}{} \left| \frac{2 \text{ mol } NH_3}{3 \text{ mol } H_2} \right. = 23.33 \text{ mol } NH_3$$

* so N_2 runs out first *

N_2 is the Limiting Reactant

How much H_2 left?

$$\frac{10 \text{ mol } N_2}{} \left| \frac{3 \text{ mol } H_2}{1 \text{ mol } N_2} \right. = 30 \text{ mol } H_2 \text{ consumed}$$

$$\underset{\text{start}}{35 \text{ mol}} - \underset{\text{consumed}}{30 \text{ mol}} = 5 \text{ mol } H_2 \text{ left}$$

We've seen that moles can be calculated from mass (using MW) or # of molecules (using Avagadro's #). The latter is useless for most practical purposes. Mass, however, is measurable, so the mass → mol conversion is really important.

Mass of a molecule is not always directly measurable. For example, what do you do if a reaction is occurring in solution?

Molecules in solution:
↳ mixture of compounds

solvent → the compound present in the highest amount
solute → all other compounds in the mixture

Unless otherwise noted, assume the solvent is H_2O

Solubility → the ability of a molecule (solute) to dissolve in a solvent

highly soluble = readily dissolves (think sugar or salt dissolving in water)

poor solubility = solute + solvent don't mix well (oil and water don't mix)

How do solutes dissolve in H_2O?

- this boils down to intermolecular forces!

3 important factors

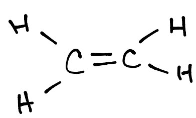
1. solute - solute interactions
2. solvent - solvent interactions
3. solute - solvent interactions

· for a molecule to be soluble, ③ MUST be favorable AND overcome ① + ②

dipole/dipole
H-bond
LDF

② solvent - solvent interactions are strong

③ any solute that can favorably interact with a polar molecules may dissolve in water
- if it can H-bond, even better!

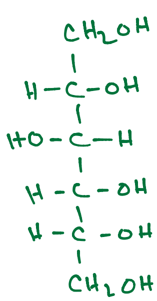


non-polar, so LDF only ① > ③

C_2H_4 will NOT easily dissolve in H_2O

Non-polar molecules are not very soluble in water

Sugar



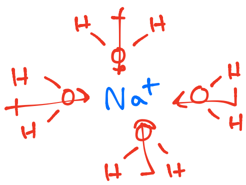
This is glucose

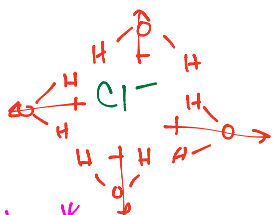
polar + lots of places for H-bonding with water

glucose is readily soluble in water

$NaCl_{(s)} \xrightarrow{H_2O_{(l)}} Na^+ + Cl^-$ ← this is a dissolution reaction (dissolving)

We know that there is lots of coulombic energy holding the ions together. How are these forces broken?





* when ions dissolve in H_2O, these solutions can conduct electricity. → Electrolytes *

* ion-dipole *

this is not as strong as ion/ion but stronger than dipole/dipole

But, not all ionic compounds actually dissolve in water

Soluble

- Group I + II (II: usually) → Always. No exceptions
- Ammonium → Always. No exceptions
- Acetate → Always. No exceptions
- Nitrate → Always. No exceptions
- Halides (exceptions: Ag^+ + Pb^{2+})
- Sulfate (exceptions: Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+})

Insoluble

- CO_3^{2-} → (except IA + NH_4^+)
- PO_4^{3-} → (except IA + NH_4^+)
- S^{2-} → (except IA, IIa + NH_4^+)
- OH^- → (except IA, NH_4^+, Ca^{2+}, Sr^{2+} + Ba^{2+})

(highlight) = always soluble

Predict phases

$NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}$

chloride is not soluble with Ag^+

$(NH_4)_2SO_{4(aq)} + BaCl_{2(aq)} \rightarrow BaSO_{4(s)} + 2NH_4Cl_{(aq)}$

$BaCl_2$: not an exception for chlorides

$BaSO_4$: exception for SO_4^{2-}

Categorize the following as soluble or non-soluble:

- heptane ($CH_3(CH_2)_5CH_3$)
- lead chloride
- Ethanol (CH_3CH_2OH)
- Ethyl ether ($CH_3CH_2OCH_2CH_3$)
- lead acetate

Rank the soluble by increasing solubility

ether < ethanol < lead acetate

Net ionic equations: Not all reactants are important. As such, chemists often write abbreviated chemical reactions that only show pieces of the equation that undergo a chemical transformation (change of state or making a new ion)

$NaCl_{(aq)} + AgNO_{3\,(aq)} \rightarrow AgCl_{(s)} + NaNO_{3\,(aq)}$

not aqueous!

All aqueous are dissolved, so separated into ions

$Na^+ + Cl^- + Ag^+ + NO_3^- \longrightarrow AgCl_{(s)} + Na^+ + NO_3^-$

Net Ionic Equation: $Ag^+ + Cl^- \rightarrow AgCl_{(s)}$

(highlighted) = spectator ions

CHEMICAL Reactions happen in solution. We cannot determine the mass of solutes!

* need to be able to determine moles from information about a solution *

$\text{Concentration} = \dfrac{\text{amount of solute}}{\text{amount of solvent}}$

For us, the REALLY important unit of concentration is Molarity

$M \equiv \text{Molarity} = \dfrac{\text{moles of solvent}}{\text{Volume of solvent}}$ ← ALWAYS in Liters

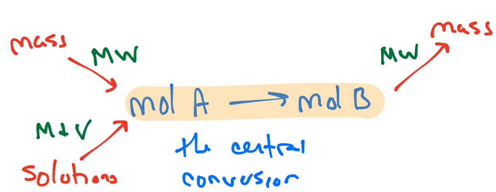
* [X] ≡ concentration of X *

$M = \dfrac{mol}{L}$ $\quad mM = \dfrac{mmol}{L}$ $\quad \mu M = \dfrac{\mu mol}{L}$

Prefixes refer to the mol term

ALWAYS Liters

So we can use molarity as an avenue to determine mols of reactants / products in chemical reactions



- I have 14 mol NaCl dissolved in 2 L. what is the concentration? $\frac{14\text{ mol}}{2} = 7M$

- 4 L of 3.8 M Na_2O. how many moles of O + Na?

$$\frac{4\text{ L}}{} \left| \frac{3.8\text{ mol } Na_2O}{\text{L}} \right. = 19.2\text{ mol } Na_2O \left| \frac{1\text{ mol O}}{1\text{ mol } Na_2O} \right. = 19.2\text{ mol O}$$

$$19.2\text{ mol } Na_2O \left| \frac{2\text{ mol Na}}{1\text{ mol } Na_2O} \right. = 38.4\text{ mol Na}$$

$$(NH_4)_2SO_{4(aq)} + BaCl_{2(aq)} \rightarrow BaSO_{4(s)} + 2\,NH_4Cl_{(aq)}$$

Starting with 0.4 L of 0.502 M $(NH_4)_2SO_4$ and excess $BaCl_2$ (aq)

Sample questions:

1. What mass of $BaCl_{2(aq)}$ will react completely with $(NH_4)_2SO_4$?
2. How much solid will form (in g)
3. What if there is a 78% yield

① central: moles $(NH_4)_2SO_4$ → moles $BaCl_2$ → mass $BaCl_2$

we know V + M

$$\frac{0.4\text{ L } (NH_4)_2SO_4}{} \left| \frac{0.502\text{ mol}}{1\text{ L}} \right| \frac{1\text{ mol } BaCl_2}{1\text{ mol } (NH_4)_2SO_4} = 0.2008\text{ mol } BaCl_2 \left| \frac{208.28\text{ g}}{\text{mol}} \right.$$

41.81 g

② Only one solid → $BaSO_4$ — 233.4 g/mol

$$\frac{0.4\text{ L } (NH_4)_2SO_4}{} \left| \frac{0.502\text{ mol}}{1\text{ L}} \right| \frac{1\text{ mol } BaSO_4}{1\text{ mol } (NH_4)_2SO_4} \left| \frac{233.4\text{ g}}{1\text{ mol}} \right. = 46.87\text{ g } BaSO_4$$

③ $$\frac{46.87\text{ g}}{} \left| \frac{78}{100} \right. = 36.56\text{ g } BaSO_4$$

④ $$\frac{0.4\text{ L } (NH_4)_2SO_4}{} \left| \frac{0.502\text{ mol}}{\text{L}} \right| \frac{2\text{ mol } NH_4Cl}{1\text{ mol } (NH_4)_2SO_4} = \frac{0.402\text{ mol } NH_4Cl}{0.4\text{ L}} = 1.04\text{ M}$$

OR

$$\frac{0.502\text{ mol } (NH_4)_2SO_4}{\text{L}} \left| \frac{2\text{ mol } NH_4Cl}{1\text{ mol } (NH_4)_2SO_4} \right. = \frac{1.04\text{ mol}}{\text{L}} = 1.04\text{M}$$