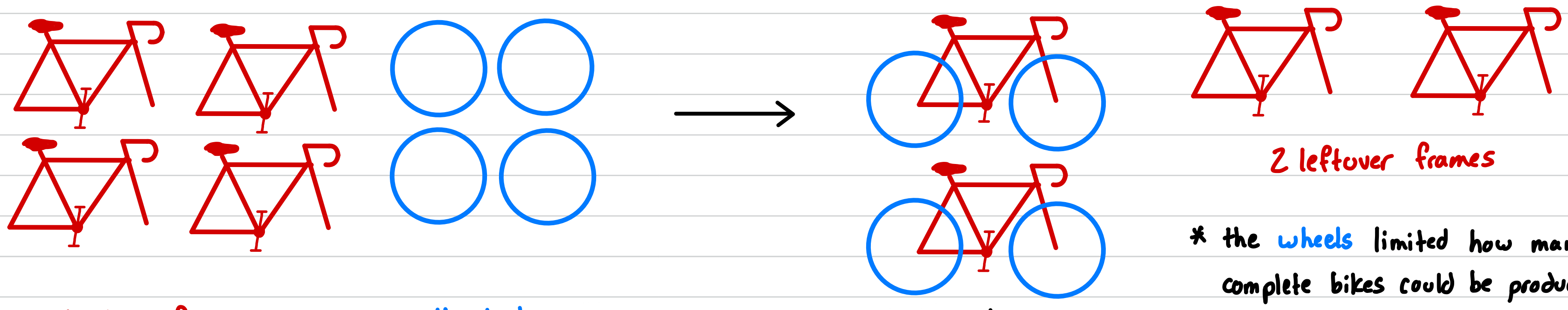
Limiting Reactant

When more than one reactant takes place in a chemical reaction, they will break apart and reform into products
↳ unless there is exactly the same amount of each, one reactant will be completely consumed and one will be leftover

limiting reactant: the reactant completely used up in a chemical reaction. The amount of product is limited by the quantity of this reactant

excess reactant: the reactant remaining after the completion of a chemical reaction.

ex:



4 bike frames — 4 wheels → 2 complete bikes — 2 leftover frames

* the wheels limited how many complete bikes could be produced
∴ wheels are limiting reactant

↳ by determining which reactant is limiting allows a calculation of theoretical maximum yield.

Example problems

(i) ~ Determining limiting and excess reactants ~

50.0g of N_2H_4 is reacted with 75.0g of N_2O_4 to produce water and N_2. Determine the limiting and excess reactants.

1- write a chemical equation: $N_2H_4 + N_2O_4 \rightarrow H_2O + N_2$

2- balance the equation: $2N_2H_4 + N_2O_4 \rightarrow 4H_2O + 3N_2$

6 ~~4~~ N ~~2~~ 6
4 O ~~1~~ 4
8 ~~4~~ H ~~2~~ 8

3- calculate number of moles for each reactant:
$50.0\,g\ N_2H_4 \times \frac{mol}{32.06\,g} = 1.56\ mol$ $\quad 75.0\,g\ N_2O_4 \times \frac{mol}{92.02\,g} = 0.815\ mol$

4- divide moles of reactants by coefficient:
$1.56\ mol\ N_2H_4 \div 2 = 0.780\ mol$ $\quad 0.815\ mol\ N_2O_4 \div 1 = 0.815\ mol$
∴ N_2H_4 is limiting reactant and N_2O_4 is excess reactant

(ii) ~ Determining how much product can be produced and how much of excess will be left over ~

a) How many grams of lead (II) chloride are produced from the reaction of 15.3g of NaCl and 60.8g of $Pb(NO_3)_2$?
b) How many grams will be left over of the excess reactant?

1- write a chemical equation: $NaCl + Pb(NO_3)_2 \rightarrow PbCl_2 + NaNO_3$

2- balance the equation: $2NaCl + Pb(NO_3)_2 \rightarrow PbCl_2 + 2NaNO_3$

2 ~~1~~ Na ~~1~~ 2
2 ~~1~~ Cl 2
2 NO_3 ~~1~~ 2

3- calculate number of moles for each reactant:
$15.3\,g\ NaCl \times \frac{mol}{58.44\,g} = 0.262\ mol$ $\quad 60.8\,g\ Pb(NO_3)_2 \times \frac{mol}{331.22\,g} = 0.184\ mol$

4- divide moles of reactants by coefficient:
$0.262\ mol\ NaCl \div 2 = 0.131\ mol$ $\quad 0.184\ mol\ Pb(NO_3)_2 \div 1 = 0.184\ mol$
∴ NaCl is limiting $\quad$ ∴ $Pb(NO_3)_2$ is in excess

5- convert mol of limiting to g of product:
$0.262\ mol\ NaCl \times \frac{1\ mol\ PbCl_2}{2\ mol\ NaCl} \times \frac{278.11\ g}{mol} = 36.4\ g\ PbCl_2$

6- convert mol of limiting to g of excess and find difference:
$0.262\ mol\ NaCl \times \frac{1\ mol\ Pb(NO_3)_2}{2\ mol\ NaCl} \times \frac{331.22\,g}{mol} = 43.39\ g$ of $Pb(NO_3)_2$ will react
$60.8\,g - 43.39\,g = 17.4\,g$ left

(iii) ~ Determining maximum yield of product given limiting reactant ~

3 mol of C_3H_8 is reacted with excess oxygen (O_2). Determine the maximum mass of CO_2 and H_2O that can be produced

1- write a chemical equation $\quad C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$

2- balance the equation $\quad C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

3 C ~~1~~ 3
8 H ~~2~~ 8
10 ~~2~~ O ~~3~~ ~~7~~ 10

3- write information underneath

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$
3 mol (limiting) $\quad$?g $\quad$?g

4- convert mol of one substance to the needed substance

$$3\ \text{mol}\ C_3H_8 \times \frac{3\ \text{mol}\ CO_2}{1\ \text{mol}\ C_3H_8} \times \frac{44.01\ g}{\text{mol}} = 396.09\ g\ CO_2$$

$$3\ \text{mol}\ C_3H_8 \times \frac{4\ \text{mol}\ H_2O}{1\ \text{mol}\ C_3H_8} \times \frac{18.02\ g}{\text{mol}} = 216.24\ g\ H_2O$$

(iv) ~ Determining maximum yield ~

Calculate the maximum mass of $AlCl_3$ that can be produced from a reaction of 2.80g of aluminum and 4.15g of chlorine gas.

1- write a chemical equation $\quad Al + Cl_2 \longrightarrow AlCl_3$

2- balance the equation $\quad 2Al + 3Cl_2 \longrightarrow 2AlCl_3$

2 ~~1~~ Al ~~1~~ 2
6 ~~2~~ Cl ~~3~~ 6

3- calculate number of moles for each reactant

$$2.80\ g\ Al \times \frac{\text{mol}}{26.98\ g} = 0.104\ \text{mol} \qquad 4.15\ g\ Cl_2 \times \frac{\text{mol}}{70.9\ g} = 0.0585\ \text{mol}$$

4- divide moles of reactants by coefficient

$0.104\ \text{mol}\ Al \div 2 = 0.052\ \text{mol}$ $\quad$ $0.0585\ \text{mol}\ Cl_2 \div 3 = 0.0195\ \text{mol}$

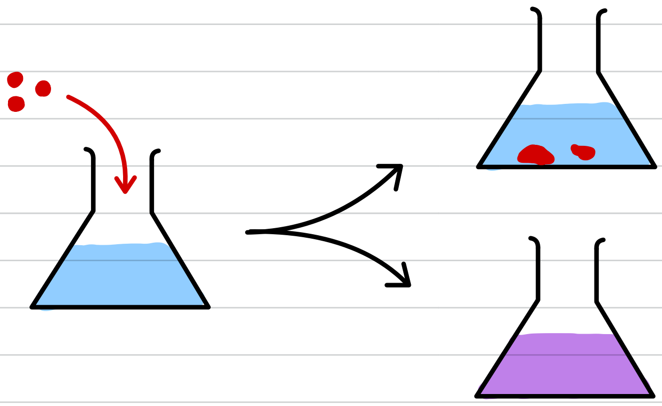
∴ Al is in excess $\quad$ ∴ Cl_2 limiting

5- convert mol of limiting to g of product

$$0.0585\ \text{mol}\ Cl_2 \times \frac{2\ \text{mol}\ AlCl_3}{3\ \text{mol}\ Cl_2} \times \frac{133.33\ g}{\text{mol}} = 5.20\ g\ \text{of}\ AlCl_3$$

solute: substance being dissolved

solvent. substance in which solvent dissolves



heterogeneous solution: solution with non-uniform composition
ex: oil and water

homogenous solution: solution with uniform composition
ex: salt water, hydrochloric acid

★ in order to speed up dissolving : ① mix the solution - helps distribute solute particles within solvent
② heat the solution - more kinetic energy, ∴ solutes collide and interact with solvent more

★ **saturated solution** : the maximum amount of solute dissolved within solvent. Adding more solute beyond this will not dissolve

concentration : quantity of moles (n) or grams dissolved in one dm^3 (L) of solution

concentration (mol/L or g/L) → $C = \frac{n}{V}$ ← moles (mol) or mass (g) of solute
← volume (L) of solution

mol/L ↙ molar concentration, M; g/L ↘ mass concentration

$1 L = 1000 mL = 1000 cm^3 = 1 dm^3$

Example problems

(i) ~ calculating molar concentration ~

A saline solution contains 0.90 g NaCl dissolved in 100 mL of solution. What is the molar concentration?

1- write given information and convert to appropriate units

C = ?

$n = 0.90 \cancel{g}\ NaCl \times \frac{mol}{58.44\ \cancel{g}} = 0.0154\ mol\ NaCl$

$V = 100 \cancel{mL} \times \frac{1\ L}{1000\ \cancel{mL}} = 0.1\ L$

2- use formula c = n/V

$C = \frac{n}{V} = \frac{0.015\ mol}{0.1\ L} = 0.15 \frac{mol}{L}$ / $0.15 \frac{mol}{dm^3}$

(ii) ~ calculating mass and molar concentration ~

0.5 g of calcium hydroxide is added to 10 mL of water. What is its mass concentration (gdm^{-3}) and molar concentration ($molL^{-1}$)?

1- write given information and convert to appropriate units

$\text{solute} = 0.5g\ Ca(OH)_2 \times \frac{mol}{74.1\ g} = 0.00675\ mol\ Ca(OH)_2$

$V = 10 \cancel{mL} \times \frac{dm^3}{1000\ \cancel{mL}} = 0.01\ dm^3$

2- use formula c = n/V

$\text{mass concentration} = \frac{\text{mass solute}}{\text{volume}} = \frac{0.5g}{0.01 dm^3} = 50\ gdm^{-3}$

$\text{molar concentration} = \frac{mol}{V} = \frac{0.00675\ mol}{0.01\ dm^3} = 0.68\ mol\,dm^{-3}$

(iii) ~ calculating amount of solute (grams) ~

A saturated solution of $CaSO_4$ (aq) has a concentration of 0.0154 mol/L.
A student takes 65 mL of the solution and evaporates it. What mass is left?

1- write given information and convert to appropriate units

C = 0.0154 mol/L

n = ?

$V = 65 \cancel{mL} \times \frac{1\ L}{1000\ \cancel{mL}} = 0.065\ L$

2- use formula c = n/V

$C = \frac{n}{V}$ $n = CV$ $= (0.0154\ mol/\cancel{L})(0.065 \cancel{L}) = 0.001001\ mol\ CaSO_4$

3- convert mol to g

$0.001001 \cancel{mol}\ CaSO_4 \times \frac{136.14\ g}{\cancel{mol}} = 0.136g$

(iv) ~ calculating amount of solute (grams) ~

Determine the mass of solute present in a 500 cm^3 solution of 0.100 $mol\,dm^{-3}$ silver nitrate.

1- write given information and convert to appropriate units

$c = 0.100\ mol/dm^3$

$n = ?$

$V = 500\ cm^3 \times \frac{dm^3}{1000\ cm^3} = 0.5\ dm^3$

2- use formula $c = n/V$

$n = cV = (0.100\ mol\,dm^{-3})(0.5\,dm^3)$
$= 0.05\ mol\ AgNO_3$

3- convert mol to g

$0.05\ mol\ AgNO_3 \times \frac{169.88\ g}{mol} = 8.49\ g$

(v) ~ calculating solution volume ~

What volume of 0.25 mol/L solution can be made using 14g of sodium hydroxide ?

1- write given information and convert to appropriate units

$c = 0.25\ mol/L$

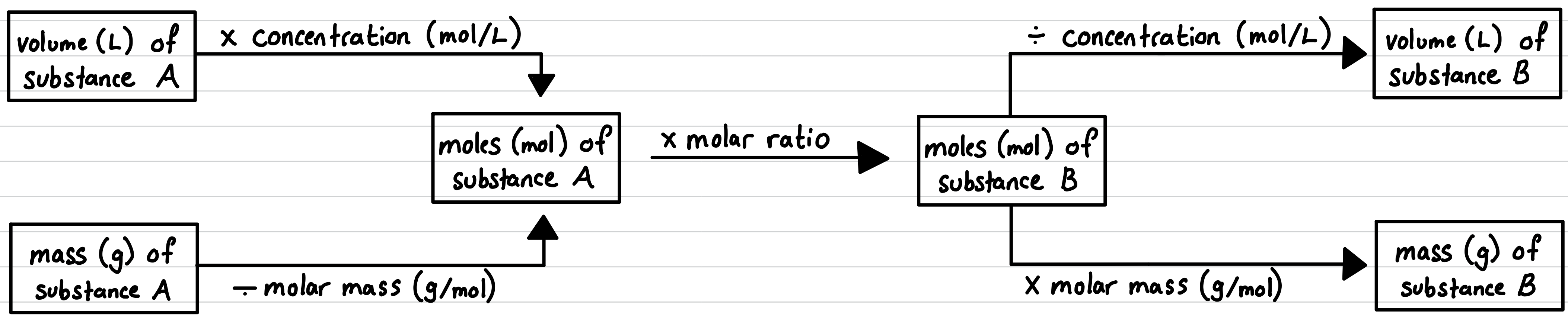
$n = 14\ g\ NaOH \times \frac{mol}{39.99\ g} = 0.35009\ mol$

$V = ?$

2- use formula $c = n/V$

$c = \frac{n}{V} \quad V = \frac{n}{c} = \frac{0.35009\ mol}{0.25\ mol/L} = 1.4\ L$

Solution Stoichiometry



Example problems

(i) ~ calculating product mass from reactant ~

Calcium chloride reacts with phosphoric acid (H_3PO_4) to produce calcium phosphate and hydrochloric acid, HCl.
How many grams of calcium phosphate can be produced if 2500 cm^3 of 0.250 M calcium chloride reacts with excess phosphoric acid?

1 - write a chemical equation $CaCl_2 + H_3PO_4 \rightarrow Ca_3(PO_4)_2 + HCl$

2 - balance the equation $3CaCl_2 + 2H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6HCl$

3 - calculating moles of given $n = VC = \left(2500\,cm^3 \times \frac{L}{1000\,cm^3}\right) \times 0.250\,\frac{mol}{L} = 0.625\ mol\ CaCl_2$

5 - convert mol of one substance to the needed substance $0.625\ mol\ CaCl_2 \times \frac{1\ mol\ Ca_3(PO_4)_2}{3\ mol\ CaCl_2} = 0.208\ mol$

6 - convert mol to mass $0.208\ mol\ Ca_3(PO_4)_2 \times \frac{310.18\,g}{mol} = 64.5\,g$

(ii) ~ calculating reactant volume ~

How many mililiters of 1.50 M nitric acid (HNO_3) is required to react with 100.0g of cuprous oxide in the following unbalanced equation:

$$HNO_3 + Cu_2O \rightarrow Cu(NO_3)_2 + NO + H_2O$$

1 - balance the equation $14HNO_3 + 3Cu_2O \rightarrow 6Cu(NO_3)_2 + 2NO + 7H_2O$

2 - calculating moles of given $100.0\,g\ Cu_2O \times \frac{mol}{143.1\,g} = 0.6988\ mol$

3 - convert mol of one substance to the needed substance $0.6988\ mol\ Cu_2O \times \frac{14\ mol\ HNO_3}{3\ mol\ Cu_2O} = 3.2611\ mol$

4 - convert mol to volume $3.2611\ mol\ HNO_3 \times \frac{L}{1.50\ mol} \times \frac{1000\ mL}{L} = 2170\ mL$

(iii) ~ calculate concentration of reactant ~

60.5 cm^3 of HNO_3 are required to react with 25.0 mL of 1.00M $Ba(OH)_2$ solution to produce barium nitrate and water.
What is the molarity of HNO_3 solution?

1 - write a chemical equation $HNO_3 + Ba(OH)_2 \rightarrow Ba(NO_3)_2 + H_2O$

2 - balance the equation $2HNO_3 + Ba(OH)_2 \rightarrow Ba(NO_3)_2 + 2H_2O$

3 - calculating moles of given $25.0\ mL\ Ba(OH)_2 \times \frac{L}{1000\ mL} \times \frac{1.00\ mol}{L} = 0.025\ mol\ Ba(OH)_2$

5 - convert mol of one substance to the needed substance $0.025\ mol\ Ba(OH)_2 \times \frac{2\ mol\ HNO_3}{1\ mol\ Ba(OH)_2} = 0.05\ mol\ HNO_3$

6 - calculate concentration $c = \frac{n}{V}$ $c = \frac{n}{V}$ $\frac{0.05\,mol\ HNO_3}{60.5\,cm^3} \times \frac{1000\,cm^3}{L} = 0.826\ mol\,L^{-1}$