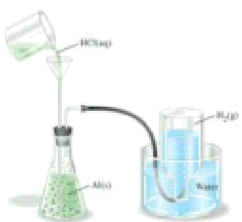
Chemical Equations and Stoichiometry

Objectives: By the end of today's class you will be able to balance chemical equations and use stoichiometric relationships to determine the amount of product from a given amount of reactant.

The Chemical Equation

Chemical equations describe changes that occur in chemical reactions.



▲ FIGURE 4-4
The reaction $2\ Al(s) + 6\ HCl(aq) \longrightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$

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The Chemical Equation

Chemical equations must be balanced, i.e. the number of atoms in the reactant side should be equal to the number of atoms in the product side (atom conservation principle).

For example, dinitrogen pentoxide decomposes to nitrogen dioxide and oxygen:

$$2\,N_2O_5 \rightarrow 4\,NO_2 + 1\,O_2$$

	Reactants	Products
Nitrogen	4	4
Oxygen	10	10

Balancing an equation is done by including stoichiometric coefficients.

The *stoichiometric chemical equation* describes only the net changes taking place in a reaction. It does not correspond necessarily to what takes place at a molecular level.

The Mechanism Equation

Mechanism equations describe the steps required to go from reactants to products at molecular level.

For the above chemical equation shown in the previous slide, a possible mechanism equation could be, for instance:

$$\begin{array}{llll} & 2\,N_2O_5 & \rightarrow & \cancel{2}\,NO_2 + \cancel{2\,NO_3} \\ & \cancel{NO_3} + \cancel{NO_3} & \rightarrow & \cancel{NO} + NO_2 + O_2 \\ & \cancel{NO_3} + \cancel{NO} & \rightarrow & 2\,NO_2 \\ \hline \text{Overall:} & 2\,N_2O_5 & \rightarrow & 4\,NO_2 + O_2 \end{array}$$

Mechanism equations must add up to the stoichiometric chemical equation.

Stoichiometric Calculations

Stoichiometric relationships are used to calculate the proportions of atoms in a molecule or the proportions of products and reactants in a given chemical reaction

Stoichiometry is simply "chemical bookkeeping"

1.0 mole of Fe_2O_3 molecules contains
2 moles of Fe atoms
3 moles of O atoms

$$2\,N_2O_5 \rightarrow 4\,NO_2 + O_2$$

2 mol N_2O_5 : 4 mol NO_2 : 1 mol O_2
4 mol N_2O_5 : 8 mol NO_2 : 2 mol O_2
1 mol N_2O_5 : 2 mol NO_2 : ½ mol O_2

Suggested Readings

4.1 Chemical Reactions and Chemical Equations
4.2 Chemical Equations and Stoichiometry

Example 1:
Baking soda ($NaHCO_3$) is often used as an antacid. It neutralizes excess hydrochloric acid secreted by the stomach according to the equation:

$$NaHCO_3(s) + HCl\,(aq) \rightarrow NaCl(aq) + H_2O\,(l) + CO_2(aq)$$

Milk of magnesia, which is an aqueous suspension of magnesium hydroxide, is also used as an antiacid, as shown below:

$$Mg(OH)_2(s) + 2HCl(aq) \rightarrow 2\,H_2O\,(l) + MgCl_2(aq)$$

Which is the most effective antacid per gram, $NaHCO_3$ or $Mg(OH)_2$?

Basis: 1g $NaHCO_3$, 1g $Mg(OH)_2$

Data: $M_{NaHCO_3} = 83g/mol$ $\quad$ $M_{Mg(OH)_2} = 58g/mol$

1 mol $NaHCO_3$ for 1 mol HCl | 1 mol $Mg(OH)_2$ for 2 mol HCl

$1g \times \frac{1\,mol}{83g} \times \frac{1\,mol}{1\,mol} = \frac{1}{83}\,mol\ HCl$ | $1g \times \frac{1\,mol}{58g} \times \frac{2\,mol}{1\,mol} = \frac{1}{29}\,mol\ HCl$

$\therefore Mg(OH)_2$ is more effective.

Example 2: An excess of aluminum foil is allowed to react with 225 mL of an aqueous solution of HCl that has a density of 1.088 g/mL and contains 18% of HCl by mass.

first check if equation is balanced. $\quad 2\,Al + 6\,HCl \rightarrow 2\,AlCl_3 + 3\,H_2$

What mass of H_2 is produced in the reaction?

1) moles of HCl
2) moles of H_2
3) g of H_2

Basis: 225 mL
Data: $\rho = 1.088g/mL$
18% HCl
6 HCl : 3 H_2

$M_{HCl} = 36g/mol$
$M_{H_2} = 2.02g/mol$

1) $225\,mL \times 1.088\,g/mL \times 0.18 \times 1\,mol/36g = x$

2&3) $x \times \frac{3\,mol\ H_2}{6\,mol\ HCl} \times 2.02g/mol = ans$
$= 1.22g\ H_2$

Example 3: Parallel or simultaneous reactions.
How many grams of CO_2 are produced in the complete combustion of 406 g of a bottled gas that consists of 72.7% propane (C_3H_8) and 27.3% butane (C_4H_{10}), by mass?

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$
$$C_4H_{10} + 13/2\ O_2 \rightarrow 4\ CO_2 + 5\ H_2O$$

$\underline{C_4H_{10}}$

$$0.273 \times 406 \times \frac{1}{58.12} \times 4 \times 44.01 = 335.72g$$
$$\doteq 336g$$

do the same fore C_3H_8

Example 4: Consecutive Reactions
Nitric acid, HNO_3, is produced from ammonia and oxygen by the consecutive reactions:

$$\boxed{4\ NH_3(g)} + 5\ O_2(g) \rightarrow \boxed{4\ NO(g)} + 6\ H_2O(g)$$
$$\boxed{2\ NO(g)} + O_2(g) \rightarrow \boxed{2\ NO_2(g)}$$
$$\boxed{3\ NO_2(g)} + H_2O(l) \rightarrow \boxed{2\ HNO_3(aq)} + NO(g)$$

How many grams of nitric acid can be obtained from 1.0 kg NH_3, if NO in the third reaction is not recycled?

$$1.0\ kg\ NH_3 \times \frac{1\ kmol}{17.03052\ kg} \times \frac{4\ kmol\ NO}{4\ kmol\ NH_3} \times \frac{2\ kmol\ HNO_3}{2\ kmol\ NO_2}$$
$$\times \frac{63.01284\ kg}{1\ kmol\ kmol}$$

$$= 2.5 kg\ HNO_3$$

$$= 2500g\ HNO_3$$