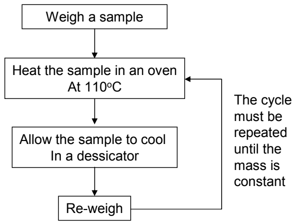
Week 2 **Gravimetric Analysis** (Analysis by Mass)

Measuring water content

- Water is a component in many consumer products
- It may occur naturally or may be added in manufacturing
- Water content can reveal the real value of a product, or it can be crucial in acceptable product quality *e.g.* grain susceptibility to sprouting.

Procedure for determining water content



An analytical chemist wanting to find the percentage of water in a can of soup obtains the following results. What is the percentage of water in the soup?

Initial mass of soup	223.1 g
Second mass, after heating	33.6 g
Third mass, after heating	24.3 g
Fourth mass, after heating	24.3 g

Initial mass – constant mass after drying
223.1 – 24.3
= 198.8

$\therefore$ % of water in the soup by mass = $\frac{198.8}{223.1}$ X 100

Amounts of gases

Gases:
- Spread to fill the volume available
- Have low densities
- Are easily compressible
- Mix together rapidly

Kinetic molecular theory of gases
- Gas particles widely separated
- Rapidly moving in random, straight-line motion

It is not convenient to measure gas amounts by weight.
When the internal volume of a gas container is known, it is possible to calculate the mol quantity using the General Gas Equation:

$pV = nRT$

p = gas pressure; V = gas volume; T = temperature;
R = General Gas Constant = 8.31 J K^{-1} mol^{-1} when pressure is in KPa; volume in L and T in °K

Once the amount of gas is found, its mass can be calculated from:

$$n = \frac{m}{M}$$

Molar Volume of a Gas

- The volume of 1 mol of a gas depends on the gas temperature and pressure.
- At Standard Temperature and Pressure (STP; 0°C and 1 atmosphere), the **Molar Volume of a gas** is 22.4 L mol^{-1}.
- At Standard laboratory Conditions (**SLC**; 25°C and 1 atmosphere) the **Molar Volume of a gas** is 24.5 L mol^{-1}.

The mol quantity of a gas can be also be calculated from:

$$n = \frac{V}{V_m}$$

A steel cylinder with a volume of 30.0 L is filled with nitrogen gas to a pressure of 2.00 atm at 25°C. What mass of nitrogen is contained?

Since $pV = nRT$

$n(N_2) = \frac{pV}{RT}$

$= \frac{(2.00 X 101.3) KPa X 30.0 L}{8.31 X (25.0 + 273) K}$

= 2.45 mol

$m(N_2) = n(N_2) X M(N_2)$

= 2.45 X 28.0

= 68.7 g

Calculate the amount in mol, of sulfur dioxide in 10.0 L of the gas measured at STP

Since $n = \frac{V}{V_m}$

$n(SO_2) = \frac{10.0 L}{22.4 L mol^{-1}}$

= 0.446 mol

So, 10.0 L of sulfur dioxide, measured at STP, contains 0.446 mol of SO_2 molecules

Chemistry 2: p15

6. Calculate the amount (in mole) of:

a. NaCl in 5.85 g of the salt	a. 0.100 mol
b. Fe atoms in 112 g of iron	b. 2.01 mol
c. CO_2 molecules in 2.2 g of carbon dioxide	c. 0.050 mol
d. Cl^- ions in 13.4 g of nickel chloride ($NiCl_2$)	d. 2.07 X 10-1 mol
e. O^{2-} ions in 159.7 g of iron(III) oxide (Fe_2O_3)	e. 3.000 mol

7. Calculate the mass of

a. 3.0 mol of oxygen molecules (O_2)	a. 96 g
b. 1.2 mol of aluminium chloride ($AlCl_3$)	b. 1.6 X 10^2 g
c. 2.0 mol of nitrogen atoms	c. 28 g

8. A small oxygen cyliner carried by an ambulance has an internal volume of 1.42 L. What mass of oxygen is present at a pressure of 15 000 KPa and temperature of 15.0°C? 285 g

9. Calculate the mass of the following gases

a. 3.5 L of argon at SLC.	a. 5.7 g
b. 250 mL of ammonia (NH_3) at STP.	b. 0.190 g

Finding the composition of a compound

Review Chemistry 2: Chap 2.2

Chemistry 2: p18

10. Determine the percentage composition of the following compounds
    a. Lead (IV) oxide (PbO_2) — a. 13.4%
    b. Sodium carbonate ($NaCO_3$) — b. 45.3%

11. A gaseous hydrocarbon that is used as a fuel for high-temperature welding of metals contains 92.3% carbon.
    a. Determine its empirical formula. — a. CH
    b. If the molar mass of the hydrocarbon is 26 g mol^{-1}, find its molecular formula. — b. C_2H_2

12. When 1.66 g of tungsten (W) is heated in excess chlorine gas, 3.58 g of tungsten chloride is produced. Find the empirical formula of tungsten chloride — WCl_6

13. A sample of blue copper (II) sulfate crystals weighing 2.55 g is heated and decomposes to produce 1.63 g of anhydrous copper (II) sulfate. Show that the formula of the blue crystals is $CuSO_4.5H_2O$.

Calculating masses of reactants and products

Review Chemistry 2: Chap 2.3

The **mole** is particularly useful for calculating the quantities of substances consumed or produced in chemical reactions. Consider:

$Pb(NO_3)_2\ (aq) + 2KI\ (aq) \longrightarrow PbI_2\ (s) + 2KNO_3\ (aq)$

The coefficients indicate the relative number of moles thus:

$$\frac{n[Pb(NO_3)]}{n(KI)} = \frac{1}{2} \qquad \frac{n[Pb(NO_3)]}{n(PbI)} = \frac{1}{1} \qquad \frac{n(KI\ )}{n(PbI)} = \frac{2}{1}$$

14. Magnesium reacts with hydrochloric acid according to the equation:

$Mg\ (s) + 2HCl\ (aq) \longrightarrow MgCl\ (aq) + H_2O$

If 10.0 g of magnesium reacts completely, calculate:

a. the mass of magnesium chloride that forms — a. 39.2 g

b. the mass of hydrogen that forms — b. 0.0824 g

15. Iron metal is extracted in a blast furnace by a reaction between iron(III) oxide and carbon monoxide:

$Fe_2O_3\ (s) + 3CO\ (g) \longrightarrow 2Fe\ (l) + 3CO_2\ (g)$

To produce 1000 kg of iron, calculate:

a. the of iron(III) oxide required — a. 1430 kg

b. the volume of carbon dioxide produced at SLC — b. 659000 L

16. A solution containing 10.0 g of silver nitrate is mixed with a solution containing 10.o g of barium chloride. What mass of silver chloride precipitate is likely to be produced?

$2AgNO_3\ (aq) + BaCl_2\ (aq) \longrightarrow 2AgCl\ (s) + BaNO_3\ (aq)$ — 8.44 g

Finding the Composition of a mixture

- Most commercial products mixtures.
- It is possible to find the percentage of one component (ion) by gravimetric analysis.
- Involves forming a suitable precipitate with the ion and calculating the amount of the ion in the precipitate.

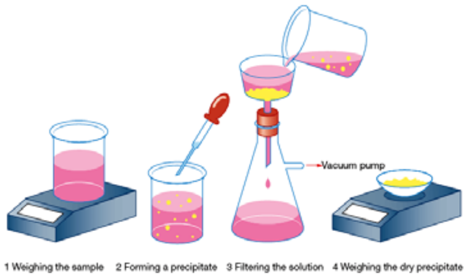
A suitable precipitate should:

- Have a known formula
- Have low solubility
- Be stable when heated (so it can be dried easily)
- Not form precipitates with other ions that are likely to be present.

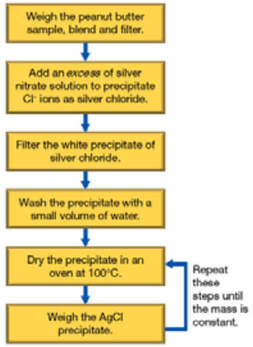
TABLE 2.4 Precipitates formed for gravimetric analysis

Element to be analysed	Precipitate	Compound name
Chlorine	$AgCl$	Silver chloride
Bromine	$AgBr$	Silver bromide
Iodine	AgI	Silver iodide
Iron	Fe_2O_3	Iron(III) oxide
Phosphorus	$Mg_2P_2O_7$	Magnesium pyrophosphate
Magnesium	$Mg_2P_2O_7$	Magnesium pyrophosphate
Sulfur	$BaSO_4$	Barium sulfate
Barium	$BaSO_4$	Barium sulfate

Key steps in gravimetric analysis by precipitation



For example to find the amount of chloride in peanut butter



A 7.802 g sample of baby cereal was blended with water and filtered. Excess silver nitrate was added, causing silver chloride to precipitate. The precipitate was collected by filtration, dried and weighed. A mass of 0.112 g was obtained. What is the percentage of sodium chloride in the baby food assuming that all the chloride is present as sodium chloride?

Solution

The full equation for the reaction is:

$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$

Alternatively, this may be written as an ionic equation:

$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$

Calculating the amount in mol of AgCl present in the precipitate:

$$n(\mathrm{AgCl}) = \frac{m(\mathrm{AgCl})}{M(\mathrm{AgCl})} = \frac{0.112\ \mathrm{g}}{143.4\ \mathrm{g\ mol^{-1}}} = 0.000\ 781\ \mathrm{mol}$$

From the equation, 1 mole of NaCl yields 1 mole of AgCl.

$$\frac{n(\mathrm{NaCl})}{n(\mathrm{AgCl})} = \frac{1}{1}$$

$$n(\mathrm{NaCl}) = n(\mathrm{AgCl}) = 0.000\ 781\ \mathrm{mol}$$

$$m(\mathrm{NaCl}) = n(\mathrm{NaCl}) \times M(\mathrm{NaCl})$$

$$= 0.000\ 781\ \mathrm{mol} \times 58.5\ \mathrm{g\ mol^{-1}} = 0.0457\ \mathrm{g}$$

The content of saccharine ($C_7H_7NO_3S$) in diet sweetener tablets can be determined by oxidising the sulfur to sulfate and precipitating it as barium sulfate ($BaSO_4$). A 0.607 g sample yields 0.3196 g barium sulfate. What is the percentage of saccharine in the sample?

Solution

$$n(\mathrm{BaSO_4}) = \frac{m(\mathrm{BaSO_4})}{M(\mathrm{BaSO_4})} = \frac{0.3196\ \mathrm{g}}{233.4\ \mathrm{g\ mol^{-1}}} = 0.001\ 369\ \mathrm{mol}$$

1 mole of $C_7H_7NO_3S$ yields 1 mole of $BaSO_4$ (as the number of sulfur atoms in each compound must be the same).

So, the ratio $\frac{n(\mathrm{C_7H_7NO_3S})}{n(\mathrm{BaSO_4})} = \frac{1}{1}$

$$n(\mathrm{C_7H_7NO_3S}) = n(\mathrm{BaSO_4}) = 0.001\ 369\ \mathrm{mol}$$

$$m(\mathrm{C_7H_7NO_3S}) = n(\mathrm{C_7H_7NO_3S}) \times M(\mathrm{C_7H_7NO_3S})$$

$$= 0.001\ 369\ \mathrm{mol} \times 185.2\ \mathrm{g\ mol^{-1}} = 0.2535\ \mathrm{g}$$

So, the 0.607g sample contains 0.2535 g of $C_7H_7NO_3S$. Therefore,

$$\%\ \mathrm{C_7H_7NO_3S} = \frac{0.2535\ \mathrm{g} \times 100}{0.607\ \mathrm{g}} = 41.76\%$$

The percentage of saccharine in the tablets is 41.8% (to three significant figures).

Chapter review

19. Find the amount in mol of:
    a. Ca atoms in 60.0 g of calcium. — a. 1.50 mol
    c. H_2O molecules in 20.0 g of $CuSO_4.5H_2O$ — b. 0.401 mol

20. Find the mass of:
    a. 0.30 mol of zinc atoms. — a. 20 g
    c. 0.16 mol of iron(III) oxide (Fe_2O_3) — b. 26 g

22. 6.00 g of helium gas was blown into a fairground balloon. On the day, the temperature was 28.0°C and the pressure inside the balloon was 103.4 KPa. Assuming it is infinitely elastic, to what volume would the balloon inflate? — 36.3 L

23. Calculate the volume of the following gases:
    b. 1.50 mol of oxygen at STP — a. 22.4 L
    d. 1.23×10^{22} atoms of helium at SLC — b. 0.49 L

25. Solutions of silver nitrate and potassium chromate react to produce a red precipitate of silver chromate:

$2AgNO_3\ (aq) + K_2CrO_4\ (aq) \longrightarrow Ag_2CrO_4\ (s) + 2KNO_3\ (aq)$

If 0.778 g of precipitate is formed in a reaction, find:
    a. the mass of potassium chromate that reacted — a. 0.455 g
    b. the mass of silver nitrate that reacted — b. 0.797 g

26. Magnesium in distress flares burns in air according to the equation:

$2Mg\ (s) + O_2\ (g) \longrightarrow 2MgO\ (s)$

If 10.0 g of magnesium burns in air, calculate:
    a. the mass of magnesium oxide produced — a. 16.6 g
    b. the mass of oxygen that reacts — b. 6.58 g

27. Lithium peroxide may be used as a portable oxygen source for astronauts. Calculate the volume of oxygen gas, measured at 25oC and pressure of 101.3 KPa, that is available from the reaction of 0.500 kg of lithium peroxide with carbon dioxide according to the equation:

$2Li_2O_2\ (s) + 2CO_2\ (g) \longrightarrow 2Li_2CO_3\ (s) + O_2\ (g)$ — 133 L

31. If 16.0 g of hydrogen sulfide is mixed with 20.0 g of sulfur dioxide and they react according to the equation:

$2H_2S\ (g) + SO_2\ (g) \longrightarrow 2H_2O\ (l) + 2S\ (s)$
    a. what mass of sulfur is produced? — a. 22.6 g
    b. what mass of reactant is left after the reaction? — b. 4.94 g

33. The following compounds are used in fertilizers as a source of nitrogen. Calculate the percentage of nitrogen, by mass, in:
    c. urea {$CO(NH_2)$} — 46.7%

34. Find the empirical formula of:
    b. an oxide of copper that contains 89% copper by mass — Cu_2O

38. A student is given solutions of lead(II) nitrate, copper(II) chloride and barium hydroxide.
    a. using Table 2.5, name the precipitates that could be made by mixing together pairs of solutions.
    b. write ionic equations for each of the reactions

TABLE 2.5 Solubilities of common ionic compounds

High solubility	Low solubility
Compounds containing the following ions are generally soluble in water: ■ Na^+, K^+, NH_4^+, NO_3^-, CH_3COO^- ■ Cl^-, Br^-, I^- (unless combined with Ag^+ or Pb^{2+}) ■ SO_4^{2-} (except $PbSO_4$ and $BaSO_4$; Ag_2SO_4 and $CaSO_4$ are slightly soluble)	Compounds containing the following ions are generally insoluble, unless combined with Na^+, K^+ or NH_4^+: ■ CO_3^{2-}, PO_4^{3-}, S^{2-}, OH^- (unless combined with Ba^{2+} or Sr^{2+}; $Ca(OH)_2$ is slightly soluble)

a. Lead(II) chloride, lead(II) hydroxide, copper(II) hydroxide.

b. $Pb(NO_3)_2$ (aq) + $CuCl_2$ (aq) ⟶ $PbCl_2$ (s) + $Cu(NO_3)_2$ (aq)
   Pb^{2+} (aq) + Cl^- (aq) ⟶ $PbCl_2$ (s)

   $Pb(NO_3)_2$ (aq) + $Ba(OH)_2$ (aq) ⟶ $Pb(OH)_2$ + $Ba(NO_3)_2$ (aq)
   Pb^{2+} (aq) + $2OH^-$ (aq) ⟶ $Pb(OH)_2$ (s)

   $CuCl_2$ (aq) + $Ba(OH)_2$ (aq) ⟶ $Cu(OH)_2$ (s) + $BaCl_2$ (aq)
   Cu^{2+} (aq) + $2OH^-$ (aq) ⟶ $Cu(OH)_2$ (s)

39. Design a flowchart to show how the salt content of a savory spread could be determined by gravimetric analysis.

Summary

- The amount of substance is measured in mole (*n*)
- The number of particles in one mole is called Avogadro's Number (*NA*). N_A = 6.02 X 10^{23} particles
- The relationship between amount of substance (*n*) and, mass (*m*), and molar mass (*M*) is given by
  $$n = \frac{m}{M}$$
- The relationship between volume (*V*), pressure (*P*), temperature (*T*) and amount of a gas in mol (*n*) is given by the general gas equation *pV = nRT*
- At STP one mole of a gas occupies 22.4 L and at SLC one mole of gas occupies 24.5 L.

- The number of mole of a gas can be determined from the volume (*V*) and the molar volume (*Vm*) $n = \frac{V}{Vm}$
- Empirical formula indicates the simplest whole-number ratio of atoms present in a compound.
- A molecular formula gives the actual number of atoms of each element present in a molecule of the compound.
- The molecular formula can be determined from an empirical formula if the molar mass (molecular weight) is known.
- The stoichiometry of a chemical reaction can be used to determine the amount of product formed or the amount of reactant consumed.