CHEM 2.1

Standard 91161 Carry out quantitative analysis

This standard requires calculations, basic algebra is needed.
All answers should be in three significant figures (3 s.f.)
This standard can be divided into 2 parts
Please read **this document**

1. **Concept of amount**
    a. Relationship between mass and amount
    b. Relationship between concentration and amount
    c. Stoichiometry
2. **Titration (skill based)**
    a. Titration experiments
    b. Calculations

Formulas involve*

$$n = \frac{m}{M} \qquad c = \frac{n}{V}$$

* Formulas will not be given in any assessment

Concept of amount

- In a chemical equation, the numbers are amount.
- For example
  - $2H_2 + O_2 \rightarrow 2H_2O$
  - For each 2 hydrogen molecules and one oxygen molecule forming 2 water molecules
- However since chemistry is dealing with large amount of substance, the **amount (*n*)** is measured **in moles** the symbol of the unit is **mol**.
- It is similar to the concept of dozen
  - 1 dozen = 12
  - 1 mole = 6.02×10^{23}

Relationship between mass and amount

- Since there is a **mass** for **each substances**, the **mass of one mole of substance** is called the **molar mass (*M* in g mol^{-1})**.
- Molar Mass **(g mol^{-1})** is the mass **(*m* in g)** per amount of substance **(*n* in mol)**.
- The **molar mass** is the **sum of all the masses** in the **substances**.
- **Molar mass** can be found in the **periodic table**.
- For example
  - The molar Mass for:
    - Hydrogen (H_2) is
      - 1.00 g mol^{-1} × 2 = 2.00 g mol^{-1}
    - Oxygen (O_2) is
      - 16.0 g mol^{-1} × 2 = 32.0 g mol^{-1}
    - Water (H_2O) is
      - 1.0 g mol^{-1} × 2 + 16.0 g mol^{-1} = 18.0 g mol^{-1}
- The relationship between mass, amount and molar mass is

$$n = \frac{m}{M} \ \left(mol = \frac{g}{g\ mol^{-1}} \right)$$

- For example
  - The amount of water in 40.0 g of water
    - $n = \frac{m}{M}$
    - $mol = \frac{40\ g}{18\ g\ mol^{-1}} = 2.22\ mol$
  - The mass of oxygen in 0.50 mol of oxygen
    - $n = \frac{m}{M}$
    - $0.5\ mol = \frac{g}{32\ g\ mol^{-1}}$
    - $0.5\ mol \times 32\ g\ mol^{-1} = 16.0\ g$

Relationship between concentration and amount

- Concentration (c in $molL^{-1}$) is defined as amount of substance (n in mol) per unit volume (V in L)

$$c = \frac{n}{V} \; \left(molL^{-1} = \frac{mol}{L}\right)$$

- Example of simple calculation involves concentration.
  - What is the amount of HCl when 25.0 mL of 0.150 $molL^{-1}$ of hydrochloric acid HCl?
    - $c = \frac{n}{V}$
    - $0.150\ molL^{-1} = \frac{mol}{0.0250\ L}$
    - $0.150\ molL^{-1} \times 0.0250L = 3.75 \times 10^{-3}\ mol$
- Example of calculation involves combining both molar mass and concentration
  - What is the concentration of NaOH when 4.00 g of NaOH is dissolved in 250 mL of water?
    - Molar mass for NaOH is
      - 23.0 + 16.0 + 1.00 = 40.0 g mol^{-1}
    - The amount of NaOH is
      - $mol = \frac{4.00\ g}{40.0\ gmol^{-1}} = 0.100\ mol$
    - The concentration of NaOH in 250 mL of water is
      - $c = \frac{n}{V}$
      - $molL^{-1} = \frac{0.100mol}{0.25L} = 0.400\ molL^{-1}$

Stoichiometry

- Stoichiometry is using the molar ratio in the equation for chemical calculation
- For example:
  - $2H_2 + O_2 \rightarrow 2H_2O$
  - The ratio between
    - $H_2 : H_2O = 1:1$
    - $H_2 : O_2 = 2:1$
    - $O_2 : H_2O = 1:2$
  - Therefore if there are 4 mol of hydrogen, there will be
    - 2 mol of oxygen and 4 mol of water
- This can be applied in concept of molar mass and concentration
- For example
  - $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$
  - Calculate the mass of NaOH needed to neutralise 25 mL of 0.125 mol L^{-1} of H_2SO_4
    - Amount of H_2SO_4 in 25 mL
      - $c = \frac{n}{V}$
      - $0.125\ mol\ L^{-1} = \frac{mol}{0.0250\ L}$
      - $0.125\ mol\ L^{-1}\ \times 0.0250\ L = 3.125 \times 10^{-3}\ mol$
    - The ratio between H_2SO_4 : NaOH is 1:2
    - Therefore the amount of NaOH is 3.125×10^{-3} mol × 2 = 6.25×10^{-3} mol
    - The molar mass of NaOH is 23.0 + 16.0 + 1.00 = 40.0 g mol^{-1}
    - Therefore the mass of NaOH needed will be
      - $n = \frac{m}{M}$
      - $6.25 \times 10^{-3} mol = \frac{g}{40.0\ gmol^{-1}}$
      - $6.25 \times 10^{-3}\ mol\ \times 40.0\ g\ mol^{-1} = 0.25\ g$
- Another example
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - Calculate the mass of water (H_2O) is produced when 42.0g of methane CH_4 is burnt
    - The molar mass for methane is
      - 12.0 g mol^{-1} + 4 × 1.00 g mol^{-1} = 16.0 g mol^{-1}
    - The amount of methane is
      - $n = \frac{m}{M}$
      - $mol = \frac{42.0\ g}{16.0\ gmol^{-1}} = 2.625\ mol$
    - The ratio between CH_4 : H_2O is 1:2
    - Therefore the amount of water is 2.625 mol × 2 = 5.25 mol
    - Molar Mass of water is 16 + 1 × 2 = 18.0 g mol^{-1}
    - $5.25\ mol = \frac{g}{18.0\ g\ mol^{-1}}$
    - $5.25\ mol\ \times 18.0\ g\ mol^{-1} = 94.5\ g$

Exercises for concept of amount

1. Calculate the molar mass (g mol^{-1}) of the following
    a. Na_2CO_3
    b. $CaCl_2$
    c. $CuSO_4$
    d. $Zn(NO_3)_2$
2. Calculate the amount of the following
    a. 4.00 g of Na_2CO_3
    b. 15.0 g of $CaCl_2$
    c. 0.006 g of $CuSO_4$
    d. 80 kg of $Zn(NO_3)_2$
3. Calculate the mass of the following
    a. 0.250 mol of Na_2CO_3
    b. 3.67 mol of $CaCl_2$
    c. 4.01 mol of $CuSO_4$
    d. 2.34×10^{-3} mol of $Zn(NO_3)_2$
4. Calculate the concentration of the following
    a. 3.20 mol in 250 mL
    b. 2.56 mol in 2 L
    c. 0.0321 mol in 25 mL
5. Calculate the amount of the following
    a. 25.0 mL of 0.156 mol L^{-1}
    b. 30.2 mL of 0.567 mol L^{-1}
    c. 3.21 L of 0.102 mol L^{-1}
6. The mass of Na_2CO_3 needed to make 250 mL of 0.100 mol L^{-1} of Na_2CO_3

7. For Haber process

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

    a. Determine the mass of nitrogen (N_2) needed to form 300 kg of ammonia (NH_3).

    b. What is the mass of hydrogen (H_2) that is needed to react with 150 kg of Nitrogen (N_2) and the mass of ammonia (NH_3) produced.

Titration

- Titration is a technique to determine the concentration of an unknown solution by reacting it with a solution of a known concentration.
  - The unknown solution is called the sample
  - The known solution is called the standard
- In level 2 chemistry, the titration is an acid and base titration

Titration experiments

- Below are the equipments needed for a titration experiment
  - **Burette**
    - This glassware is used to dispense volume gradually.
    - It has a tap in the bottom to dispense the solution in the burette.
    - The markings on the side indicate the volume dispensed.
    - To remain consistent, the volume is read at the bottom of the meniscus disk
      - For example

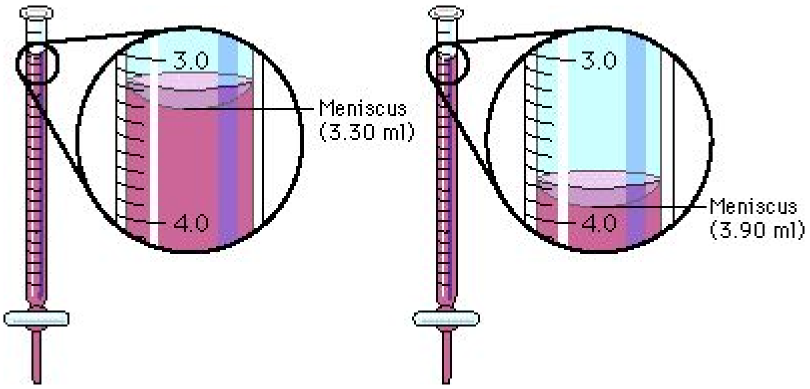

Figure 2.1- How to read a burette[1]

    - The **reading from the burette** is called the **titre**
  - **Pipette**
    - This glassware is used to dispense a fixed volume of solution accurately.
    - A pump of some sort is used to fill the pipette.
    - Once again, in order to obtain an accurate volume, when the bottom of the meniscus disk on the mark, it is the volume indicated on the pipette.
    - A good practice is to overfill the pipette then release the solution slowly until the bottom of the meniscus disk reaches the mark.
  - **Conical flask**
    - The solution from the pipette is then placed in the conical flask where indicator is added.

[1] http://www.phschool.com/science/biology_place/labbench/lab2/burette.html accessed 20/11/2017

Calculations

- Titration calculation is a stoichiometry calculation between two solutions.
    - There should be three titres with concordant result (±0.200 mL)
    - A table should be setup to record the results in an orderly manner

	Titration #1 (rough)	Titration #2	Titration #3	Titration #4
Final Volume				
Initial Volume				
Titre Volume				

- First an average titre is calculated AFTER the removal of outlier.
- Here are the steps of the calculation
    1. Convert all volume into litres (÷1000)
    2. Determine the amount of standard used

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

$$c\ (mol\ L^{-1}) = \frac{n\ (mol)}{V\ (L)}$$

$$c\ (mol\ L^{-1})\ \times V\ (L) = n\ (mol)$$

    3. Using the ratio, determine the amount of sample present
    4. Using the volume of the sample, determine the concentration

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

$$c\ (mol\ L^{-1}) = \frac{n\ (mol)}{V\ (L)}$$

- Do not do any rounding until the final answer.

- Here is an example
    - 25.0 mL of unknown concentration of NaOH is titrated against 0.100 $molL^{-1}$ H_2SO_4.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

	Titration #1 (rough)	Titration #2	Titration #3	Titration #4
Final Volume	24.3	24.3	0	23.7
Initial Volume	0	48.1	23.7	47.5
Titre Volume	~~24.3~~ (outlier)	23.8	23.7	23.8

1. The average titre is (0.0238 L + 0.0237 L + 0.0238 L) ÷ 3 = 0.02376... L
2. Determine the amount of standard used

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

$$0.100\ mol\ L^{-1} = \frac{n\ (mol)}{0.02376...\ L}$$

$$0.100\ mol\ L^{-1} \times 0.02376...\ L = 0.002376...\ mol$$

3. Using the ratio, determine the amount of the sample present
   Ratio between H_2SO_4 and NaOH is 1:2
   Therefore the amount of NaOH is 0.002376… mol × 2 = 0.004753...mol
4. Using the volume of the sample to determine the concentration

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

$$mol\ L^{-1} = \frac{0.004753...mol)}{0.025L} = 0.190\ mol\ L^{-1}(3\ s.f.)$$

Exercise for Titration

1. 25.0 mL of 0.102 mol L^{-1} of NaOH is titrated against an unknown concentration of H_2SO_4. Determine the concentration of the unknown H_2SO_4

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

	Titration #1 (rough)	Titration #2	Titration #3	Titration #4
Final Volume	15.2	30.1	45.1	15.1
Initial Volume	0	15.2	30.1	0
Titre Volume				

2. 25.0 mL of unknown Na_2CO_3 is titrated against 0.102 mol L^{-1} of HCl. Determine the concentration of the unknown Na_2CO_3

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + 2H_2O + CO_2$$

	Titration #1 (rough)	Titration #2	Titration #3	Titration #4
Final Volume	20.1	39.0	19.0	38.0
Initial Volume	0	20.1	0	19.0
Titre Volume				