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PHYSICAL SCIENCE

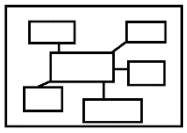
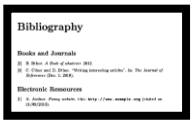
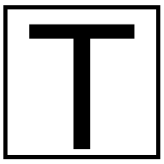
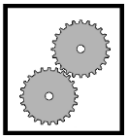
GRADE 12

WINTER CLASSES 2026

TEACHER AND LEARNER CONTENT MANUAL

1. RATES AND EXTENT OF REACTIONS;
2. ACIDS AND BASES;
3. ELECTRIC CIRCUITS;
4. ELECTROSTATICS.

ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

CONTENTS **PAGE**

TOPIC 1: RATES AND EXTENT OF REACTIONS

EXAMINATION GUIDELINE

Energy and Change
(This section must be read in conjunction with the CAPS, p. 90–91.)

Energy changes in reactions related to bond energy changes

- Define heat of reaction (ΔH) as the energy absorbed or released in a chemical reaction.
- Define *exothermic reactions* as reactions that release energy.
- Define *endothermic reactions* as reactions that absorb energy.
- Classify (with reason) reactions as exothermic or endothermic.

Exothermic and endothermic reactions

- State that ΔH > 0 for endothermic reactions, i.e. reactions in which energy is absorbed.
- State that ΔH < 0 for exothermic reactions, i.e. reactions in which energy is released.

Activation energy

- Define *activation energy* as the minimum energy needed for a reaction to take place.
- Define an *activated complex* as the unstable transition state from reactants to products.
- Draw or interpret fully labelled sketch graphs (potential energy versus course of reaction graphs) of catalysed and uncatalysed endothermic and exothermic reactions.

REVISION OF GRADE 11 WORK

A. ENERGY AND CHANGE

Important terms and definitions:

1. Heat of reaction, ΔH: is the energy absorbed or released in a chemical reaction.

Mathematically :

$$\Delta H = E_{PRODUCTS} - E_{REACTANTS}$$

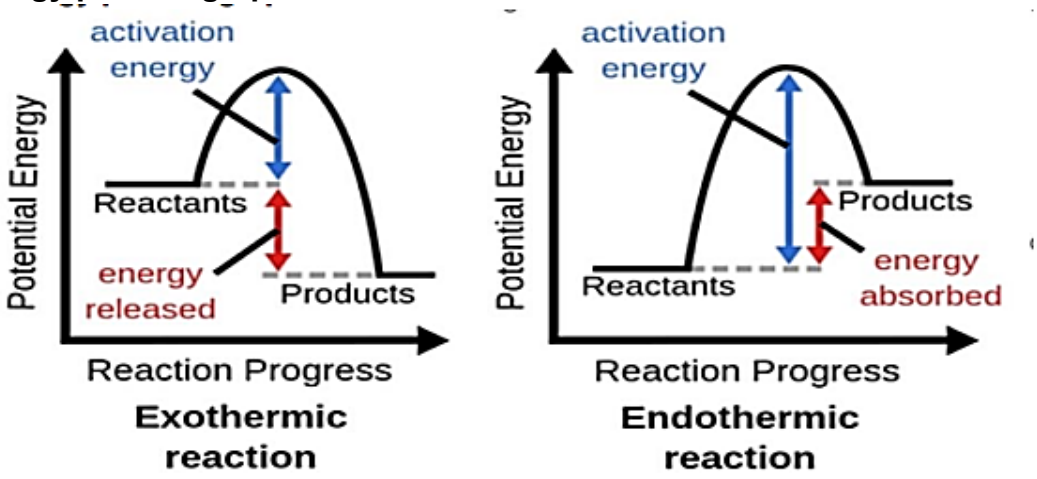
- **Exothermic reaction:** is a reaction in which energy is released to the surroundings.
  For exothermic reactions the energy of the products is **less** than that of reactants and, therefore, the heat of reaction (ΔH) is negative, i.e ΔH < 0.
- **Endothermic reaction**: is a reaction in which energy is absorbed from the surroundings.

  For endothermic reactions the energy of products is **more** than that of reactants and, therefore, the heat of reaction is positive, i.e ΔH > 0.

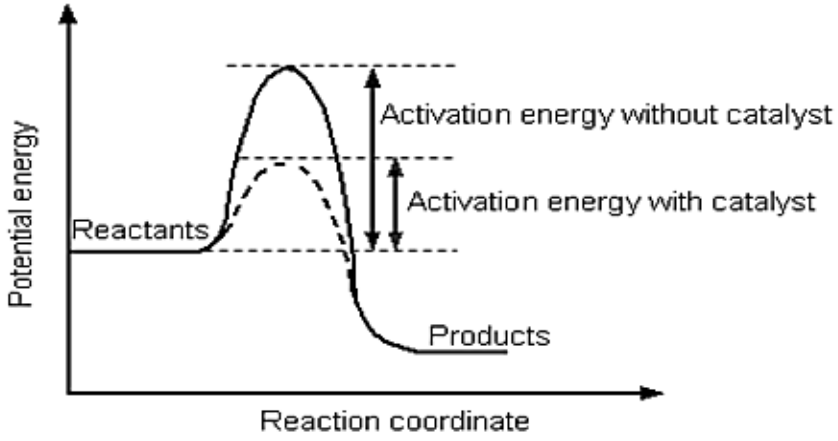
2. **Activated complex:** is the unstable transition state from reactants to products.
3. **Activation energy (E_A):** is the minimum amount of energy needed to start a chemical reaction.
   Mathematically :

   $$E_A = E_{ACTIVATED\ COMPLEX} - E_{REACTANTS}$$

4. **Energy profiles/graphs for exothermic and endothermic reactions:**



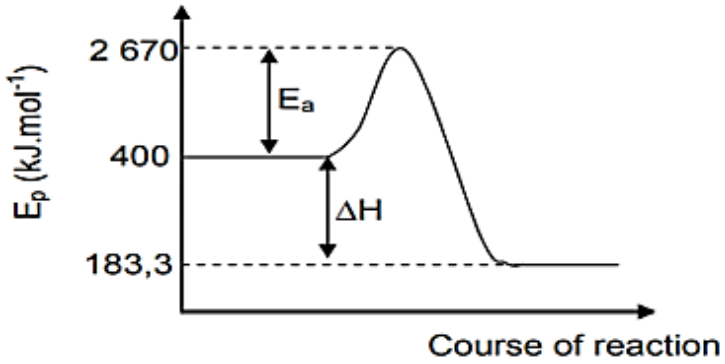
5. **Catalyst:** is a chemical substance that speeds up the rate of a reaction without undergoing a permanent change itself.
   A catalyst lowers the activation energy, thereby providing an alternative route for the reaction.
   The graphs below show the effect of a catalyst:



CLASS EXERCISE 1

The following reaction between ammonia and oxygen takes place in a closed system at constant pressure and temperature:

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$



1.1 Define the term activation energy. (2)

1.2 Give a reason why this reaction is exothermic. (1)

1.3 Calculate the heat of reaction, ΔH. (3)

1.4 Redraw the graph and indicate with a dotted line the effect of a catalyst on the activation energy. (2)

1.5 If 6 dm^3 of NH_3 and 9 dm^3 of O_2 are used, calculate the TOTAL VOLUME of the gases at the end of the reaction. (4)

[12]

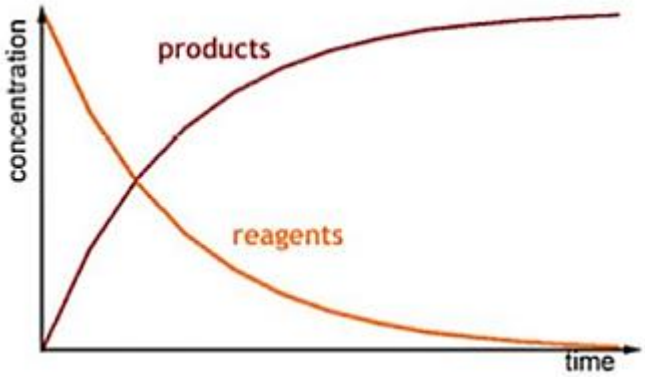
RATES OF REACTIONS: GRADE 12 WORK

Rate of reaction: is the change in concentration of reactants or products per Unit time.

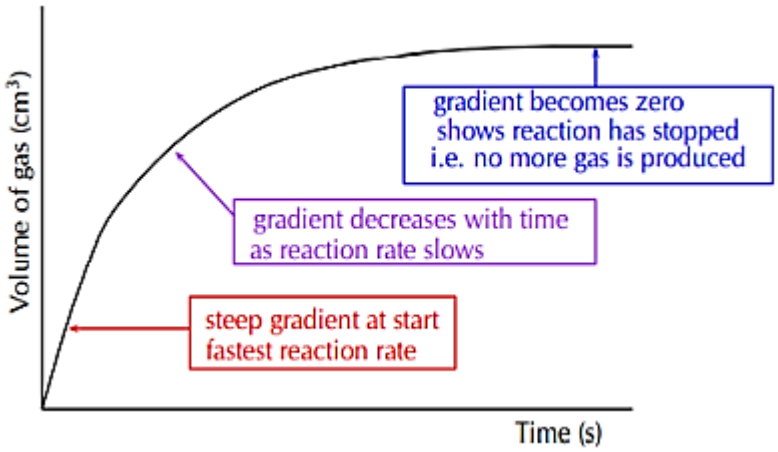
Units of rate can be :

CALCULATION OF RATE	$\frac{\Delta[C]}{\Delta t}$	$\frac{\Delta n}{\Delta t}$	$\frac{\Delta m}{\Delta t}$	$\frac{\Delta V}{\Delta t}$
UNITS OF RATE	mol.dm^{-3}.s^{-1}	mol.s^{-1}	g.s^{-1}	cm^3.s^{-1}

GRAPH OF REACTION RATE



EXPLAINING THE GRAPH FOR RATE OF PRODUCTION OF PRODUCT



THE COLLISION THEORY: is a model that explains how certain factors affect the rates of reactions.

It states that:

• for particles (atoms, molecules or ions) to react they must collide;

• only effective collisions result in a chemical reaction;

• for an effective collision to occur:

➢ particles must have **sufficient kinetic energy**, i.e kinetic energy equal to or more than the activation energy;

➢ particles must have the **correct orientation;**

• increasing the number of effective collisions per unit time will lead to an increase in the reaction rate.

FACTORS THAT AFFECT THE RATES OF REACTIONS:

(i) The concentration of reactants (for aqueous solutions and gases)**:** the higher the concentrations of reactants the higher the rate of reactions.

According to the collision theory, when the concentration of one of the reactants is increased:

- the particles are much closer, i.e the number of particles per unit volume increases;
- the number of effective collisions per unit time increases;
- the rate of reaction also increases.

(ii) Temperature of reactants: the higher the temperature of reactants the higher the rate of reactions.

According to the collision theory, when temperature of reactants is increased:

- the average kinetic energy of the particles increases;
- more particles now have sufficient kinetic energy to react;
- the number of effective collisions per unit time increases;
- the rate of reaction increases.

(iii) Surface area/ state of division (for a solid reactant) : increasing the surface area/state of division of a solid reactant will increase the rate of reaction.

According to the collision theory, when the surface area/state of division of a solid reactant is increased:

- the number of particles per unit volume increases;
- the number of effective collisions per unit time increases;
- the rate of reaction increases.

NOTE: surface area/state of division increases as follows: powder > granules >lumps.

(iv) Pressure (for gaseous reactants): increasing the pressure on gaseous reactants increases the rate of reaction.

According to the collision theory, when the pressure on gaseous reactants is Increased (by decreasing the volume):

• the number of particles per unit volume increases;

• the number of effective collisions per unit time increases;

• the rate of reaction increases.

(v) Catalyst: using a catalyst increases the rate of reaction.

According to the collision theory when a catalyst is used:

• the activation energy for the reaction is lowered;

• more particles have sufficient kinetic energy;

• the number of effective collisions per unit time increases;

• the rate of reaction increases.

(vi) The nature of reactants: some substances react faster than others.

For example:

➢ gases react faster than liquids and solids;

➢ alkali earth metals are the most reactive metals;

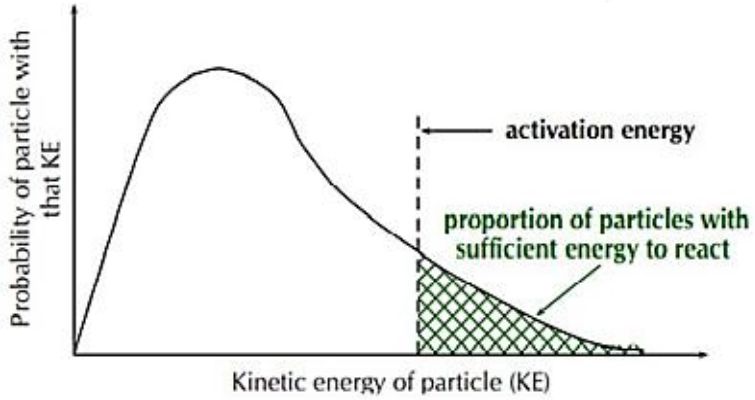
➢ inorganic molecules react faster than organic molecules.

➢ cations and anions react faster than atoms.

THE MECHANISM OF REACTIONS

The Maxwell Boltzmann distribution curve: is a curve that shows the distribution of the kinetic energy of the particles in a system.

The distribution curve below shoes the distribution of particles at a fixed temperature:

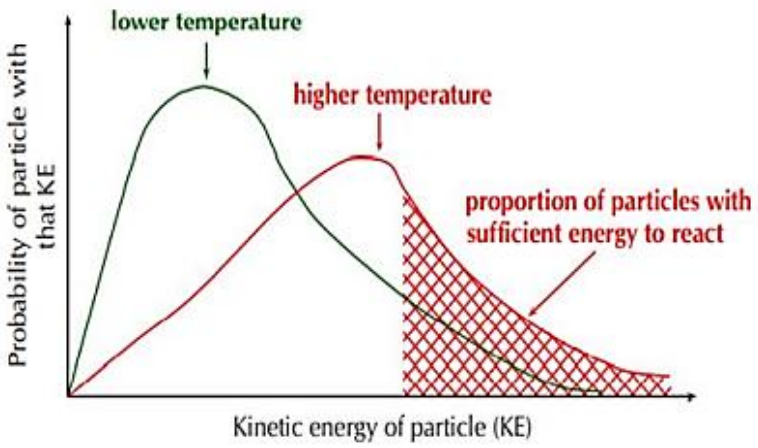


NOTE:

- The area under the graph represents the total number of particles or molecules;
- The shaded area represents the proportion of particles with sufficient energy to react;

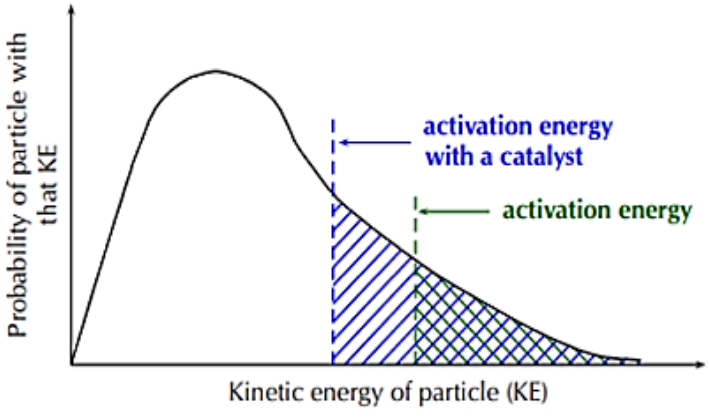
(a) The effect of increasing the temperature:

- The average kinetic energy of the particles increases;
- The graph shifts to the right and becomes more flat, but the total area remains the same;
- More particles have suffient amount of energy to react;
- the rate of reaction increases.



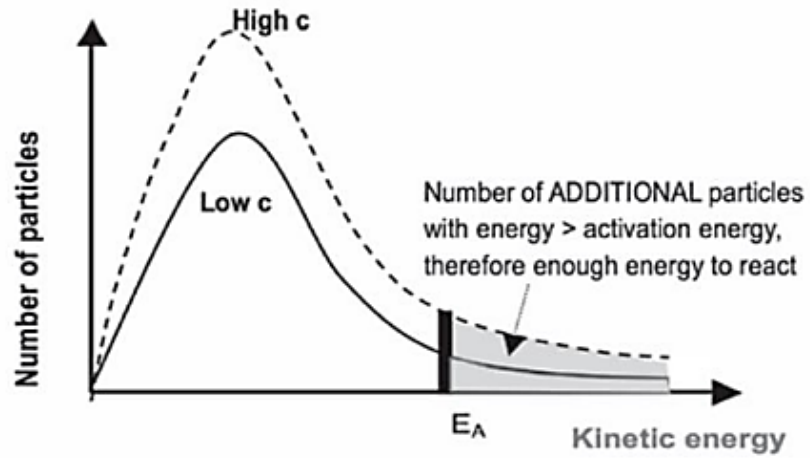
(b) The effect of using a catalyst:

- A catalyst lowers the activation energy;
- The line representing activation energy shifts to the left;
- More particles have sufficient kinetic energy to react;
- Rate of reaction increases.



(b) The effect of increasing concentration (or mass):

- The height of the graph increases because there are more particles per unit volume;
- The proportion of particles with sufficient kinetic energy increases;
- Rate of reaction increases.



MEASURING THE RATES OF REACTIONS:

The three experimental methods of measuring the rates of reactions are:

1. Measuring turbidity;
2. Measuring the volume of a gas produced;
3. Measuring the total mass of reactants and the mass lost.

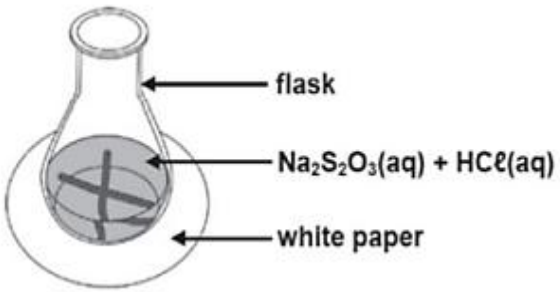
METHOD 1: MEASURING TURBIDITY

Example: the reaction between sodium thiosulphate with dilute hydrochloric acid.

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(g) + S(s)$$

- This reaction forms a yellow sulphur precipitate which clouds the resulting solution.
- The formation of the precipitate can be used to measure the reaction rate.

Apparatus:



Method:

1. Draw a black cross on a piece of paper.
2. Add an exact volume of $Na_2S_2O_3$ to a conical flask and place it on the cross.
3. Quickly add HCℓ to the solution and start the stopwatch.
4. Swirl (turn) the flask carefully and allow the reaction to continue until the black cross can no longer be seen.
5. Record the time.

In this experiment, the concentration of the HCℓ(aq) and $Na_2S_2O_3$(aq) can be changed, keeping the temperature constant.

OR: In another experiment, the temperature can be changed, but keeping the concentrations constant.

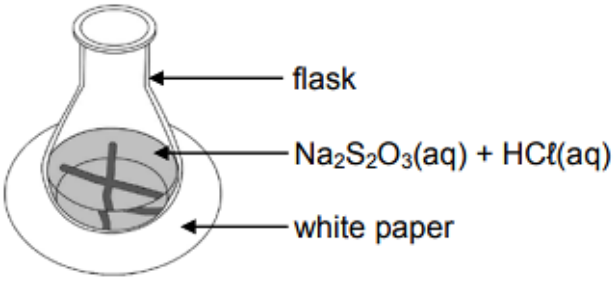
The time it takes for the solution to become opaque is a measure of the reaction rate.

CLASS EXERCISE 2

The reaction between dilute hydrochloric acid and sodium thiosulphate ($Na_2S_2O_3$) is used to investigate one of the factors that influences reaction rate. The balanced equation for the reaction is:

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + S(s) + H_2O(\ell) + SO_2(g)$$

The hydrochloric acid solution is added to the sodium thiosulphate solution in a flask. The flask is placed over a cross drawn on a sheet of white paper, as shown in the diagram below. The time that it takes for the cross to become invisible is measured to determine the reaction rate.



Four experiments, A to D, are conducted during this investigation. The volumes of reactants used in each of the four experiments and the times of the reactions are summarised in the table below.

Experiment	Volume of $Na_2S_2O_3(aq)$ (cm^3)	Volume of $H_2O(\ell)$ (cm^3)	Volume of $HC\ell(aq)$ (cm^3)	Time (s)
A	25	0	5	50,0
B	20	5	5	62,5
C	15	10	5	83,3
D	10	15	5	125,0

2.1 State TWO factors that can influence the rate of the reaction above. (2)

2.2 Write down the NAME or FORMULA of the product that causes the cross to become invisible. (1)

2.3 Give a reason why water is added to the reaction mixture in experiments B to D. (1)

2.4 Write down an investigative question for this investigation. (2)

2.5 In which experiment (A, B, C or D) is the reaction rate the highest? (1)

2.6 Use the collision theory to explain the difference in reaction rate between experiments B and D. (3)

2.7 The original $Na_2S_2O_3$ solution was prepared by dissolving 62,50 g $Na_2S_2O_3$ crystals in distilled water in a 250 cm^3 volumetric flask.

Calculate the mass of sulphur, S, that will form in experiment D if $Na_2S_2O_3$ is the limiting reactant. (7)

[17]

METHOD 2: MEASURING THE VOLUME OF GAS PRODUCED.

Examples: the reactions;

1. $Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$
2. $CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$
3. $2KC\ell O_3(s) \xrightarrow{MnO_2(s)} 2KC\ell(s) + 3O_2(g)$

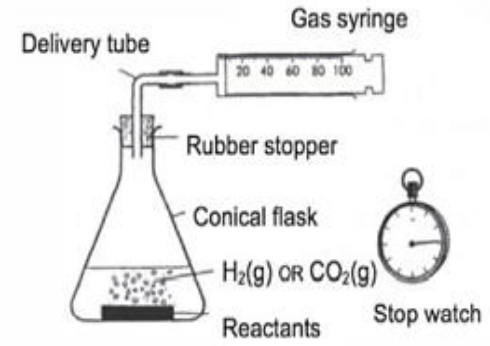
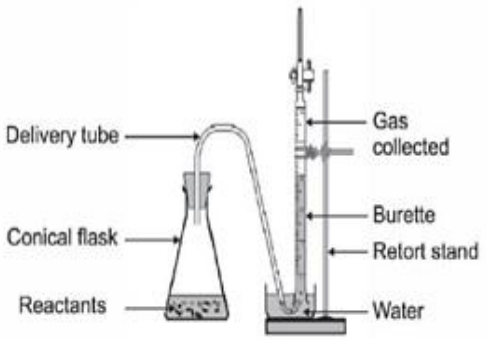
(The catalysed decomposition of potassium chlorate)

➢ The rate of the reaction is determined by measuring the volume of the gas produced (the dependent variable) in specific time intervals (the independent variable);

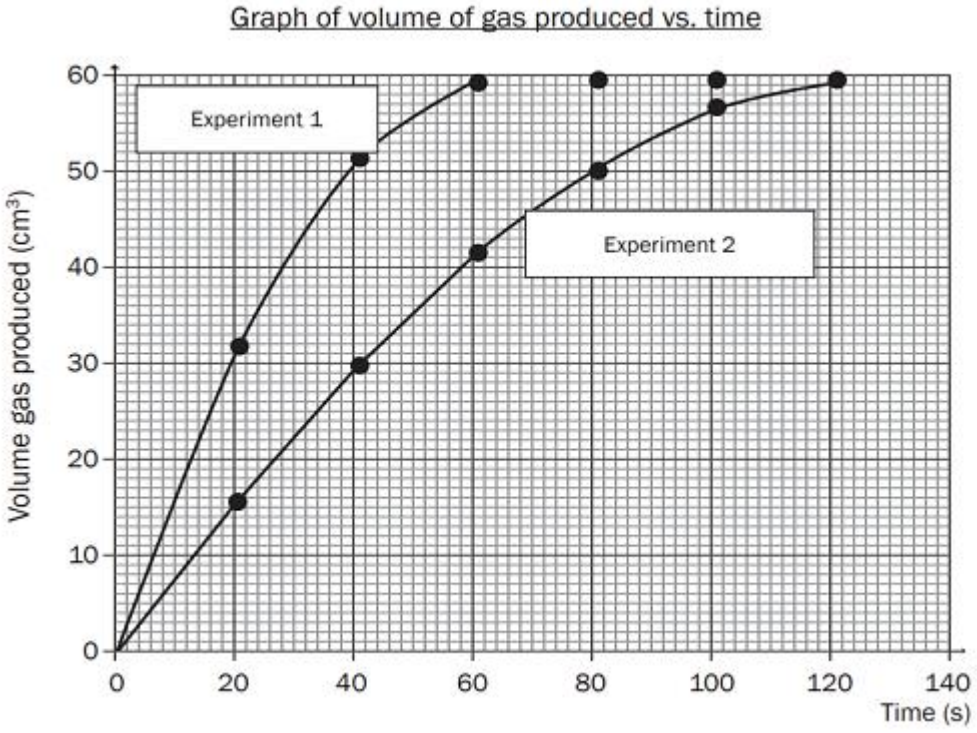
➢ The gas is collected in a graduated gas syringe or by the downward displacement of water in a burette. The volume of the gas produced can be determined accurately;

➢ The stopwatch is started when the reactants are added and stopped when no new bubbles form, i.e. when the volume of gas produced stays constant.

Apparatus:

Measuring volume with a gas syringe:	Measuring volume by the downward displacement of water
	

The results of the experiment are used to plot a graph(s) as shown below:



CLASS EXERCISE 3

3.1 The reaction between pure aluminium, Aℓ(s), and EXCESS hydrochloric acid, HCℓ(aq), is used to investigate the factors that affect the rate of a reaction.

The balanced equation for the reaction is:

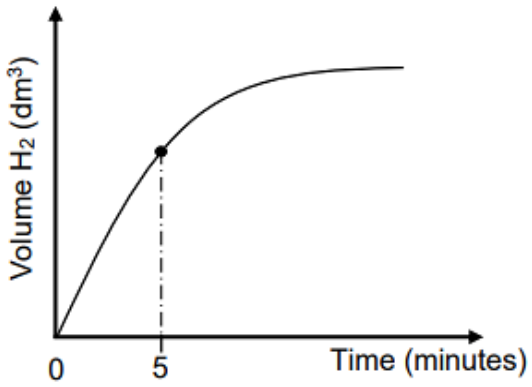
$$2A\ell(s) + 6HC\ell(aq) \rightarrow 2A\ell C\ell_3(aq) + 3H_2(g)$$

3.1.1 Define the term reaction rate. (2)

EXPERIMENT I

In this experiment, 1 mol·dm-3 HCℓ solution reacts with a 0,5 g Aℓ strip from an aluminium roll at room temperature.

The graph of volume $H_2(g)$ versus time for this experiment, not drawn to scale, is shown below.



3.1.2 For the time interval t = 0 to t = 5 minutes, the average reaction rate for the formation of $H_2(g)$ is 0,033 $dm^3 \cdot min^{-1}$.

Calculate the mass of Aℓ present in the container at t = 5 minutes.

Take the molar gas volume as 24,5 $dm^3 \cdot mol^{-1}$. (6)

Assume that the concentration of the HCℓ(aq) stays constant for the duration of the reaction.

3.1.3 Use the collision theory to explain the change in the reaction rate from t = 0 to t = 5 minutes. (4)

EXPERIMENT II

Experiment I is repeated using a 2 mol·dm^{-3} HCℓ solution.

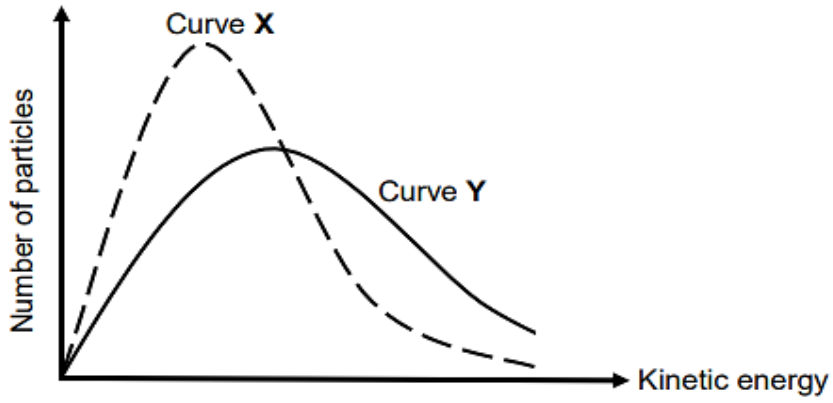
3.1.4 Redraw the above graph (NO numerical values need to be shown) in your ANSWER BOOK and label the curve **A**. On the same set of axes, draw the curve that will be obtained for **Experiment II**. Label this as curve **B**. (2)

EXPERIMENT III

Experiment I is repeated using 0,5 g **pure powdered** Aℓ.

3.1.5 How will the volume of $H_2(g)$ produced in **Experiment III** compare to that in **Experiment I**? Choose from GREATER THAN, LESS THAN or EQUAL TO. (1)

3.2 Curve **X** is the Maxwell Boltzmann distribution curve for a reaction under a set of reaction conditions. A change was made to one of the reaction conditions to obtain curve **Y**.



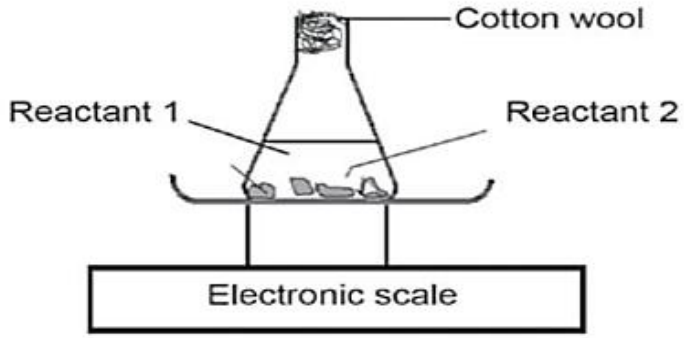
3.2.1 What change was made to obtain curve **Y**? (1)

3.2.2 Give a reason for the answer to QUESTION 3.2.1. (1)

[17]

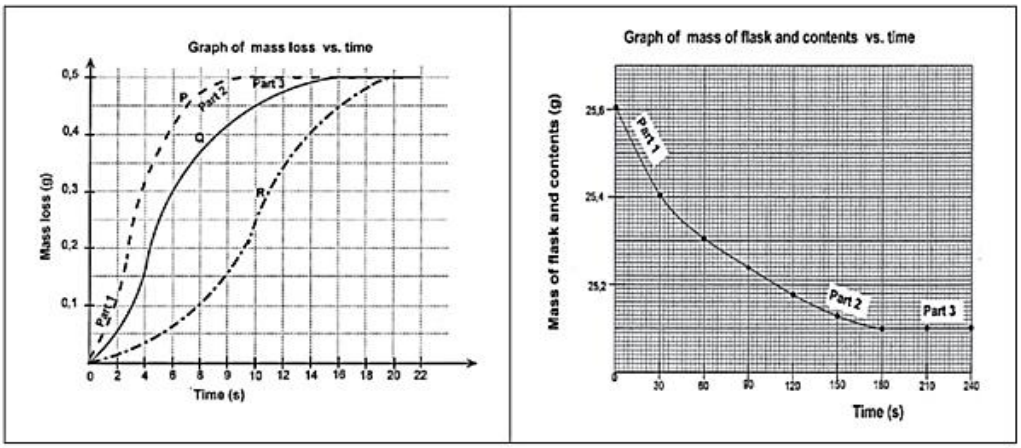
METHOD 3: MEASURING THE MASS OF REACTANTS AND AND THE MASS LOST :

Apparatus:



Method:

- The rate of the reaction is determined by measuring the mass of the gas produced (the dependent variable) in specific time intervals (the independent variable).
- The reactants are added to the flask and the mouth of the flask is plugged with some cotton wool.
- The mass of the reaction system (the reactants, flask and cotton wool) is recorded at the start of the experiment and the stop watch is started.
- The gas that is produced passes through the cotton wool plug and escapes from the system, so the mass (the reading on the scale) decreases.
- The mass of the system is recorded at regular time intervals e.g. every 30 seconds.
- The stopwatch is stopped when no new bubbles form – i.e. when the mass reading on the scale stays constant.
- The results are used to plot a graph of: mass of the flask and contents versus time OR mass loss (mass of gas escaped) versus time.

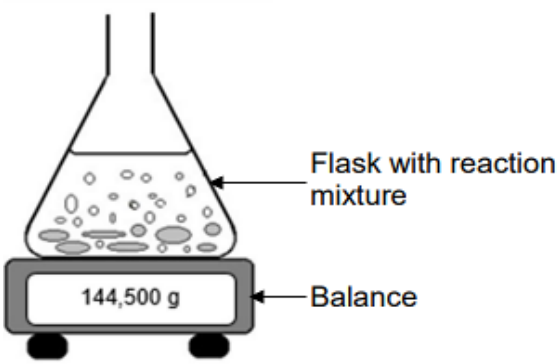


CLASS EXERCISE 4

The reaction between magnesium carbonate pellets, $MgCO_3(s)$, and EXCESS dilute hydrochloric acid, $HC\ell(aq)$, is used to investigate the effect of concentration on the rate of a reaction.

$$MgCO_3(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

The apparatus used for this investigation is shown below.



4.1 Define the term rate of reaction. (2)

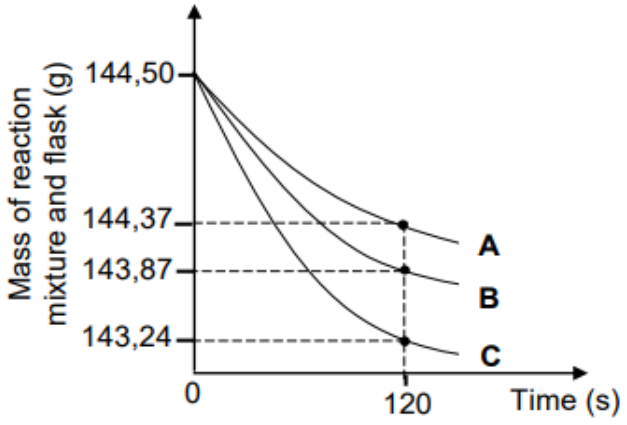
4.2 Write down ONE controlled variable for this investigation. (1)

Three experiments using different concentrations of $HC\ell(aq)$ are carried out.

The concentration of the $HC\ell(aq)$ during each experiment does not change.

EXPERIMENT	CONCENTRATION OF $HC\ell(aq)$ ($mol \cdot dm^{-3}$)
1	0,1
2	0,5
3	1,0

The INCOMPLETE graph of the results of the experiments is shown below.



4.3 Give a reason why the mass of the reaction mixture and flask decreases. (1)

4.4 For curve **B**, calculate the average rate at which $CO_2(g)$ is produced for the first 120 s in $dm^3 \cdot s^{-1}$. The molar gas volume is 24,5 $dm^3 \cdot mol^{-1}$. (6)

4.5 Which curve represents **EXPERIMENT 1**? Choose from **A**, **B** or **C**. Use the collision theory to explain the answer. (5)

4.6 How will the final mass of $CO_2(g)$ produced in **EXPERIMENT 2** compare to that of **EXPERIMENT 3**? Choose from MORE THAN, LESS THAN or THE SAME. Give a reason for the answer. (2)

[17]

ACTIVITIES

ACTIVITY 1

The reaction between aluminium and EXCESS sulphuric acid is used to investigate factors affecting rates of reactions.

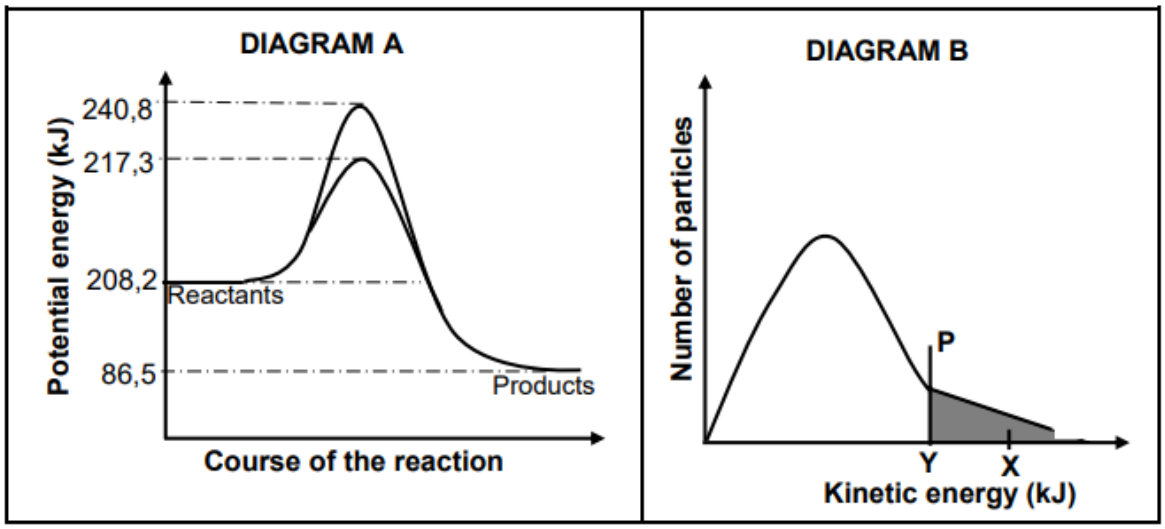
$$2A\ell(s) + 3H_2SO_4(aq) \rightarrow A\ell_2(SO_4)_3(aq) + 3H_2(g)$$

1.1 **INVESTIGATION I**

The effect of a catalyst on the rate of reaction is determined.

Aluminium powder of mass 5 g reacts with excess 0,1 $mol \cdot dm^{-3}$ H_2SO_4 at 60 °C.

Consider the following energy diagrams (not drawn to scale) for this investigation. **X** and **Y** in diagram **B** represent the activation energies.



1.1.1 Is the reaction between Aℓ(s) and dilute H_2SO_4(aq) ENDOTHERMIC or EXOTHERMIC? Give a reason for the answer by referring to the above diagrams. (2)

1.1.2 What does the shaded area to the right of line **P** represent? (1)

1.1.3 Determine the numerical value represented by the letter **X** on diagram **B**. (2)

1.2 **INVESTIGATION II**

The investigation is now repeated at 30 °C using the same reactants (5g Aℓ powder and excess 0,1 mol·dm^{-3} H_2SO_4) and catalyst.

How will this affect EACH of the following when compared to INVESTIGATION I? Choose from INCREASES, DECREASES or REMAINS THE SAME.

1.2.1 The size of the shaded area (diagram **B**). (1)

1.2.2 The value of **Y**. (1)

1.2.3 The TOTAL volume of hydrogen gas produced. (1)

1.3 **INVESTIGATION III**

In this investigation, 5 g of the same sample of IMPURE aluminium powder reacts with an EXCESS diluted H_2SO_4 at 60 °C in each of three runs. The table below summarises the conditions and the results obtained. (Assume that the impurities do not react.)

$$2Aℓ(s) + 3H_2SO_4(aq) \rightarrow Aℓ_2(SO_4)_3(aq) + 3H_2(g)$$

RUN	CONCENTRATION H_2SO_4(aq) (mol·dm^{-3})	AVERAGE RATE OF VOLUME H_2(g) PRODUCED (cm^3·s^{-1})
1	0,1	15
2	0,2	19
3	0,4	40

1.3.1 Write down the independent variable for this investigation. (1)

1.3.2 Use the collision theory to explain how the average rate of the reaction is affected in this investigation. (3)

1.3.3 The time for the reaction to reach completion in RUN 3 is 2,6 minutes.

Calculate the percentage purity of the aluminium. Take the molar gas volume at 60 °C to be 27 000 $cm^3 \cdot mol^{-1}$. (6)

[18]

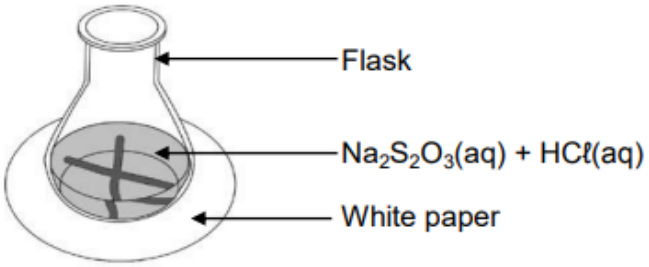
ACTIVITY 2

The reaction between EXCESS dilute hydrochloric acid and sodium thiosulphate is used to investigate factors that influence reaction rate.

$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + S(s) + H_2O(\ell) + SO_2(g)$

The concentration of $HC\ell(aq)$ used is 1 mol·dm-3 . The same volume of $HC\ell(aq)$ is used in each run.

The time taken for the cross on the paper under the flask to become invisible is measured.



The table below summarises the reaction conditions and results of the experiment.

RUN	VOLUME $Na_2S_2O_3(aq)$ (cm^3)	VOLUME $H_2O(\ell)$ ADDED (cm^3)	CONCENTRATION $Na_2S_2O_3(aq)$ ($mol \cdot dm^{-3}$)	TIME (s)
1	50	0	0,13	20,4
2	40	10	0,10	26,7
3	30	20	**P**	33,3

2.1 Define reaction rate. (2)

2.2 Write down the independent variable for this investigation. (1)

2.3 Calculate the value of **P** in the table. (3)

2.4 When 0,21 g of sulphur has formed in Run 1, the cross becomes invisible.

Calculate the average reaction rate with respect to sodium thiosulphate, $Na_2S_2O_3(aq)$, in $g \cdot s^{-1}$. (5)

Another investigation is performed at different temperatures.

2.5 Sketch the Maxwell-Boltzmann distribution curve for the reaction at 20 °C.

Label this curve as **A**. On the same set of axis, draw the curve that will be obtained at 35 °C and label it as **B**. (4)

2.6 Explain the effect of temperature on reaction rate in terms of the collision theory. (4)

[19]

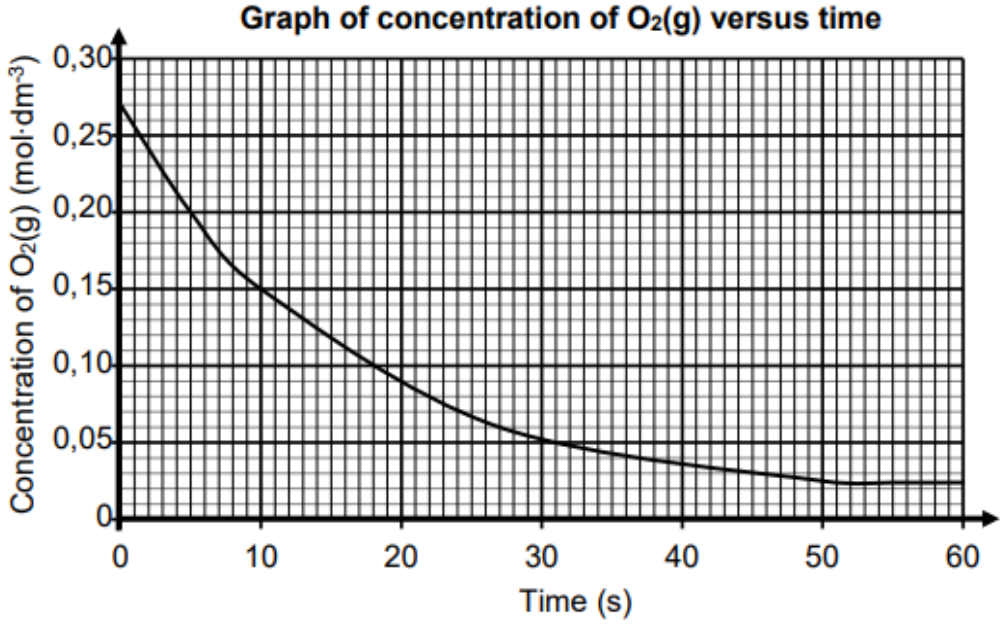
ACTIVITY 3

3.1 Define the term reaction rate. (2)

3.2 Carbon monoxide, CO(g), reacts with oxygen, $O_2(g)$, to form carbon dioxide, $CO_2(g)$, in a sealed container according to the balanced equation:

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

The graph below shows the concentration of $O_2(g)$ versus time.



3.2.1 At which time, 10 s or 30 s, is the reaction rate higher? (1)

3.2.2 The reaction takes place in a 3 dm^3 container. Calculate the average rate (in $mol \cdot s^{-1}$) at which $CO_2(g)$ is formed in the first 10 s. (5)

3.2.3 Which reactant is in excess, CO or O_2? (1)

3.2.4 This reaction was repeated using a smaller sealed container.

How will this affect the magnitude of the gradient of the graph at the beginning of the reaction? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

3.3 The reaction between sulphur dioxide, $SO_2(g)$, and oxygen, $O_2(g)$, takes place in a sealed container according to the balanced equation below.

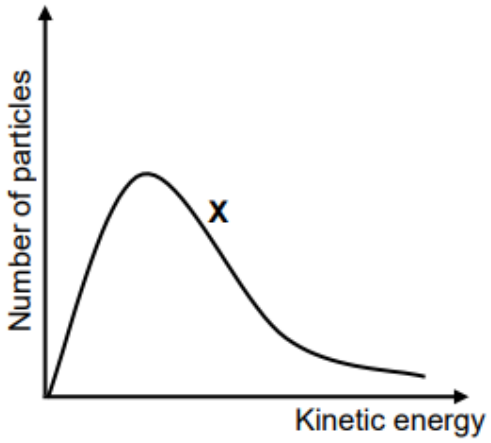
$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\ kJ \cdot mol^{-1}$$

3.3.1 Was there a net release or net absorption of energy during the REVERSE reaction? (1)

3.3.2 Define the term activated complex. (2)

3.3.3 A catalyst, vanadium pentoxide, is added to the reaction. Explain, in terms of the collision theory, why the rate of the reaction will increase. (3)

Curve **X** is the Maxwell Boltzmann distribution curve for the reaction above.



More $SO_2(g)$ is now added to the container at constant temperature.

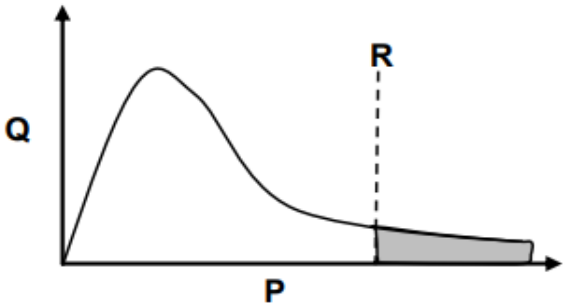
3.3.4 How will this change affect the heat of the reaction? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

3.3.5 Redraw the above graph in the ANSWER BOOK. On the same set of axes, draw the curve that will now be obtained. Label this as curve Y. (2)

[20]

QUESTION 4

4.1 Study the Maxwell-Boltzmann distribution curve for a certain reaction below.



P and **Q** are the labels of the axes. What quantity is represented by:

4.1.1 P. (1)

4.1.2 Q. (1)

4.2 Line **R** represents the <u>minimum energy required for the reaction to take place</u>.

4.2.1 Write down the term for the underlined phrase. (1)

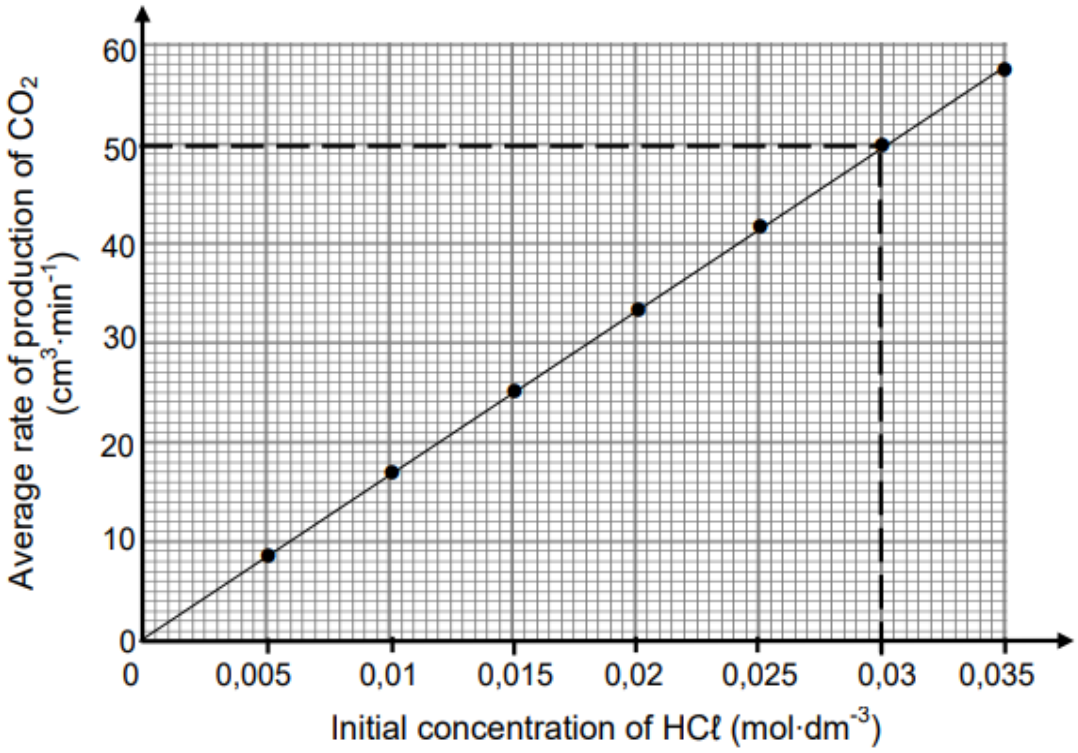
4.2.2 How will the shaded area on the graph be affected when a catalyst is added? Choose from INCREASE, DECREASE or REMAINS THE SAME. (1)

4.3 Use the collision theory to explain how a catalyst influences the rate of reaction. (4)

4.4 The reaction between POWDERED calcium carbonate, $CaCO_3(s)$, and EXCESS hydrochloric acid, $HC\ell(aq)$, is used to investigate reaction rate at 25 °C. The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

Several experiments are conducted using the same mass of IMPURE calcium carbonate and different initial concentrations of dilute hydrochloric acid. The graph below represents the results obtained. Assume that impurities do not react.



For this investigation, write down a:

4.4.1 Controlled variable. (1)

4.4.2 Conclusion. (2)

The $CaCO_3(s)$ in 6 g of the impure sample reacts completely with 0,03 $mol \cdot dm^{-3}$ HCℓ(aq) in 26 minutes.

4.4.3 Use the information in the graph to calculate the percentage purity of the calcium carbonate. Assume that the molar gas volume at 25 °C is 24 000 cm^3. (6)

[17]

TOPIC 2: ACIDS AND BASES

EXAMINATION GUIDELINE:

Acids and Bases
(This section must be read in conjunction with the CAPS, p. 127–128.)

Acid-base reactions

- Define *acids* and *bases* according to Arrhenius and Lowry-Brønsted theories:
  Arrhenius theory: Acids produce hydrogen ions (H^+/H_3O^+/hydronium ions) in aqueous solution. Bases produce hydroxide ions (OH^-) in aqueous solution.
  Lowry-Brønsted theory: An acid is a proton (H^+ ion) donor. A base is a proton (H^+ ion) acceptor.

Relative strengths of acids and bases

- Distinguish between *strong acids/bases* and *weak acids/bases* with examples.
  Strong acids ionise completely in water to form a high concentration of H_3O^+ ions.
  Examples of strong acids are hydrochloric acid, sulphuric acid and nitric acid.
  Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions.
  Examples of weak acids are ethanoic acid and oxalic acid.
  Strong bases dissociate completely in water to form a high concentration of OH^- ions.
  Examples of strong bases are sodium hydroxide and potassium hydroxide.
  Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^- ions.
  Examples of weak bases are ammonia, calcium carbonate, potassium carbonate, calcium carbonate and sodium hydrogen carbonate.
- Distinguish between *concentrated acids/bases* and *dilute acids/bases*.
  Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to the volume of water.
  Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to the volume of water.

Acid-base reactions

- Write down the reaction equations of aqueous solutions of acids and bases.
  Examples: $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$ (HCl is a monoprotic acid.)
  $NH_3(g) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$
  $H_2SO_4(aq) + 2H_2O(l) \rightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$ (H_2SO_4 is a diprotic acid.)
- Identify conjugate acid-base pairs for given compounds.
- Describe a substance that can act as either acid or base as ampholyte. Water is a good example of an ampholyte substance. Write equations to show how an ampholyte substance can act as acid or base.
- Write down neutralisation reactions of common laboratory acids and bases.
  Examples: $HCl(aq) + NaOH(aq)/KOH(aq) \rightarrow NaCl(aq)/KCl(aq) + H_2O(l)$
  $HCl(aq) + Na_2CO_3(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$
  $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$
  $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$
  $(COOH)_2(aq) + NaOH(aq) \rightarrow (COO)_2Na_2(aq) + H_2O(l)$
  $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$

  NOTE: The above are examples of equations that learners will be expected to write from given information. However, any other neutralisation reaction can be given in the question paper to assess, e.g. stoichiometry.

Hydrolysis

- Define *hydrolysis* as the reaction of a salt with water.
- Determine the approximate pH (equal to, smaller than or larger than 7) of salts in salt hydrolysis.
  - Hydrolysis of the salt of a weak acid and a strong base results in an alkaline solution, i.e. the pH > 7. Examples of such salts are sodium ethanoate, sodium oxalate and sodium carbonate.
  - Hydrolysis of the salt of a strong acid and a weak base results in an acidic solution, i.e. the pH < 7. An example of such a salt is ammonium chloride.
  - The salt of a strong acid and a strong base does not undergo hydrolysis and the solution of the salt will be neutral, i.e. pH = 7.

Acid-base titrations

- Motivate the choice of a specific indicator in a titration. Choose from methyl orange, phenolphthalein and bromothymol blue.
- Define the *equivalence point of a titration* as the point at which the acid/base has completely reacted with the base/acid.
  Define the *endpoint of a titration* as the point where the indicator changes colour.
- Perform stoichiometric calculations based on titrations of a strong acid with a strong base, a strong acid with a weak base and a weak acid with a strong base. Calculations may include percentage purity.
- For a titration, e.g. the titration of oxalic acid with sodium hydroxide:
  - List the apparatus needed or identify the apparatus from a diagram.
  - Describe the procedure to prepare a standard oxalic acid solution.
  - Describe the procedure to conduct the titration.
  - Describe safety precautions.
  - Describe measures that need to be in place to ensure reliable results.
  - Interpret given results to determine the unknown concentration.

pH and the pH scale

- Explain the pH scale as a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.
- Calculate pH values of strong acids and strong bases using $pH = -\log[H_3O^+]$.
- Define K_w as the equilibrium constant for the ionisation of water or the ion product of water or the ionisation constant of water, i.e. $K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ by 298 K.

TERMS, DEFINITIONS AND CONCEPTS

1. THEORIES ON ACIDS AND BASES:

A. THE ARRHENIUS THEORY: says that:

• An acid is a substance that produces hydrogen/hydronium ions (H^+ or H_3O^+) in solution;

Examples :(a) $HC\ell \rightleftharpoons H^+(aq) + C\ell^-(aq)$

OR $HC\ell + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + C\ell^-(aq)$

(b) $H_2SO_4 \rightleftharpoons 2H^+(aq) + SO_4^{2-}(aq)$

OR $H_2SO_4 + 2H_2O(\ell) \rightleftharpoons 2H_3O^+(aq) + SO_4^{2-}(aq)$

• A base is a substance that produces hydroxide ions (OH^-) in solution;

Examples: (a) $NaOH \rightleftharpoons Na^+(aq) + OH^-(aq)$

(b)$Mg(OH)_2(aq) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$

B. THE LOWRY-BRONSTED THEORY: says that :

• An acid is a proton donor;

Examples : (a) $HC\ell + H_2O \rightleftharpoons H_3O^+ + C\ell^-$

(b) $NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3$

• A bases is a proton acceptor;
Examples : (a) $OH^- + H^+ \rightleftharpoons H_2O$

(b) $NH_3 + H_2O \rightleftharpoons OH^- + NH_4^+$

2. COMMON ACIDS AND BASES:

ACIDS : **Mineral acids**: examples are: hydrochloric acid ($HC\ell$);
nitric acid (HNO_3);
nitrous acid (HNO_2);
carbonic acid (H_2CO_3);
sulphuric acid (H_2SO_4);
sulphurous acid (H_2SO_3);
phosphoric acid (H_3PO_4);
phosphorous acid (H_3PO_3);

Organic acids: methanoic acid ($HCOOH$);

ethanoic acid (CH_3COOH);

propanoic acid (CH_3CH_2COOH); etc.

BASES : **Metal oxides**: e.g Na_2O, MgO, CuO;

Metal hydroxides: e.g $NaOH$, $Mg(OH)_2$, $A\ell(OH)_3$;

Metal carbonates: e.g Na_2CO_3, $MgCO_3$, $A\ell_2(CO_3)_3$.

Ammonia (NH_3).

3. STRONG AND WEAK ACIDS AND BASES:

A **strong acid**: is an acid that ionises completely/fully in solution (to give a high concentration of hydrogen(H^+)/hydronium(H_3O^+) ions in solution).

Examples are : $HC\ell$, HNO_3 , H_2SO_4;

A **strong base**: is a base that ionises completely/fully in solution (to give a high concentration of hydroxide (OH^-) ions in solution).

Examples are: $NaOH$, $LiOH$, KOH.

A weak acid: is an acid that ionises incompletely/partially in solution (to give a low concentration of hydrogen(H^+)/hydronium(H_3O^+) ions in solution).

Examples are : $C_2H_2O_4$(oxalic acid); H_3PO_4(phosphoric acid); all organic acids.

A **weak base**: is a base that ionises incompletely/partially in solution (to give a low concentration of hydroxide (OH^-) ions in solution).

Examples are: NH_3; $CaCO_3$; K_2CO_3; $CaCO_3$; $NaHCO_3$.

4. CONCENTRATED AND DILUTE ACIDS AND BASES:

CONCENTRATION: is a ratio of the amount of solute to the volume of solvent.

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

The units are: $mol.dm^{-3}$

A **concentrated acid** or **base**: is one with a large amount of solute in a small volume of solvent.

A **dilute acid** or **base**: is one with a small amount of solute in a large volume of solvent.

5. CLASSIFICATION OF ACIDS

Acids can be classified as:

(i) Monoprotic acids: are acids which can donate one proton per molecule of the acid.

Examples are: $HC\ell$, HNO_3 , all organic acids.

(ii) Diprotic acids: are acids which can donate two protons per molecule of the acid.

Examples are: H_2CO_3; H_2SO_4; $H_2C_2O_4$.

(iii) Triprotic acids: are acids which can donate three protons per molecule of the acid.

Example: H_3PO_4.

6. CONJUGATE ACID-BASE PAIRS

Examples are: Identify the conjugate acid-base pairs in each of the following:

1. $HC\ell + H_2O \rightleftharpoons H_30^+ + C\ell^-$

   Acid 1 Base 2 Acid 2 Base 1

   - $HC\ell$ and $C\ell$;
   - H_2O and H_3O.

2. $HNO_3 + NH_3 \rightleftharpoons NH_4^+ + NO_3^-$

   Acid 1 Base 2 Acid 2 Base 1

   - HNO_3 and NO_3;
   - NH_3 and NH_4^+.

CLASS EXERCISE 1

1. Identify the conjugate acid-base pairs in each of the following:

   1.1 $H_2SO_4 + 2H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$. (2)

   1.2 $H_2CO_3 + 2H_2O \rightleftharpoons 2\ H_3O^+ + \ CO_3^{2-}$. (2)

   1.3 $CH_3COOH + OH^- \rightleftharpoons CH_3COO^- + H_2O$. (2)

2. Write down the conjugate base of HNO_3. (1)

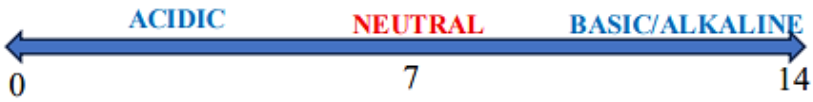
3. Write down the conjugate acid of $H_2PO_4^-$. (1)

[8]

6. pH and the pH scale:

pH:is the degree of acidity or basicity of a solution.

The pH scale runs from 0 to 14 as follows:



pH is calculated using the formula:

$$\mathbf{pH = -\log [H_3O^+]}$$

7. AUTO-IONISATION OF WATER

Equation for auto-ionisation of water is:

$$H_2O(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

Ionisation constant of water: $K_w = [H_3O^+][OH^-] = 1x10^{-14}$ mol.dm^{-3} at 25 ºC;

And: $[H_3O^+] = [OH^-] = 1x\ 10^{-7}$ mol.dm^{-3}.

pH calculations of strong acids and bases:

CLASS EXERCISE 2

1. A hydrochloric acid, HCℓ, solution has a concentration of 0.2 mol.dm^{-3} at 25ºC.

   Calculate the:

   1.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

   1.2 pH of the solution. (3)

   1.3 concentration of the hydroxide ion, $[OH^-]$, in the solution. (3)

2. A sulphuric acid, H_2SO_4, solution has a concentration of 0.2 mol.dm^{-3} at 25ºC.

   Calculate the:

   2.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

   2.2 pH of the solution. (3)

   2.3 concentration of the hydroxide ion, $[OH^-]$, in the solution. (3)

3. A sodium hydroxide, NaOH, solution has a concentration of 0.4 mol.dm^{-3} at 25ºC.

Calculate the:

3.1 concentration of the hydroxide ion, $[OH^-]$. (3)

3.2 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

3.3 pH of the solution. (3)

4. A magnesium hydroxide, $Mg(OH)_2$, solution has a concentration of $0.4\ mol.dm^{-3}$ at 25ºC.

Calculate the:

4.1 concentration of the hydroxide ion, $[OH^-]$. (3)

4.2 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

4.3 pH of the solution. (3)

[33]

CLASS EXERCISE 3

1. The pH of a hydrochloric acid, HCℓ, solution is 0.45 at 25ºC.

Calculate the:

1.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

1.2 concentration of the acid, HCℓ. (3)

2. The pH of a sulphuric acid, H_2SO_4, solution is 0.32 at 25ºC.

Calculate the:

2.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

2.2 concentration of the acid, H_2SO_4. (3)

3. A sodium hydroxide, NaOH, solution has a pH of 10.6 at 25ºC.

Calculate:

3.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

3.2 concentration of the hydroxide ion, $[OH^-]$. (3)

3.3 concentration of the base, NaOH. (3)

4. A magnesium hydroxide, $Mg(OH)_2$, solution has a pH of 11.6 at 25ºC.

Calculate:

4.1 concentration of the hydronium ion, $[H_3O^+]$, in the solution. (3)

4.2 concentration of the hydroxide ion, $[OH^-]$. (3)

4.3 concentration of the base, $Mg(OH)_2$. (3)

[30]

8. HYDROLYSIS OF SALTS

Hydrolysis of a salt: is the reaction of ions of a salt with water [to form an acidic solution (pH7 or neutral solution (pH=7)].

Salts can be classified as:

(i) acidic salts: are salts that ionise in solution to produce acidic solutions.

Example is: NH4Cℓ.

Step 1: Ionisation of the salt: $NH_4C\ell \rightleftharpoons NH_4^+ + C\ell^-$

From a weak base (NH_3) — From a strong acid ($HC\ell$)

NOTE: only ions from weak acids and weak bases will react with water.

Ions from strong acids and bases and metal ions will NOT react with water.

Step 2: reaction of ion with water: $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

Weak base — Strong acid

Acidic solution

pH < 7

(ii) basic salts: are salts that ionise in solution to produce basic solutions.

Example is: $CaCO_3$.

Step 1: Ionisation of the salt: $CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$

Metal ion — From a weak acid (H_2CO_3)

Step 2: reaction of ion with water: $CO_3^{2-} + 2H_2O \rightleftharpoons H_2CO_3 + OH^-$

Weak acid — Strong base

Basic solution

pH > 7

(iii) neutral salts: are salts that ionize in water to produce neutral solutions.

Example is: NaCℓ.

Step 1: ionisation of the salt: $NaC\ell \rightleftharpoons Na^+ + C\ell^-$

Metal ion/ From a strong base (NaOH)

From a strong acid

Step 2: No ion to react with water; resulting solution is neutral; pH = 7.

TABLE OF IONS FOR HYDROLYSIS OF SALTS

ION	ACID/BASES	STRONG/WEAK
Cl^-	HCl	Strong acid
NO_3^-	HNO_3	Strong acid
CH_3COO^-	CH_3COOH	Weak acid
SO_4^{2-}	H_2SO_4	Strong acid
CO_3^{2-}	H_2CO_3	Weak acid
NH_4^+	NH_3	Weak base
Na^+	NaOH	Strong base
K^+	KOH	Strong base
Li^+	LiOH	Strong base
Mg^{2+}	$Mg(OH)_2$	Strong base
Ca^{2+}	$Ca(OH)_2$	Weak base

CLASS EXERCISE 4

1. The following salts were dissolved in water. What will be the pH?

   Choose from : pH < 7, pH > 7 or pH = 7. Motivate your answer with a relevant equation.

   1.1 CH_3COOK; (3)

   1.2 $(NH_4)_2SO_4$; (3)

   1.3 Na_2SO_4. (3)

   [9]

9. ACID-BASE TITRATIONS

1. **Titration**: is a technique used to determine the unknown concentration of an acid or base.
2. **Standard solution**: is a solution whose exact concentration is known.
3. **Equivalence point**: is a point at which the acid/base has completely reacted with the acid/base.
4. **End point**: is the point at which the indicator changes colour.

5. Indicator: is the substance/solution that changes colour in acidic or basic medium.

CLASS EXERCISE 5: Preparation of a standard solution.

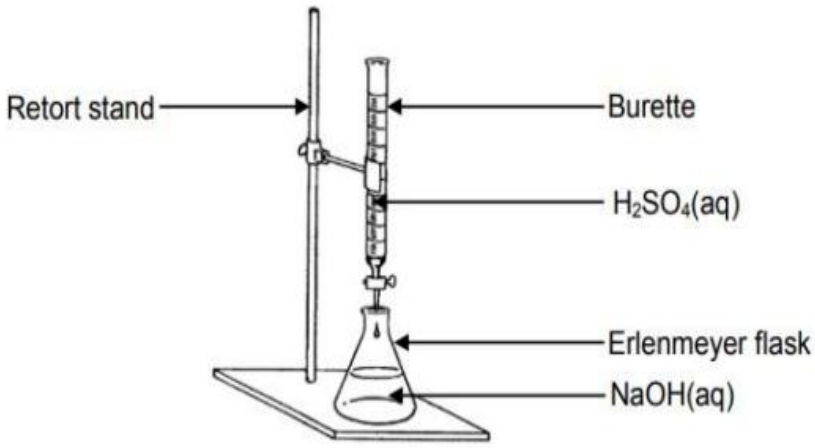
Outline steps in the preparation of 500 cm^3 standard solution of oxalic acid, $H_2C_2O_4$ with a concentration of 0.2 $mol.dm^3$.

10. COMMONLY USED INDICATORS

NAME OF INDICATOR	pH RANGE	COLOUR CHANGE	USED TO TITRATE
1. Methyl orange	3.1 - 4.4	Red to orange to yellow	• Strong acid and weak base
2. Bromothymol blue	6.0 – 7.8	Yellow to blue	• Strong acid and strong base; • Weal acid and weak base.
3. Phenolphthalein	8.3 - 10	Pink-purple in range; Colourless outside rang.	• Weak acid and strong base

11. APPARATUS NEEDED FOR TITRATION

- ➢ Pippete;
- ➢ Burette;
- ➢ Conical/elernmeyer flak;
- ➢ Retort stand;
- ➢ White tile;
- ➢ Thistle funnel.



ACTIVITIES

ACTIVITY 1

1.1 A standard solution is prepared by dissolving 10 g of sodium carbonate, $Na_2CO_3(s)$, in 0,7 dm^3 of water.

1.1.1 Calculate the concentration of the solution. (3)

1.1.2 Will the pH of the solution be GREATER THAN or LESS THAN 7? (1)

1.1.3 Write an equation that explains the answer to QUESTION 1.1.2. (2)

The sodium carbonate solution is titrated with dilute hydrochloric acid, $HC\ell(aq)$. The following indicators are available for this titration.

INDICATOR	pH RANGE
P	3,4–4,5
Q	6,8–7,2
R	8,3–10

1.1.4 Which ONE of the indicators (P, Q or R) is most suitable for this titration? Give a reason for the answer by referring to the data in the table. (2)

1.2 When 0,01 moles of dilute sulphuric acid, $H_2SO_4(aq)$, is mixed with 0,024 moles of potassium hydroxide, KOH(aq), the total volume of the final solution is 0,2 dm^3.

$$2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O(\ell)$$

1.2.1 What is meant by a dilute acid? (2)

1.2.2 Calculate the pH of the final solution. (8)

[18]

ACTIVITY 2

2.1 Ethanoic acid is a weak acid that reacts with water according to the following balanced equation:

$$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

2.1.1 Define an acid in terms of the Lowry-Brønsted theory. (2)

2.1.2 Give a reason why ethanoic acid is classified as a WEAK acid. (1)

2.1.3 Write down the formulae of the TWO bases in the equation above. (2)

2.2 A flask contains 300 cm^3 of dilute sodium hydroxide, NaOH(aq), of concentration 0,167 $mol \cdot dm^{-3}$.

2.2.1 Calculate the number of moles of sodium hydroxide in the flask. (3)

Ethanoic acid of volume 500 cm^3 and of unknown concentration, **X**, is now added to this flask to give a solution of volume 800 cm^3.

It is found that the pH of the mixture is 11,4.

The balanced equation for the reaction is:

$$NaOH(aq) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$$

Calculate the:

2.2.2 Concentration of the OH^- (aq) in the mixture. (4)

2.2.3 Initial concentration, **X**, of the ethanoic acid solution. (6)

[18]

ACTIVITY 3

3.1 Phosphoric acid, $H_3PO_4(aq)$, is an example of an acid that can ionise in three steps, as shown below.

$$H_3PO_4(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq) \quad K_a = 6.9 \times 10^{-3}$$

$$H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HPO_4^{2-}(aq) \quad K_a = 6.2 \times 10^{-8}$$

$$HPO_4^{2-}(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq) \quad K_a = 4.8 \times 10^{-13}$$

3.1.1 Which one is the stronger acid, $H_2PO_4^-$ or HPO_4^{2-}?

Give a reason for the answer by referring to the data above. (2)

3.1.2 Write down the FORMULA for the conjugate base of $H_2PO_4^-$ (aq). (1)

3.1.3 Identify a substance behaving as an ampholyte in the reactions above. (1)

Sodium hydrogen phosphate, $Na_2HPO_4(s)$, is dissolved in water.

3.1.4 Will the resulting solution be ACIDIC or BASIC? (1)

3.1.5 Write a balanced equation to explain the answer to QUESTION 3.1.4. (3)

3.2 Barium hydroxide, $Ba(OH)_2$, dissolves in water according to the balanced equation:

$$Ba(OH)_2(s) \rightarrow Ba^{2+}(aq) + 2OH^-(aq)$$

A 100 cm^3 solution is prepared by dissolving an unknown amount of $Ba(OH)_2$ at 25 °C.

25 cm^3 of this $Ba(OH)_2$ solution is reacted with 15 cm^3 of a 0,2 $mol \cdot dm^{-3}$ HCℓ solution in a flask, according to the balanced equation:

$$Ba(OH)_2(aq) + 2HC\ell(aq) \rightarrow BaC\ell_2(aq) + 2H_2O(\ell)$$

The final pH of the solution is 12,62 at 25 °C.

Calculate the:

3.2.1 Final concentration of the hydroxide ions in the flask. (4)

3.2.2 Number of moles of $Ba(OH)_2$ used to prepare the 100 cm^3 solution. (8)

[20]

ACTIVITY 4

To identify metal **M** in an unknown metal carbonate, MCO_3, the following procedure is carried out:

Step 1: 0,198 g of IMPURE MCO_3 is reacted with 25 cm^3 of 0,4 $mol \cdot dm^{-3}$ nitric acid, HNO3(aq).

Step 2: The EXCESS $HNO_3(aq)$ is then neutralised with 20 cm^3 of 0,15 $mol \cdot dm^{-3}$ barium hydroxide, $Ba(OH)_2(aq)$.

Assume that the volumes are additive.

The following reactions take place:

$$2HNO_3(aq) + MCO_3(s) \rightarrow M(NO_3)_2(aq) + CO_2(g) + H_2O(\ell)$$

$$2HNO_3(aq) + Ba(OH)_2(aq) \rightarrow Ba(NO_3)_2(aq) + 2H_2O(\ell)$$

4.1 Define the term strong base. (2)

4.2 Calculate the:

4.2.1 Number of moles of $Ba(OH)_2(aq)$ that reacted with the excess $HNO_3(aq)$. (3)

4.2.2 pH of the solution after **Step 1**. (5)

4.3 The percentage purity of the $MCO_3(s)$ in the sample is 85%.

Identify metal **M**. (8)

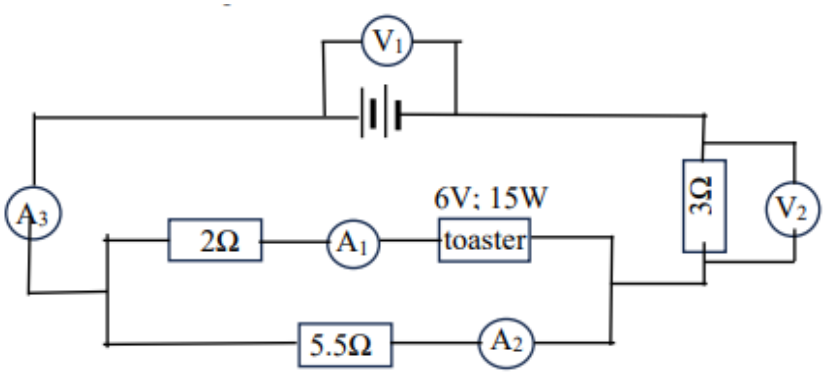
[18]

TOPIC 3: ELECTRIC CIRCUITS

REVISION OF GRADE 11 WORK

CLASS EXERCISE 1

Refer to the circuit diagram below. The toaster is rated 6V; 15W.



1.1 Calculate the:

1.1.1 reading on the ammeter A_1. (3)

1.1.2 reading on the ammeter A_2. (4)

1.1.3 reading on the ammeter A_3. (3)

1.1.4 reading on the voltmeter V_2. (3)

1.1.5 reading on the voltmeter V_1. (3)

1.2 Calculate the energy dissipated in the 5.5Ω resistor in 5 minutes. (3)

1.3 Calculate the cost of using the toaster for 2 hours per day for 30 days if the unit cost of electricity is R1.50 per kWh. (3)

[22]

GRADE 12 WORK

ELECTROMOTIVE FORCE (emf) AND INTERNAL RESISTANCE

1. Electromotive force /emf (ε): is the total amount of electric energy supplied by the cell to every coulomb of charge that passes through it.

OR

Electromotive force is the potential difference across the battery when there is no current flowing in the circuit.

Like potential difference, emf is also measured in volts (V).

2. Internal resistance (r): is the small resistance or amount of energy used up inside the cell or battery.

The volts used up in the cell are referred to as the "lost volts" (V_{lost} / $V_{internal}$).

3. FORMULA

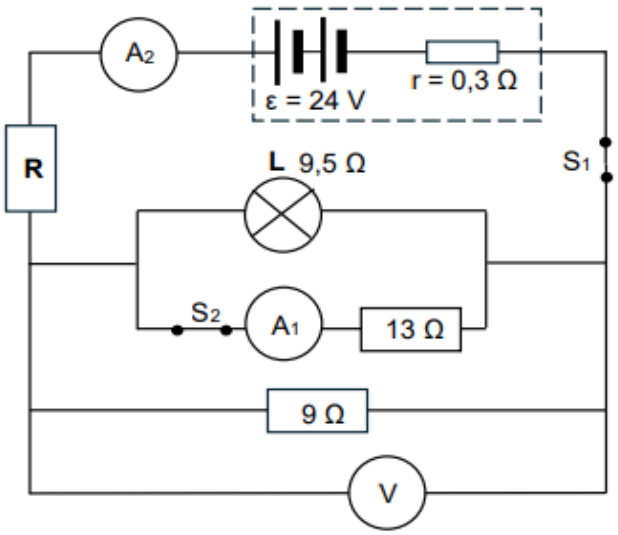
ELECTRIC CIRCUITS/*ELEKTRIESE STROOMBANE*

$R = \frac{V}{I}$	emf (ε) = I(R + r) emk (ε) = I(R + r)
$R_s = R_1 + R_2 + \ldots$ $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$	$q = I\Delta t$
$W = Vq$ $W = VI\Delta t$ $W = I^2R\Delta t$ $W = \frac{V^2\Delta t}{R}$	$P = \frac{W}{\Delta t}$ $P = VI$ $P = I^2R$ $P = \frac{V^2}{R}$

ACTIVITIES

ACTIVITY 1

In the circuit diagram below, the battery has an emf of 24 V and an internal resistance of 0,3 Ω. Light bulb L has a resistance of 9,5 Ω and R is a resistor of unknown resistance. Ignore the resistance of the ammeters and the connecting wires.



1.1 State Ohm's law in words. (2)

When both switches S_1 and S_2 are CLOSED, the reading on ammeter A_1 is 0,8 A.

1.2 Calculate the:

1.2.1 Current through light bulb **L**. (3)

1.2.2 Reading on ammeter **A_2**. (4)

1.2.3 Resistance of resistor **R**. (5)

Switch **S_2** is now **OPENED**, while switch **S_1** remains **CLOSED**.

1.3 How will this affect the reading on ammeter A2? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

1.4 How will the brightness of bulb L be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME. Explain the answer. (4)

The letters **A** to **F** represent different quantities in the circuit, as shown in the table below.

A	Voltage across the battery	D	Current through ammeter A_2
B	Internal resistance of the battery	E	Resistance of resistor R
C	Current through ammeter A_1	F	Potential difference across the 9 Ω resistor

Switch **S_1** is now **OPENED**, while switch **S_2** is **CLOSED**.

1.5 Write down the **LETTERS** of the quantities that will now be equal to zero. (3)

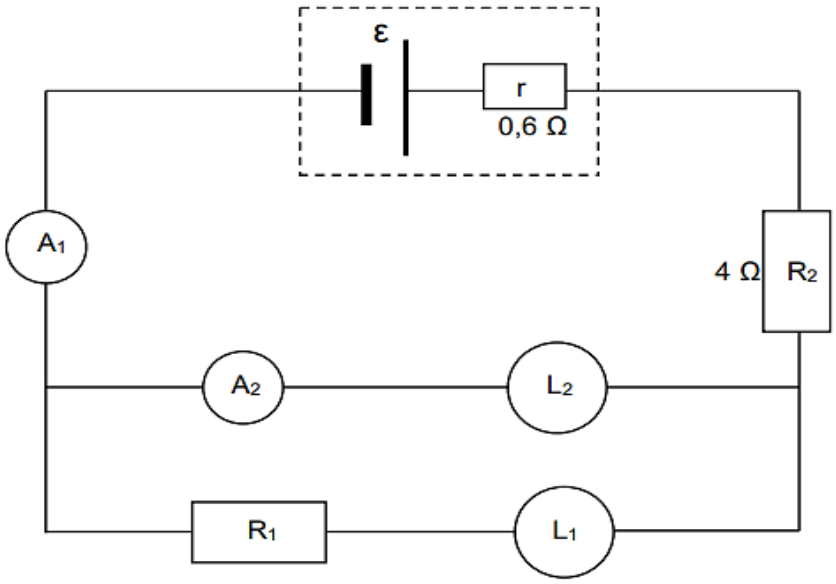
[23]

ACTIVITY 2

L_1 and **L_2** are two light bulbs that have the following ratings:

L_1: 36 W; 20 V and **L_2**: 48 W; 32 V

The two bulbs are connected as shown in the circuit diagram below. The battery has an internal resistance of 0,6 Ω while the conducting wires and \ the ammeters have negligible resistance. **R_1** and **R_2** are resistors.



2.1 Define the term power. (2)

2.2 If both light bulbs operate as RATED, calculate the:

2.2.1 Reading on ammeter **A_2**. (3)

2.2.2 Reading on ammeter **A_1**. (3)

2.2.3 Resistance of resistor **R_1**. (4)

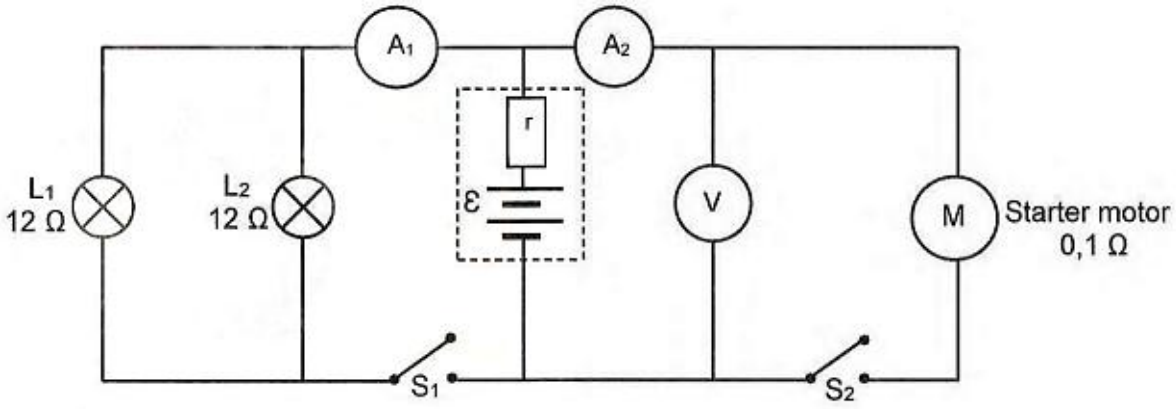
2.2.4 Emf of the battery. (4)

2.3 Bulb **L_1** burns out after a while. Assume that the resistance of bulb **L_2** remains constant. Will bulb **L_2** continue to glow after bulb **L_1** burns out? Choose from YES or NO. Support your answer with a suitable calculation. (5)

[21]

ACTIVITY 3

Two identical headlights, L_1 and L_2, and a starter motor, M, of a car are connected to a battery, as shown in the circuit diagram below. The resistance of each headlight is 12 Ω, while the resistance of the starter motor is 0.1 Ω. The emf (Ɛ) and the internal resistance (r) of the battery are unknown. The ammeters and the connecting wires have negligible resistance, while the voltmeter has a high resistance. Switches S_1 and S_2 are initially open.



3.1 Define the term emf. (2)

3.2 Switch S_1 is remains open while switch S_2 is closed.

The reading on ammeter A_2 is 120 A.

Calculate the reading on the voltmeter. (3)

3.3 Switch S_1 is now closed and switch S_2 is opened. The power dissipated by each headlight is 15 W.

3.3.1 Calculate the current passing through L_1. (3)

3.3.2 Write down the reading on ammeter A_1. (1)

3.4 Calculate the emf of the battery. (6)

3.5 Both switches are now closed.

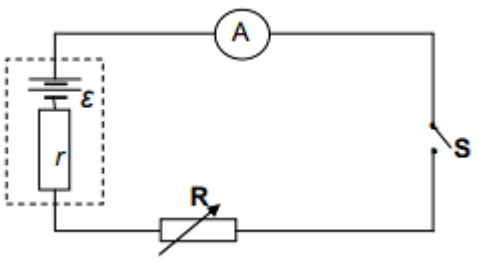
How will the reading on ammeter A_1 be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

Explain the answer WITHOUT the use of a calculation. (5)

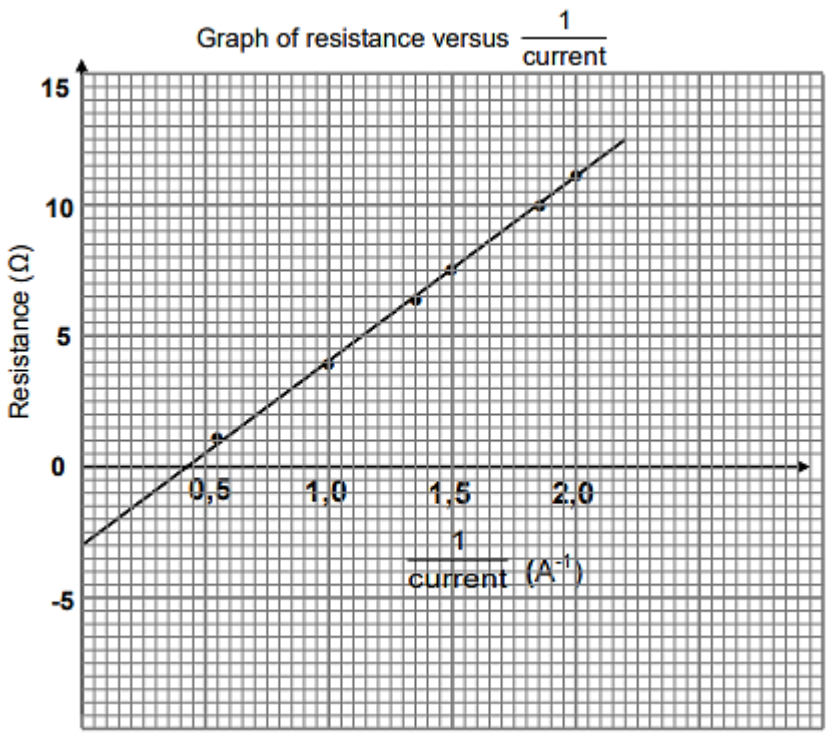
[20]

ACTIVITY 4

Learners perform an experiment to determine the emf (ε) and the internal resistance (r) of a battery using the circuit below.



The learners use their recorded readings of current and resistance, together with the equation $R = \frac{\varepsilon}{I} - r$, to obtain the graph below.



4.1 Which variable has to be kept constant in the experiment? (1)

4.2 Refer to the graph.

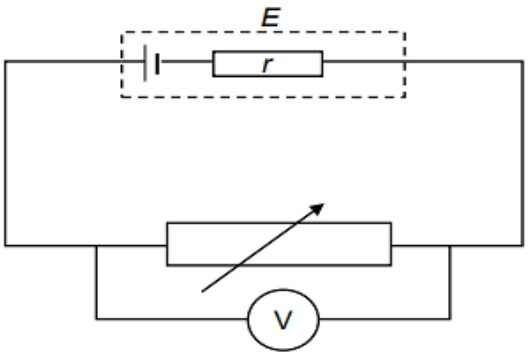
4.2.1 Write down the value of the internal resistance of the cell. (2)

4.2.2 Calculate the emf of the battery. (3)

[6]

ACTIVITY 5

5.1 In an experiment, learners use the circuit below to determine the internal resistance of a cell.



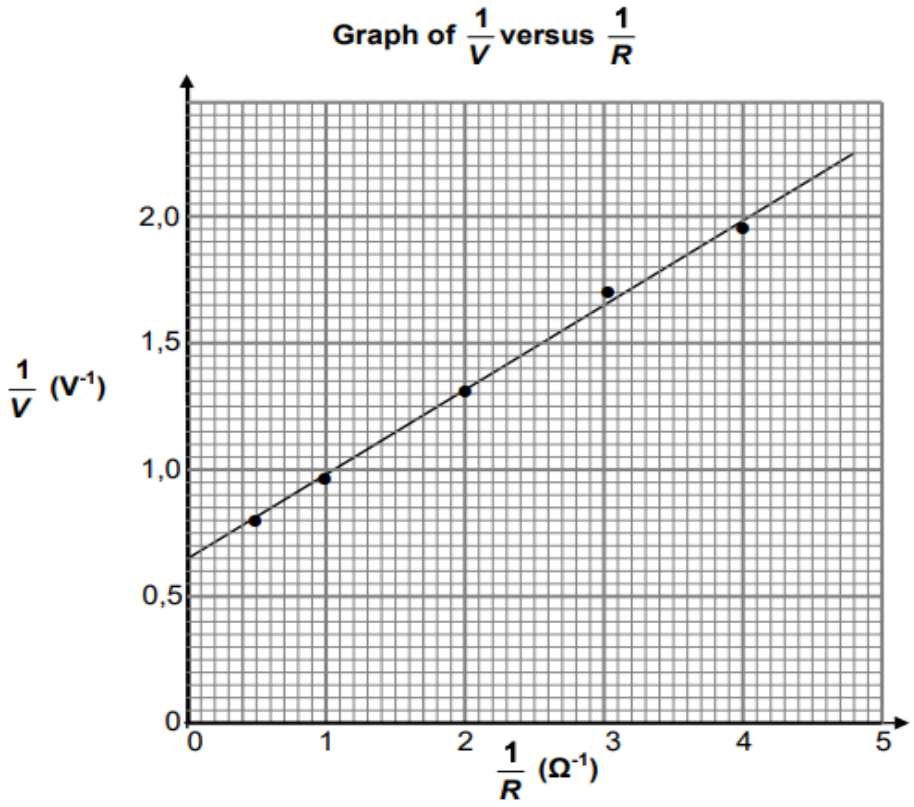
The circuit consists of a cell of emf E and internal resistance r.

A voltmeter is placed across a variable resistor which can be set to known values R.

The equation used by the learners is:

$$\frac{1}{V} = \frac{r}{\varepsilon R} + \frac{1}{\varepsilon}$$

They obtain the graph below.



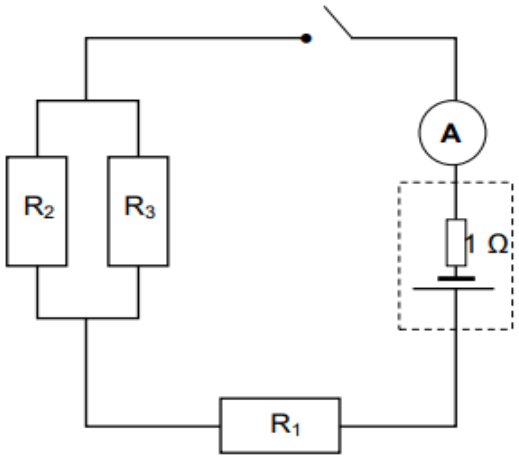
5.1.1 Write down a mathematical relationship for the slope of the graph. (1)

Use the information in the graph and calculate the:

5.1.2 Emf of the cell. (2)

5.1.3 Internal resistance of the cell. (3)

5.2 In the electrical circuit shown below, the battery has an emf of 6 V and an internal resistance of 1 Ω. The total external resistance of the circuit is 9 Ω.



5.2.1 Calculate the current in R_1 when the switch is closed. (3)

The power dissipated in resistor R_1 is 1,8 W. The resistance of resistor R_3 is 4 times that of resistor R_2. ($R_3 = 4R_2$).

5.2.2 Calculate the resistance of resistor R_2. (5)

5.3 A hair dryer operates at a potential difference of 240 V and a current of 9,5 A.

It takes a learner 12 minutes to completely dry her hair. Eskom charges energy usage at R1,47 per unit. Calculate the cost of operating the hairdryer for the 12 minutes. (1 unit = 1 kW·h). (4)

[18]

TOPIC 4: ELECTROSTATICS

EXAMINATION GUIDELINE

Electrostatics
(This section must be read in conjunction with the CAPS, p. 84–85.)

Coulomb's law

- State Coulomb's law: The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them:
- Solve problems using the equation $F = \frac{kQ_1Q_2}{r^2}$ for charges in one dimension (1D) (restrict to three charges).
- Solve problems using the equation $F = \frac{kQ_1Q_2}{r^2}$ for charges in two dimensions (2D) – for three charges in a right-angled formation (limit to charges at the 'vertices of a right-angled triangle').

Electric field

- Describe an *electric field* as a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.
- Draw electric field lines for the following configurations:
  - A single point charge
  - Two point charges (one negative, one positive OR both positive OR both negative)
  - A charged sphere

  NOTE: Restrict to situations in which the charges are identical in magnitude.
- Define *electric field at a point*: The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point. In symbols: $E = \frac{F}{q}$
- Solve problems using the equation $E = \frac{F}{q}$.
- Calculate the electric field at a point due to a number of point charges, using the equation $E = \frac{kQ}{r^2}$ to determine the contribution to the field due to each charge. Restrict to three charges in a straight line.

IMPORTANT TERMS AND CONTENT

1. **Coulomb's law**: states that the magnitude of the electrostatic force exerted by one point charge (Q1) on another point charge (Q2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them.
2. **Electric field**: is a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.

3. Electric field at a point: is the electrostatic force experienced per unit positive charge placed at that point.

THE NATURE OF CHARGES

There are two types of charges:

(i) the positive charge;

(ii) the negative charge.

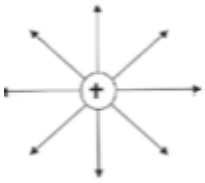
Charges is measured in Coulombs (C);

Other units used are:

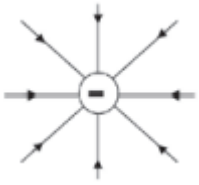
- micro-Coulombs : $1\mu C = 1 \times 10^{-6}C$;
- nano-Coulombs : $1nc = 1 \times 10^{-9}C$;
- pico-Coulombs : $1pc = 1 \times 10^{-12}C$.

Electric field patterns around the two types of charges:

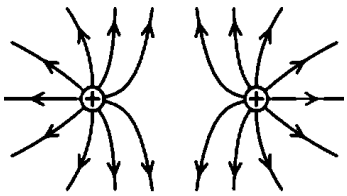
Around a positive charge



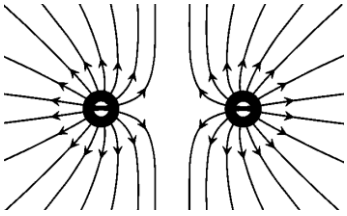
Around a negative charge



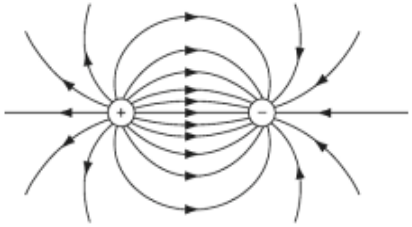
Between two positive charges



Between two negative charges



Between two unlike charges



QUANTISATION OF CHARGE: The principle of conservation of charge states that charge can neither be created nor be destroyed, but can be transferred from one object to another. When two spheres are brought into contact, electrons are transferred from the more negative sphere to the less negative sphere.
When the two spheres are separated, they will be carrying the same charge, called the net charge, Q_{net}.

$$Q_{net} = \frac{Q_1 + Q_2}{2}$$

The number of electrons can be calculated by:

$$n = \frac{Q}{q_e} \qquad \text{where } q_e = \pm 1.6 \times 10^{-19} \text{ C}$$

CLASS EXERCISE 1

1. Consider two spheres, A and B, of charges +5μC and -11μC respectively, are brought into contact and then separated.
   1.1 Will electrons be transferred from A to B or from B to A?
   1.2 Calculate:
      1.2.1 the net charge (Q_{net}) after separation of the spheres.
      1.2.2 the number of electrons transferred.
2. Sphere **P** has a charge of -7.5nc. Electrons are added or removed from sphere **P** to give it a final charge of +4.3nC.
   2.1 Were electrons added or removed from sphere **P**? Explain your answer.
   2.2 Calculate the number of electrons added or removed from sphere **P**.

ELECTROSTATIC FORCE (F/Fe)

Coulomb's law: states that the magnitude of the electrostatic force exerted by one point charge (Q1) on another point charge (Q2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them.

Thus: $F = \frac{kQ_1Q_2}{r^2}$

Where: Q_1 and Q_2 = magnitudes of charges Q_1 and Q_2 in Coulombs (C);

r = distance between the two point charges in metres;

k = Coulomb's constant (= 9×10^9 N.m^2.C^{-2})

CLASS EXERCISE 2

1. Two point charges, A and B, with magnitudes of +2.4 pC and -3.6 pC respectively, are placed 50 cm apart. Calculate the electrostatic force that charge B exerts on sphere A.
2. Two-point charges, X and Y, with magnitudes of +2.3 μC and +3.4 μC respectively, are placed a distance of r metres apart. If the electrostatic force that one exerts on the other is 5.745×10^{-3} N, calculate the distance r between them.
3. Two point charges, R and S, are placed 40 cm apart. The magnitude of charge R is -12nC and that of charge S is unknown. If the electrostatic force that each exerts on the other is 3.375×10^{-6} N, calculate the magnitude of charge S.

NET FORCE (F_{net}): is the sum of all the forces acting on an object.

If there are more than two charges involved, a free-body diagram has to be drawn in order to calculate the net force or net electric field.

TIPS ON DRAWING OF FREE-BODY DIAGRAMS: [For electrostatic forces and electric field]

Rule 1: Identify the object and represent it as a dot in the diagram. Only the object can move.

Rule 2: Consider the object and one other sphere;

Remember: (1) objects with unlike charges attract each other and the identified object will move towards the sphere. This movement toward the sphere can represents a **force** or **electric field**;

(2) objects with like charges will repel each other and the identified object will move away from the sphere.This movement away from the sphere can represents a **force** or **electric field**.

Rule 3: Consider the object and the second sphere and repeat rule 2.

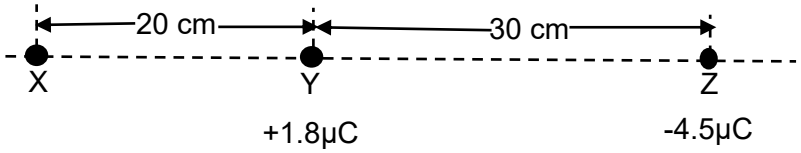
NOTE: Forces and electric fields will go in the same direction.

CLASS EXERCISE 3

1. Three point charges are placed in a straight line as shown in the diagram below.

Calculate the net electrostatic force experienced by point charge B due to the presence of point charges A and C.

2. Three spheres are placed in a straight line as shown in the diagram below.



Sphere Y experiences a net electrostatic force of 0.49 N to the left.

2.1 What is the nature of the charge on sphere X? Choose from POSITIVE or NEGATIVE.

2.2 Calculate the magnitude of sphere X.

ELECTRIC FIELD AT A POINT: is the electrostatic force experienced per unit positive charge placed at that point.

Electric field at a point is calculated using the formulae:

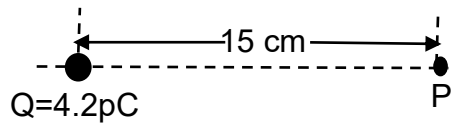
$$E = \frac{kQ}{r^2} \qquad OR \quad E = \frac{F}{q}$$

NET ELECTRI FIELD (E_{net}): is the sum of electric fields exert by other charges on one charge.

A free-body diagram need to be drawn in order to calculate the net electric field at a point.

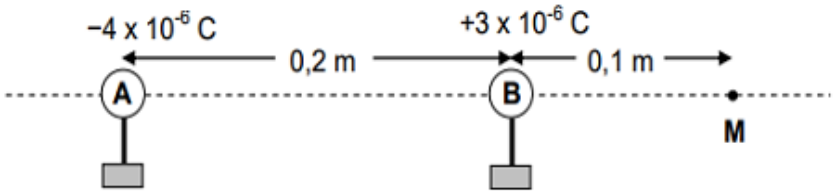
CLASS EXERCISE 4

1. Point charge **Q** with a magnitude of 4.2pC is placed 15 cm from a point **P** as shown in the diagram below.



Calculate the electric field at point P due to point charge **P**.

2. Two small charged spheres, A and B, are placed on insulated stands, 0,2 m apart, as shown in the diagram below. They carry charges of -4×10^{-6} C and $+3 \times 10^{-6}$ C respectively.



M is a point that is a distance of 0,1 m to the right of sphere **B**.

2.1 Calculate the number of electrons in excess on sphere **A**. (3)

2.2 Calculate the magnitude of the electrostatic force exerted by sphere **A** on sphere **B**. (3)

2.3 Calculate the magnitude of the net electric field at point M. (5)

[11]

ACTIVITIES

ACTIVITY 1

1.1 A small neutral sphere acquires a charge of $-1,95 \times 10^{-6}$ C.

1.1.1 Were electrons ADDED TO or REMOVED FROM the sphere? (1)

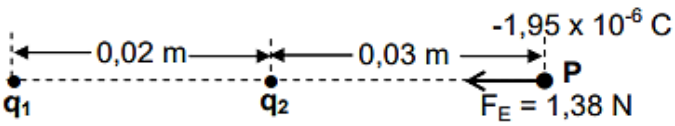
1.1.2 Calculate the number of electrons which were added or removed. (3)

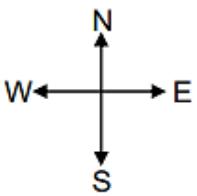
1.1.3 Define the term electric field at a point. (2)

1.1.4 Calculate the magnitude of the electric field at a point 0,5 m from the centre of the charged sphere. (3)

1.2 Two point charges, q_1 and q_2, are fixed 0,02 m apart. The magnitude of charges q_1 and q_2 is the same and q_1 is NEGATIVELY charged.

The small charged sphere with the charge of $-1,95 \times 10^{-6}$ C is placed at point P, 0,03 m east of charge q_2, as shown in the diagram below. The sphere at point P experiences a net electrostatic force of 1,38 N west.



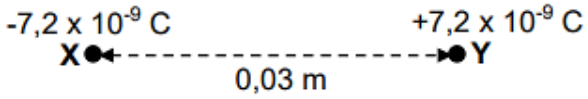


Calculate the magnitude of the charge on q_2. (5)

[14]

ACTIVITY 2

Two point charges, **X** and **Y**, are held 0,03 m apart, as shown in the diagram below. The charge of **X** is -7,2 x 10^{-9} C, while the charge of **Y** is +7,2 x 10^{-9} C.

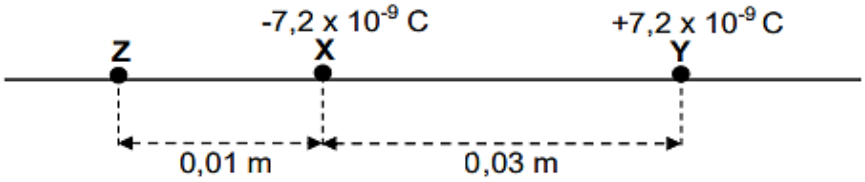


2.1 State Coulomb's law in words. (2)

2.2 Draw the net electric field pattern due to the two point charges. (3)

2.3 Calculate the magnitude of the electrostatic force that **Y** exerts on **X**. (3)

A third point charge, **Z**, of unknown positive charge, is positioned 0,01 m to the left of point charge **X** on the line joining point charges **X** and **Y**, as shown in the diagram below.



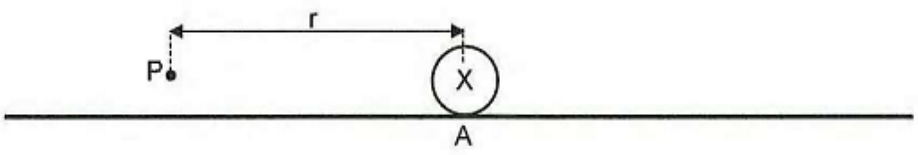
2.4 Draw a labelled vector diagram to show the directions of the electric fields at the point where X is positioned. (2)

2.5 The magnitude of the resultant electric field at the point where **X** is positioned is 4,91 x 10^5 N·C $^{-1}$. Calculate the magnitude of charge **Z**. (5)

[15]

ACTIVITY 3

A sphere **X** is placed at point **A** on a horizontal surface. **X** carries a charge of +3x10^{-7} C. Point **P** is r metres to the left of point **A**.



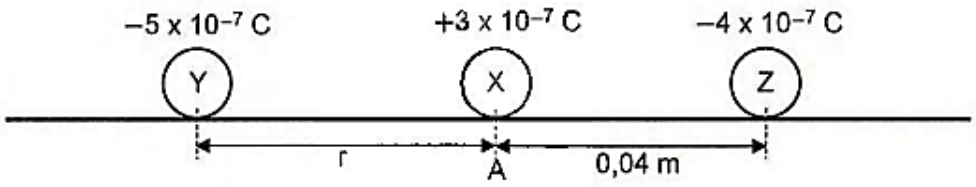
The magnitude of the electric field at point **P** is 1.08 x 10^6 N.C^{-1}.

3.1 Describe an electric field. (2)

3.2 Draw the electric field pattern due to the charge on sphere **X**.

3.3 Show, by means of a calculation, that r = 0.05 m. (3)

Sphere **Y**, carrying a charge of -5 x 10^{-7} C, is now fixed at point **P** and sphere **Z**, carrying a charge of -4 x 10^{-7} C, is fixed 0.04 m to the right of sphere **X**.



3.4 The NET FORCE acting on sphere X is 0.0427 N at point **A**.

Is the surface frictionless? Choose from YES or NO. Explain the answer by means of a calculation. (6)

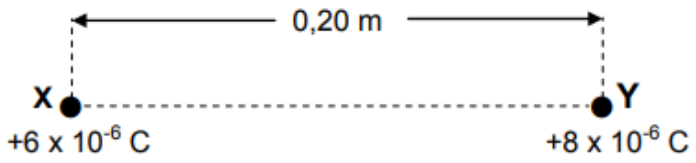
3.5 Sphere **Y** is brought into contact with sphere **X**, and is placed back in its original position.

How will the magnitude of the force that sphere **X** now exerts on sphere **Y** be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME. (2)

[15]

ACTIVITY 4

Two small spheres, **X** and **Y**, carrying charges of +6 x 10^{-6} C and +8 x 10^{-6} C respectively, are placed 0,20 m apart in air.

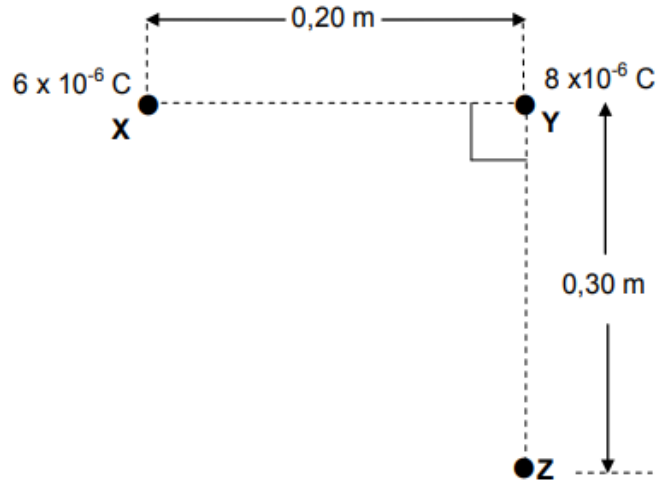


4.1 State Coulomb's law in words. (2)

4.2 Calculate the magnitude of the electrostatic force experienced by charged sphere **X**. (4)

A third sphere, **Z**, of unknown negative charge, is now placed at a distance of 0,30 m below sphere **Y**, in such a way that the line joining the charged

spheres **X** and **Y** is perpendicular to the line joining the charged spheres **Y** and **Z**, as shown in the diagram below.



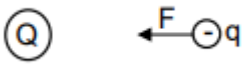
4.3 Draw a vector diagram showing the directions of the electrostatic forces and the net force experienced by charged sphere **Y** due to the presence of charged spheres **X** and **Z** respectively. (3)

4.4 The magnitude of the net electrostatic force experienced by charged sphere **Y** is 15,20 N. Calculate the charge on sphere **Z**. (4)

[13]

ACTIVITY 5

5.1 A small negative charge q placed at a fixed distance from charged sphere **Q**, experiences a force **F**, as shown in the diagram below.

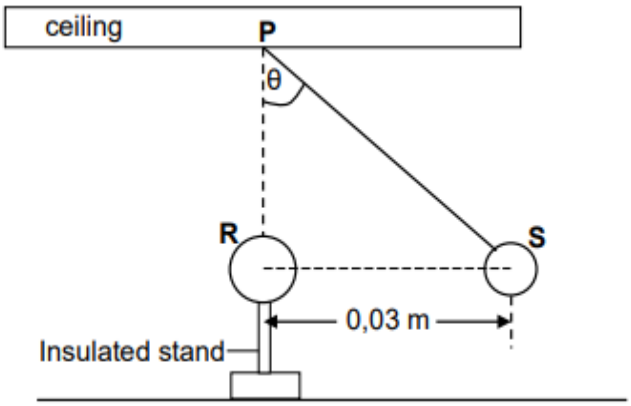


The charge q is now removed.

Draw the electric field pattern for the charged sphere **Q**. (3)

7.2 Sphere **S** is attached to the ceiling at point **P** by a light inextensible string. When sphere **R**, on an insulated stand, is brought close to sphere **S** they repel and sphere **S** comes to rest with the horizontal distance between the centres of the spheres equal to 0,03 m.

Sphere **R** is directly below point **P**. The string makes an angle θ with the vertical, as shown in the diagram below.



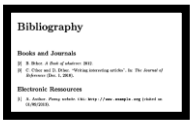
5.2.1 State Coulomb's law in words. (2)

5.2.2 Draw a labelled free-body diagram showing ALL the forces acting on sphere **S** when it is at rest. (3)

Sphere **R** has a charge of +6 nC. Sphere **S** has a charge +3 nC and a mass of 0,15 g.

5.2.3 Calculate angle θ. (5)

[13]



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