JENN
Training and Consultancy
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Province of the
EASTERN CAPE
EDUCATION

PHYSICAL SCIENCES

GRADE 12

WINTER CLASSES

Topics:
Work, Energy and Power
Acids and Bases
Rates of Reactions

TEACHER AND LEARNER CONTENT MANUAL

SCAN ME

PHYSICAL SCIENCES PROGRAMME FOR 2024 WINTER CLASSES

PAPER	TOPICS	TOTAL MARKS	WEIGHTING
WEEK 1 AND WEEK 2			
PHYSICS (PAPER 1)	Work, Energy and Power (5 hours)	± 14	± 9%
CHEMISTRY (PAPER 2)	Acids and Bases (8 hours)	± 19	± 13%
	Rates of reactions (5 hours)	± 18	± 12%
TOTAL		**± 41**	**± 33%**
Pre-test and Post-test to be administered since it's a revision of Term 1 & 2.			

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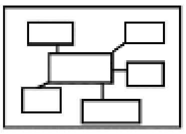
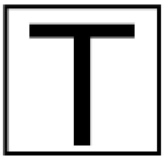
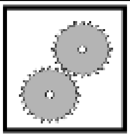
ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

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PHYSICAL SCIENCES

GRADE 12

WINTER CLASSES

Topic: Work, Energy and Power

TEACHER AND LEARNER CONTENT MANUAL

Work, Energy and Power
(This section must be read in conjunction with the CAPS, p. 117–120.)
Work

- Define the work done on an object by a constant force F as $F\Delta x cos\theta$, where F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement. (Work is done by a force – the use of the term 'work is done against a force', e.g. work done against friction, must be avoided.)
- Draw a force diagram and free-body diagrams.
- Calculate the net work done on an object.
- Distinguish between positive net work done and negative net work done on the system.

Work-energy theorem

- State the work-energy theorem: The work done on an object by a net force is equal to the change in the object's kinetic energy OR the work done on an object by a net force is equal to the change in the object's kinetic energy. In symbols: $W_{net} = \Delta K = K_f - K_i$
- Apply the work-energy theorem to objects on horizontal, vertical, and inclined planes (for both frictionless and rough surfaces).

Conservation of energy with non-conservative forces present.

- Define a conservative force as a force for which the work done in moving an object between two points is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulombic forces).
- Define a non-conservative force as a force for which the work done in moving an object between two points depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc.
- State the principle of conservation of mechanical energy: The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant. NOTE: A system is isolated when the net external force (excluding the gravitational force) acting on the system is zero.
- Solve conservation of energy problems using the equation: $W_{nc} = \Delta E_k + \Delta E_p$
- Use the relationship above to show that in the absence of non-conservative forces, mechanical energy is conserved.

Power

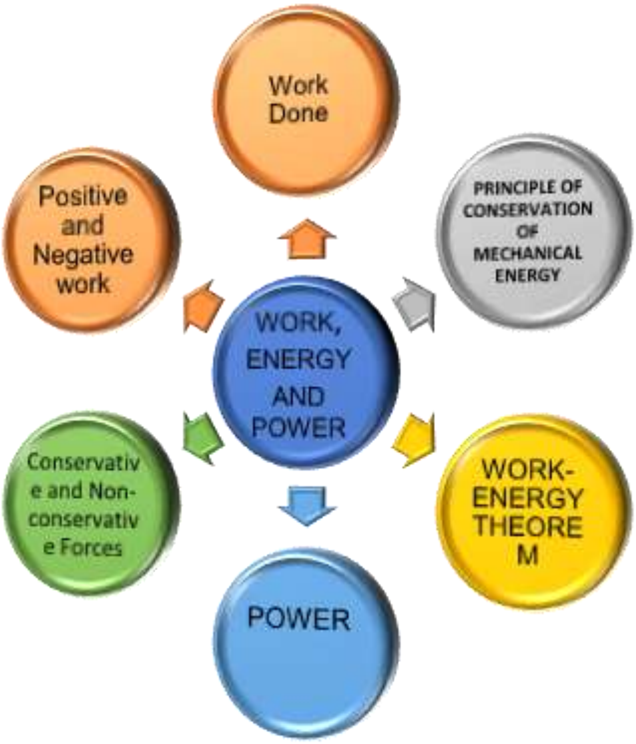
- Define power as the rate at which work is done or energy is expended. In symbols: $P = \frac{W}{\Delta t}$
- Calculate the power involved when work is done.
- Perform calculations using $P_{ave} = Fv_{ave}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

IMPORTANT TERMS AND DEFINITIONS	
Work	Work done on an object by a constant force is the product of the magnitude of the force, the magnitude of the displacement and the angle between the force and the displacement. In symbols: $W = F\Delta x cos\theta$
Positive work	The kinetic energy of the object increases.
Negative work	The kinetic energy of the object decreases.
Work-energy theorem	The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy. In symbols: $W_{net} = \Delta K = K_f - K_i$.
Principle of conservation of mechanical energy	The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant. (A system is isolated when the resultant/net external force acting on the system is zero.) In symbols: $E_{M(intial)} = E_{M(final)}$ OR $(E_p + E_k)_{initial} = (E_p + E_k)_{final}$
Conservative force	A force for which the work done (in moving an object between two points) is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulomb forces).
Non-conservative force	A force for which the work done (in moving an object between two points) depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc
Power	The rate at which work is done or energy is expended. In symbols: $P = \frac{W}{\Delta t}$ Unit: watt (W)

TABLE 1: WORK, ENERGY AND POWER

$W = F\Delta x \cos\theta$	$U = mgh$ or/*of* $E_P = mgh$
$K = \frac{1}{2}mv^2$ or/*of* $E_k = \frac{1}{2}mv^2$	$W_{net} = \Delta K$ or/*of* $W_{net} = \Delta E_k$ $\Delta K = K_f - K_i$ or/*of* $\Delta E_k = E_{kf} - E_{ki}$
$W_{nc} = \Delta K + \Delta U$ or/*of* $W_{nc} = \Delta E_k + \Delta E_p$	$P = \frac{W}{\Delta t}$
$P_{ave} = Fv_{ave}$ / $P_{gemid} = Fv_{gemid}$	

MIND MAP



WORK DONE

- **Work** is the transfer of energy.

- **Work done (W)** on an object by a constant force is the product of the displacement and the component of the force parallel to the displacement.

  ✓ $W = F\Delta x cos\theta$

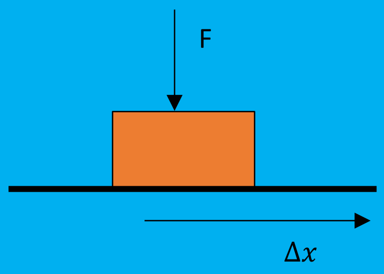
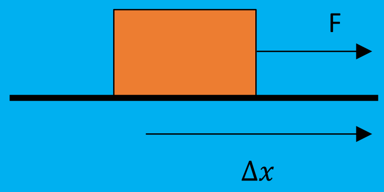
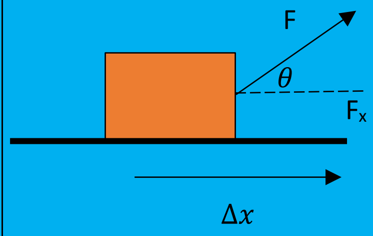
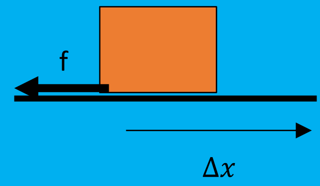
WHERE:

✓ $\boldsymbol{W} \rightarrow \boldsymbol{Work\ done\ in\ Joules(J)}$
✓ $\boldsymbol{F} \rightarrow \boldsymbol{magnitude\ of\ force\ in\ Newtons(N)}$
✓ $\boldsymbol{\Delta x/\Delta y} \rightarrow \boldsymbol{magnitude\ of\ displacement\ in\ metres(m)}$
✓ $\boldsymbol{\theta} \rightarrow \boldsymbol{magnitude\ of\ the\ angle\ between\ force\ and\ displacement}$

- Work is a scalar quantity, i.e. no direction.
- The joule is the amount of work done when a force of one newton moves its point of application one metre in the direction of the force.

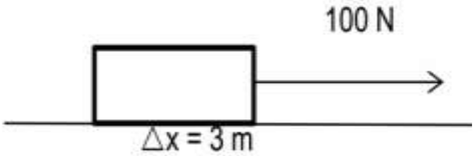
Work always involves two things:

- A constant force which acts on a certain object.
- The displacement of that object.

Zero Work done	Positive Work done		Negative Work done
			
$W = F\Delta x\cos\theta$ $F \text{ and } \Delta x$ $\boldsymbol{perpendicular\ to\ each\ other}$ $\theta = 90^{\circ}$ $\boldsymbol{\cos\theta = \cos 90^{\circ} = 0}$	$W = F\Delta x\cos\theta$ $F \text{ and } \Delta x \text{ parallel to each other}$ $\boldsymbol{same\ diraction}$ $\theta = 0^{\circ}$ $\boldsymbol{\cos\theta = \cos 0^{\circ} = 1}$	$W = F_x\Delta x\cos\theta$ $F \text{ and } \Delta x$ $\boldsymbol{angle\ \theta\ to\ each\ other}$ $F_x = F\cos\theta$ $W = F\cos\theta\Delta x\cos\theta$ $\theta = 0^{\circ}$ $\boldsymbol{\cos\theta = \cos 0^{\circ} = 1}$	$W = f\Delta x\cos\theta$ $F \text{ and } \Delta x \text{ parallel to each other}$ $\boldsymbol{opposite\ diraction}$ $\theta = 180^{\circ}$ $\boldsymbol{\cos\theta = \cos 180^{\circ} = -1}$
• No Work done on an object if the force and displacement are perpendicular to each other.	• A force in the direction of the displacement does positive work on the object. The force increases the energy of the object.	• A force component in the direction of the displacement does positive work on the object. The force increases the energy of the object.	• A frictional force in the opposite direction of the displacement does negative work on the object. The force decreases the energy of the object.
	• Positive work means that energy is added to the system.		Negative work means that energy is removed to the system.

EXAMPLE 1

A box lying on a horizontal frictionless surface is pulled by a horizontal force of 100 N. The box is displaced 3m to the right, as shown in the sketch below. Calculate the work done by the force on the box.



There is one force acting on the object.

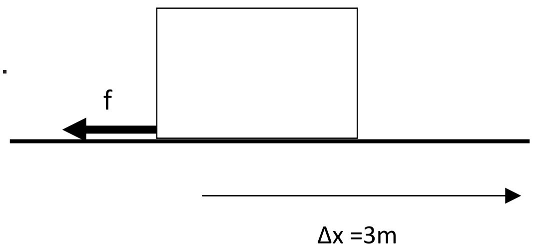
$\boldsymbol{W = F\Delta x cos\theta}$

$\boldsymbol{W = (100)(3)cos0^{\circ}}$

$\boldsymbol{W = 300\, J}$

EXAMPLE 2

A box on a horizontal rough surface slide to the right and experiences a frictional force of 100 N. The box is displaced 3 m to as shown in the sketch below. Calculate the work done by the frictional force on the box.



There is one force acting on the object.

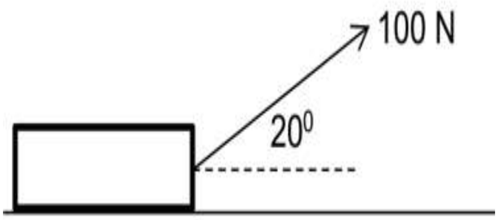
$\boldsymbol{W = f\Delta x cos\theta}$

$\boldsymbol{W = (100)(3)cos180^{\circ}}$

$\boldsymbol{W = -300\, J}$

EXAMPLE 3

Calculate the work done on a box lying on a horizontal frictionless surface, by a 100 N force, which acts at an angle of 20º to the horizontal. The force displaces the box 3 m, as shown in the diagram below.



Again, there is one force (100 N) acting on the object.

$\boldsymbol{F_x = Fcos\theta}$

$\boldsymbol{F_x = 100cos20^{\circ}}$

$\boldsymbol{F_x = 93.9692620786\, N}$

$\boldsymbol{W = F_x\Delta x cos\theta}$

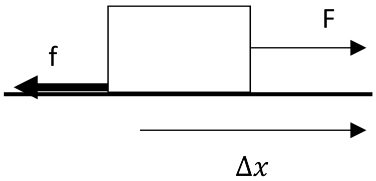
$\boldsymbol{W = (93.9692620786)(3)cos0^{\circ}}$

$\boldsymbol{W = 281.91\, J}$

NET WORK ON AN OBJECT

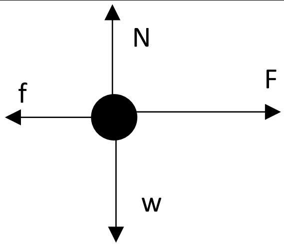
- Several forces can act on an object at the same time.
- Each force can do work on the object to change the energy of the object.
- The net work done on the object is the sum of the work done by each force acting on the object.
  - ✓ If W_{net} is **positive**, **energy is added** to the system.
  - ✓ If W_{net} is **negative**, **energy is removed** from the system.

EXAMPLE 4



Calculate the net work done on a crate if a force of 60 N is applied on a crate. The crate moves 6 m to the right and experiences a frictional force of 10 N to the left.

N.B Draw a free-body diagram showing all the forces acting on the crate and label the forces.



Work done by weight and Normal force equal 0J BOTH are perpendicular to the displacement ($\theta = 90^\circ$)

OPTION 1

$W_{net} = W_F + W_f$

$W_{net} = F\Delta x cos\theta + f\Delta x cos\theta$

$W_{net} = (60)(6)cos0^\circ + (10)(6)cos180^\circ$

$W_{net} = 300J$

OPTION 2

$F_{net} = F - f$

$F_{net} = 60 - 10$

$F_{net} = 50\ N$

$W_{net} = F_{net}\Delta x cos\theta$

$W_{net} = (50)(6)cos0^\circ$

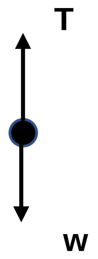
$W_{net} = 300\ J$

OPTION 3

EXAMPLE 5

An electric motor is used to lift a load of bricks through a vertical height of 20m. The tension in the cable attached to the lift is 2000 N. Calculate the work done by the electric motor on the bricks.

- Draw a free-body diagram showing all the forces acting on the bricks and label the forces. There is one acting on the bricks, which is the tension (T) in the cable. Note that there is no normal force in this example**.**



The angle between w and Δx is 180^0.

There are two forces, and we use W_{net} and F_{net}. $W_{net} = F_{net}\Delta x\cos\theta$

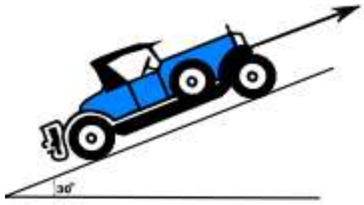
$$W_T = T\Delta x cos\theta$$
$$W_T = 2000(20)\ cos0^\circ$$
$$= 40000\ J$$

$$W_w = w\Delta x cos\theta$$
$$W_w = (50\ x\ 9,8)\ (20)cos180$$
$$= -9800\ J$$

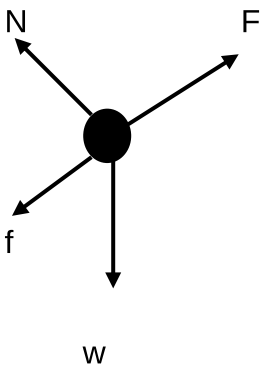
$$W_{net} = W_T + W_w$$
$$= 40000 + (-9800)$$
$$= 30200\ J$$

EXAMPLE 4

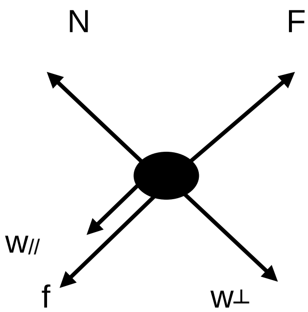
A 1200kg car is pulled 3m up an incline (30^0 with the ground) by a rope exerting a force of 8000N on the car. The car experiences a 20N frictional force.



4.1. Draw a labelled free body diagram of all the forces acting on the car.



or



4.2. Calculate the net work done on the car.

Work done by force applied (F)	Work done by friction (f)	Work done by weight.
$W_F = F\Delta x cos\theta$ $W_F = 8000(3)cos0°$ $W_F = 24000J$	$W_f = f\Delta x cos\Theta$ $W_f = 20(3)cos180°$ $W_f = -60J$	$W_{w//} = w_{//}\,\Delta x cos\theta$ $W_{w//} = [mgsin\theta]\,\Delta x cos\theta$ $W_{w//} = [(1200)(9,8)sin30°](3)cos\,180°$ $W_{w//} = -17640J$

Work Net

$W_{net} = W_F + W_f + W_{w//}$

$W_{net} = 24000 - 60 - 17640$

$W_{net} = 6300\,J$

WORK - ENERGY THEOREM:

- The net work done on an object is equal to the change in the object's kinetic energy.
- The work done on an object by a resultant/net force is equal to the change in the object's kinetic energy.

$$W_{net} = \Delta E_k$$

$$W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

- The work - energy theorem can be applied to the objects on horizontal, vertical, and inclined planes for both frictionless and rough surfaces.

CONSERVATIVE AND NON-CONSERVATIVE FORCES

CONSERVATIVE FORCE

- Conservative force is a force for which the work done in moving an object between two points is independent of the path taken.

A force is a conservative force if:

- ✓ The work done by the force in moving an object from point A to point B is independent of the path taken.
- ✓ The net work done in moving an object in a closed path which starts and ends at the same point is zero.

NON-CONSERVATIVE FORCE

- Non-conservative force is a force for which the work done in moving an object between two points depends on the path taken.

A force is a non-conservative force if:

- ✓ The work done by the force in moving an object from point A to point B is dependent of the path taken.
- ✓ The net work done in moving an object in a closed path which starts and ends at the same point is not zero.

CONSEVATIVE FORCES	NON-CONSEVATIVE FORCES
Gravitational force	Frictional force
Electrostatic force	Tension
Elastic force	Applied force
	Air resistance

ENERGY

PRINCIPLE OF CONSERVATION OF MECHANICAL ENERGY

The total mechanical energy in an isolated system remains constant.

- Mechanical energy is **sum of gravitational potential energy** and **kinetic energy**.
- A system is isolated when the resultant/net external force acting on the system is zero.
- Be in the position to use the principles of energy to show that in the absence of non-conservative forces, mechanical energy is conserved.
- The **mechanical energy of a system is conserved** when **only conservative forces are present** in the system.
- The **mechanical energy of a system is not conserved when non-conservative forces are present** in the system (e.g. friction, air resistance, applied forces and tension).
- The **work done by these non-conservative forces** is **equal to the change in the total mechanical energy** of the system.

POWER
the rate at which work is done or energy is expended.

$$P = \frac{W}{\Delta t}$$

P → Power in Watts(W)
W → work done in Joules (J).
Δt → change in time in seconds (s).

- Be in the position to calculate the power involved when work is done.
- Perform calculations using when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.

AVERAGE POWER (CONSTANT VELOCITY)

- We can calculate the average power needed to keep an object moving at constant speed.
- If the car is driven at a constant speed, the magnitude of the forward force is equal to the magnitude of the frictional force.
- If the car is driven at constant speed, then the force of the engine up the slope must be equal in magnitude to the force down the slope.
- Be able to calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

Velocity is given by displacement over time:

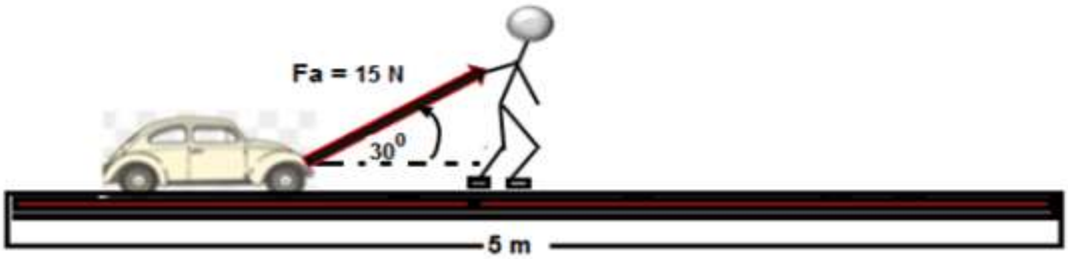
$$v_{ave} = \frac{\Delta x}{\Delta t} \qquad P_{ave} = Fv_{ave}$$

NOTE:
P → Average Power
F → Force
V → Constant Velocity

ACTIVITY 1 **12 Marks, 12 minutes**

A boy uses a rope to pull a MODEL CAR on a rough surface. The rope makes an angle of 30° with the horizontal, the boy exerts a 15 N force. The MODEL CAR moves 5 m while the boy exerts the force.

The frictional force experienced by the MODEL CAR during this process is 2 N.



1.1 Define the term work done in words. (2)

1.2 Draw a free body diagram to indicate all the forces experienced by the MODEL CAR. (4)

1.3 Calculate the work done by the:

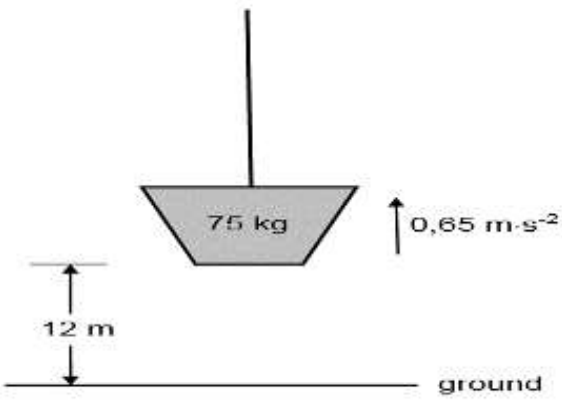
1.3.1 Applied force (4)

1.3.2 Kinetic frictional force (2)

[12]

ACTIVITY 2 **13 Marks, 13 minutes**

A load of mass 75 kg is initially at rest on the ground. It is then pulled vertically upwards at a constant acceleration of 0,65 $m \cdot s^{-2}$ by means of a light inextensible rope. Refer to the diagram below. Ignore air resistance, rotational effects, and the mass of the rope.



2.1 Draw a labelled free-body diagram for the load while it moves upward. (2)

2.2 Name the non-conservative force acting on the load. (1)

2.3 Calculate the work done on the load by the gravitational force when the load has reached a height of 12 m. (3)

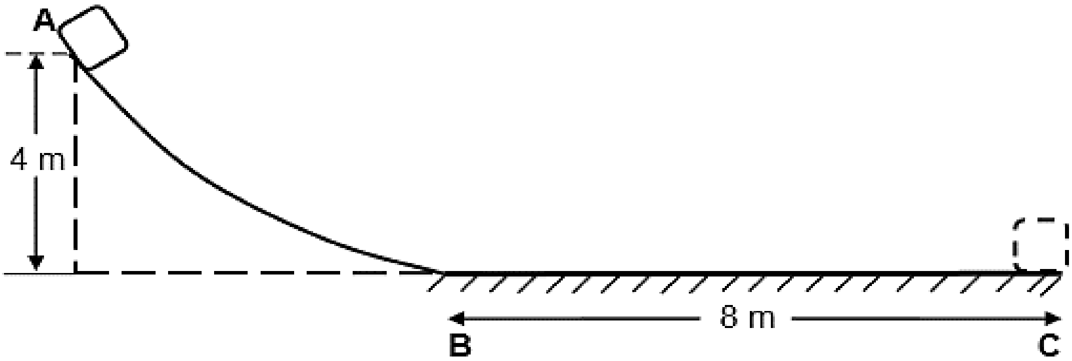
2.4 State the work-energy theorem in words. (2)

2.5 Use the work-energy theorem to calculate the speed of the load when it is at a height of 12 m. (5)

[13]

ACTIVITY 3 **13 Marks, 13 minutes**

3.1 The diagram below shows a track, ABC. The curved section, AB, is frictionless. The rough horizontal section, BC, is 8 m long.



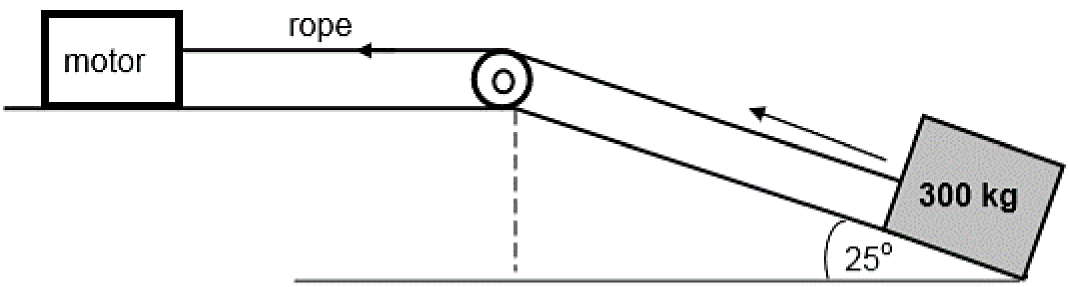
An object of mass 10 kg is released from point A which is 4 m above the ground. It slides down the track and comes to rest at point C.

3.1.1 State the principle of conservation of mechanical energy in words. (2)

3.1.2 Is mechanical energy conserved as the object slides from A to C? Write only YES or NO. (1)

3.1.3 Using ENERGY PRINCIPLES only, calculate the magnitude of the frictional force exerted on the object as it moves along BC. (6)

3.2 A motor pulls a crate of mass 300 kg with a constant force by means of a light inextensible rope running over a light frictionless pulley as shown below. The coefficient of kinetic friction between the crate and the surface of the inclined plane is 0,19.



3.2.1 Calculate the magnitude of the frictional force acting between the crate and the surface of the inclined plane. (3)

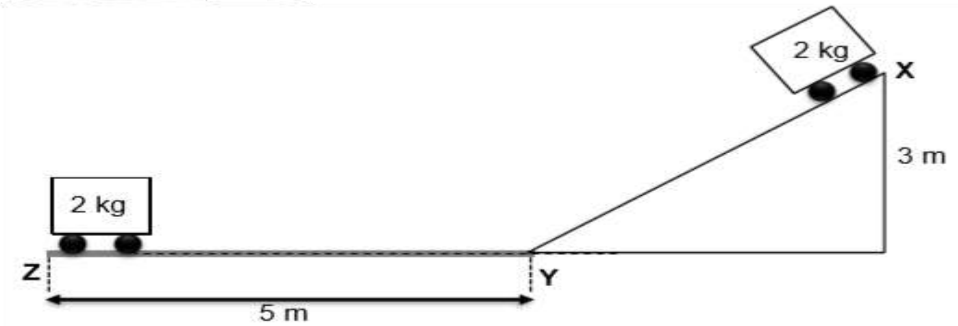
The crate moves up the incline at a constant speed of 0,5 m·s-1.

3.2.2 Calculate the average power delivered by the motor while pulling the crate up the incline. (6)

[18]

ACTIVITY 4 **21 Marks, 21 minutes**

A 2 kg trolley is held stationary at point **X**, which is at the top of a frictionless track **XY**. When the trolley is released, it moves down the track and passes point **Y**, which is at the bottom of the track. The trolley then enters a ROUGH path **YZ** where it comes to a stop at point **Z**, which is 5 m from point **Y**. The height of the track **XY** is 3 m.



4.1 Is the system between points **X** and **Y** isolated? Write down YES or NO and give a reason for your answer. (2)

4.2 State the principle of conservation of mechanical energy in words. (2)

4.3 Calculate the speed of the trolley when it reaches point **Y**. (4)

4.4 Draw a free-body diagram showing ALL the forces acting on the trolley as it moves along path **YZ**. (3)

4.5 Define the term non-conservative force. (2)

4.6 Give the NAME of a conservative force acting on the trolley as it moves along path **YZ**. (1)

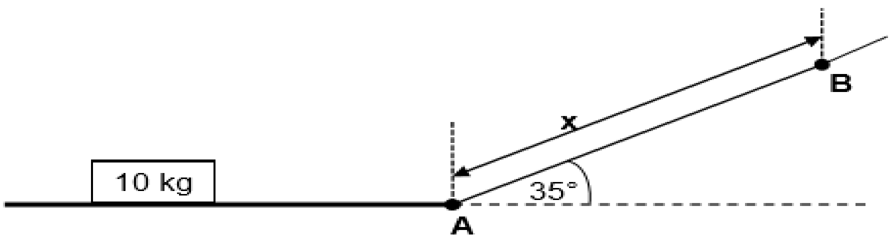
4.7 In which direction is the trolley accelerating as it moves along path **YZ**? Write down FROM **Y** TO **Z** OR FROM **Z** TO **Y**. Give a reason for your choice. (2)

4.8 Use energy principles ONLY to calculate the magnitude of the frictional force acting on the trolley as it moves along path **YZ**. (5)

[21]

ACTIVITY 5 **12 Marks, 12 minutes**

A 10 kg block is sliding along a ROUGH surface. The portion of the surface AB is inclined at an angle of 35° to the horizontal, as shown in the diagram below.



The block passes point A at a speed of 8,84 m·s-1. It slides up the incline and comes to REST at point B after covering on distance x. The frictional force exerted on the block from A to B is 45 N.

5.1 State the work-energy theorem in words. (2)

5.2 Use the work energy theorem ONLY to calculate the distance x, shown in the diagram. (4)

At point B, the block ONLY just manages to remain at rest.

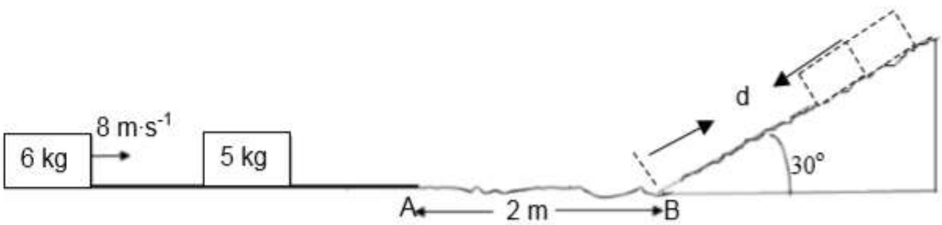
5.3 Draw a labelled free-body diagram for the block when it is at point B. (3)

5.4 Calculate the magnitude of the frictional force acting on the block at point B. (3)

[12]

ACTIVITY 6 **20 Marks, 20 minutes**

A block of mass 6 kg slides to the right with a constant velocity of 8m·s-1 on a horizontal, frictionless surface. It collides with a stationary block of mass 5 kg. The blocks move together to the right as a single system along the same surface. Refer to the diagram below.



6.1 State the law of conservation of linear momentum in words (2)

6.2 Calculate the velocity of the system of two blocks immediately after the collision. (4)

The block system continues moving with the same common velocity to point A, then continues over the rough section AB, a distance of 2 m passing point B at 1,5 m·s-1. The system continues up the rough ramp, finally coming to a stop after moving a distance d as shown in the diagram.

6.3 Use energy considerations ONLY to calculate the coefficient of sliding friction between the block system and the surface over the 2 m stretch. (5)

The system of two blocks slides up the rough ramp with the same coefficient of friction until they come to rest after covering a distance “d”.

6.3.1 Use NEWTON'S SECOND LAW of motion to calculate the distance d. (7)

6.3.2 How would the answer to QUESTION 5.4.1 change if the angle of inclination is less than 30o? Write only INCREASES, DECREASES or REMAINS THE SAME.
Give a reason for the answer. (2)

[20]

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PHYSICAL SCIENCES

GRADE 12

WINTER CLASSES

Topic: Acids and Bases

TEACHER AND LEARNER CONTENT MANUAL

EXAMINATION GUIDELINES:

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: $HC\ell(g) + H_2O(\ell) \rightarrow H_3O^+(aq) + C\ell^-(aq)$ ($HC\ell$ is a monoprotic acid.)
  $NH_3(g) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$
  $H_2SO_4(aq) + 2H_2O(\ell) \rightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$ (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: $HC\ell(aq) + NaOH(aq)/KOH(aq) \rightarrow NaC\ell(aq)/KC\ell(aq) + H_2O(\ell)$
  $HC\ell(aq) + Na_2CO_3(aq) \rightarrow NaC\ell(aq) + H_2O(\ell) + CO_2(g)$
  $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(\ell)$
  $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$
  $(COOH)_2(aq) + NaOH(aq) \rightarrow (COO)_2Na_2(aq) + H_2O(\ell)$
  $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$
  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.
- Explain the auto-ionisation of water, i.e. the reaction of water with itself to form H3O+ ions and OH^- ions.
- Interpret K_a values of acids to determine the relative strength of given acids. Interpret K_b values of bases to determine the relative strength of given bases.
- Compare strong and weak acids by looking at:
  - pH (monoprotic and diprotic acids)
  - Conductivity
  - Reaction rate

IMPORTANT TERMS AND DEFINITIONS

CHEMICAL CHANGE: ACIDS AND BASES	
Acid-base indicator	A dye used to distinguish between acidic and basic solutions by means of the colour changes it undergoes in these solutions.
Amphiprotic substance/ampholyte	A substance that can act as either an acid or a base.
Arrhenius theory	An acid is a substance that produces hydrogen ions (H^+)/ hydronium ions (H3O$^+$)when it dissolves in water. A base is a substance that produces hydroxide ions (OH^-) when it dissolves in water.
Auto-ionisation of water	A reaction in which water reacts with itself to form ions (hydronium ions and hydroxide ions).
Concentrated acids/bases	Contain a large amount (number of moles) of acid/base in proportion to the volume of water.
Conjugate acid-base pair	A pair of compounds or ions that differ by the presence of one H^+ ion. Example: CO_3^{2-} and HCO_3^- OR HCℓ and $Cℓ^-$
Conjugate acid and base	A conjugate acid has one H^+ ion more than its conjugate base. Example: HCO_3^- is the conjugate acid of base CO_3^{2-} CO_3^{2-} is the conjugate base of acid HCO_3^-.
Dilute acids/bases	Contain a small amount (number of moles) of acid/base in proportion to the volume of water.
Diprotic acid	An acid that can donate two protons. Example: H2SO4
Dissociation	The process in which ionic compounds split into ions.
Endpoint	The point in a titration where the indicator changes colour.
Equivalence point	The point in a reaction where equivalent amounts of acid and base have reacted completely.

Exam Question:

Define an **acid/base** in terms of the **Arrhenius theory**. (2 MARKS)

Arrhenius Theory

An acid is a substance that produces **hydrogen ions (H^+)/hydronium ions** (H_3O^+) when it dissolves in water.

$$HC\ell \rightarrow H^+ + C\ell^-$$

(Hydrogen ions)

$$HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$$

(Hydronium ions)

A base is a substance that produces **hydroxide ions (OH^-)** when it dissolves in water.

$$NaOH \rightarrow Na^+ + OH^-$$

(Hydroxide ions)

Exam Question:

Define an **acid/base** in terms of the **Lowry-Brønsted theory**. (2 MARKS)

Lowry-Bronsted theory

An acid is a proton (H^+ ion) donor.

$$HC\ell(aq) + H_2O(\ell) \xrightarrow{} C\ell^-(aq) + H_3O^+(aq)$$

(H^+ transferred from $HC\ell$ — Proton donor)

A base is a proton (H+ ion) acceptor.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

(H^+ transferred to NH_3 — Proton acceptor)

Exam Question:

Give a reason why Nitric acid/ Sulphuric acid/ Hydrocloric acid is classified as a strong acid. (2 MARKS)

Strong acids → ionise completely in water to form **a high concentration of H_3O^+ ions** → Hydrochloric acid **HCl**, Sulphuric acid **H_2SO_4**, Nitric acid **HNO_3**

$HCl(aq) + H_2O(\ell) \rightarrow Cl^-(aq) + H_3O^+(aq)$

Hydrochloric acid, Water, Chloride ion, Hydronium ion

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

Sulphuric acid, Water, Sulphate ion, Hydronium ion

$HNO_3(aq) + H_2O(\ell) \rightarrow NO_3^-(aq) + H_3O^+(aq)$

Nitric acid, Water, Nitrate ion, Hydronium ion

All strong acids ionizes completely with K_a greater than 1 (K_a> 1). K_a values of strong acids are very large and no values are given for K_a

Weak acids → ionise incompletely in water to form **a low concentration of H_3O^+ ions** → Ethanoic acid **CH_3COOH**, Oxalic acid **$H_2C_2O_4$**

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

Ethanoic acid (Acetic acid), Water, Hydronium ion, Ethanoate ion (Acetate ion)

$$K_a = \frac{[products]}{[reactants]} = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$$

$(COOH)_2(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + H(COO)_2^-(aq)$

oxalic acid, Water, Hydronium ion, Oxalate ion

OR

$H_2C_2O_4(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HC_2O_4^-(aq)$

oxalic acid, Water, Hydronium ion, Oxalate ion

All weak acids that ionise incompletely or only partially, with K_a smaller than one (K_a < 1).

$$K_a = \frac{[products]}{[reactants]} = \frac{[HC_2O_4^-][H_3O^+]}{[H_2C_2O_4]}$$

Strong bases

dissociates completely in water to form a high concentration of OH^- ions.

Sodium hydroxide **$NaOH$**
Potassium hydroxide **KOH**

$$NaOH(s) \xrightarrow{H_2O(\ell)} Na^+(aq) + OH^-(aq)$$

Sodium Hydroxide — Sodium ion — Hydroxide ion

All strong bases that dissociates completely with K_b greater than one ($K_b > 1$),

$$KOH(s) \xrightarrow{H_2O(\ell)} K^+(aq) + OH^-(aq)$$

Potassium Hydroxide — Potassium ion — Hydroxide ion

Weak bases

dissociate/ionise incompletely in water to form a low concentration of OH^- ions.

Ammonia **NH_3**
Sodium Carbonate **Na_2CO_3**
Potassium carbonate **K_2CO_3**
Calcium carbonate **$CaCO_3$**
Sodium hydrogen carbonate **$NaHCO_3$**

$$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$$

Ammonia — Water — Ammonium ions — Hydroxide ions

$$K_a = \frac{[products]}{[reactants]} = \frac{[NH_4^+(]\cdot[H_3O^+]}{[NH_3]}$$

All weak bases that ionizes/dissociates incompletely or only partially, with K_b smaller than one ($K_b < 1$).

Distinguish between concentrated acids/bases and dilute acids/bases.

Even when a strong acid/base is very dilute, it is still a strong acid/base

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.

For example, sodium hydroxide will always be a strong base, regardless of how much water is present in a sodium hydroxide solution.

Mono- and polyprotic acids

Acids can be classified according to the number of protons (H^+) that they can donate.

Monoprotic acid -An acid that can donate one proton.

$$HC\ell + H_2O \rightarrow C\ell^- + H_3O^+$$

$$HNO_3 + H_2O \rightarrow NO_3^- + H_3O^+$$

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$$

Conjugate acid-base pairs

Conjugate acid-base pair

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

Acid 1 | Base 2 | Acid 2 | Base 1

Conjugate acid-base pair

- When a **BASE** accepts a proton, its **CONJUGATE ACID** is produced.
  - When the base $\mathbf{H_2O}$ gains a proton, the acid $\mathbf{H_3O^+}$ is formed.
  - Add $\mathbf{H^+}$ to a given compound or ion. E.g. $H_2O + H^+ \rightarrow H_3O^+$
- When an ACID donates a proton, its **CONJUGATE BASE** is produced.
  - When the acid $\mathbf{CH_3COOH}$ donates a proton, the base $\mathbf{CH_3COO^-}$ is formed.
  - Remove $\mathbf{H^+}$ to a given compound or ion. E.g. $CH_3COOH - H^+ \rightarrow CH_3COO^-$
- Each of these acid-base pairs **differ by the presence of one hydrogen ion (H^+)** and is a called a **conjugate acid-base pair.**
- CH_3COO^- is the **conjugate base** of CH_3COOH and H_3O^+ is the **conjugate acid** of H_2O.

Conjugate acid-base pairs

$$HNO_3(aq) + H_2O(\ell) \rightarrow NO_3^-(aq) + H_3O^+(aq)$$

Stronger acid | Stronger base | Weaker base | Weaker acid

$\mathbf{HNO_3}$ is completely ionised because it is a **strong acid**.

The **forward reaction is favoured**.

Its conjugate base **(NO_3^-)** is weaker base than $\mathbf{H_2O}$ because it has a poor tendency to accept a proton to form $\mathbf{HNO_3}$

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

Weaker acid | Weaker base | Stronger acid | Stronger base

$\mathbf{CH_3COOH}$ is a weak acid and is thus incompletely ionised

The **reverse reaction is favoured.**

$\mathbf{CH_3COO^-}$ is a stronger base than $\mathbf{H_2O}$ because it readily accepts a proton from $\mathbf{H_3O^+}$ to form $\mathbf{CH_3COOH}$.

$\mathbf{H_3O^+}$ is a stronger acid than $\mathbf{CH_3COOH}$ as it readily donates a proton to $\mathbf{CH_3COO^-}$ to form $\mathbf{CH_3COOH}$.

AMPHIPROTIC SUBSTANCE/AMPHOLYTE

A substance that can act as either an acid or a base.

$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$

Base Acid

Water can thus act as acid and base and is an amphiprotic substance

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

Acid Base

AMPHIPROTIC SUBSTANCE/AMPHOLYTE

A substance that can act as either an acid or a base.

Reaction 1: $H_2SO_4(aq) + H_2O(\ell) \rightarrow H_3O^+ + HSO_4^-(aq)$

Acid 1 Base 2 Acid 2 Base 1

In reaction 1: HSO_4^- acts as a base.

In reaction 2: HSO_4^- acts as an acid.

HSO_4^- can either donate or accept a proton and is an amphiprotic substance.

Reaction 2: $HSO_4^-(aq) + H_2O(\ell) \rightarrow H_3O^+ + SO_4^{2-}(aq)$

Base 1 Acid 2 Base 2 Acid 1

ACTIVITY 1 **20 MARKS: 20 MINUTES**

Various options are provided as possible answers to the following questions. Choose the answer and write down only the letter (A–D) next to the question numbers (1.1 to 1.10) in the ANSWER BOOK, e.g. 1.5 D.

1.1 According to the Arrhenius theory, an acid ...

- A forms hydroxide ions in water
- B forms hydronium ions in water.
- C is a proton donor.
- D is a proton acceptor. (2)

1.2 The following reaction is a Lowry-Bronsted acid base reaction.

$$NH_3(g) + HC\ell(g) \leftrightharpoons NH_4C\ell(g)$$

The reason the reaction is classified as an acid base reaction is that …

- A NH_3 accepts a proton.
- B $HC\ell$ accepts a proton.
- C NH_3 donates a proton.
- D $HC\ell$ donates an electron. (2)

1.3 Consider the following reaction:

$$CH_3NH_2(aq) + H_2O(\ell) : CH_3NH_3^+(aq) + OH^-(aq)$$

The CH_3NH_2 acts as a/an …

- A proton donor.
- B proton acceptor
- C oxidising agent.
- D reducing agent. (2)

1.4 In the reaction **X** + $H_2O \leftrightharpoons H_3O^+ + HSO_4^-$, **X** represents the following:

- A acid SO_4^{2-}
- B base SO_4^{2-}
- C acid H_2SO_4
- D base H_2SO_4 (2)

1.5 Consider the four different solutions. Which of these solutions is a dilute weak acid solution?

- A 0,1 $mol{\cdot}dm^{-3}$ $HC\ell$ solution
- B 5 $mol{\cdot}dm^{-3}$ CH_3COOH solution
- C 0,5 $mol{\cdot}dm^{-3}$ oxalic acid solution

D 5 mol·dm^{-3} NaOH solution (2)

1.6 Which ONE of the following is a CORRECT description for a 0,1 mol·dm^{-3} hydrochloric acid solution?

A Dilute strong acid
B Dilute weak acid
C Concentrated weak acid
D Concentrated strong acid (2)

1.7 Consider the reactant **Y** in the following reaction:

$$\boldsymbol{Y} + H_2O \rightleftharpoons H_3O^+ + H_2PO_4^-$$

A PO_4^{3-}
B $H_2PO_4^-$
C HPO_4^{2-}
D H_3PO_4 (2)

1.8 An aqueous solution that contains more hydronium ions than hydroxide ions is a(n)

A basic solution
B acidic solution
C neutral solution
D standardised solution (2)

1.9 Consider the reaction represented by the equation below:

$$H_3PO_4(aq) + HCO_3^-(aq) \rightleftharpoons H_2PO_4^-(aq) + H_2CO_3(aq) \qquad K_a > 1$$

The strongest base in the above reaction is:

A $H_2PO_4^-$
B HCO_3^-
C H_3PO_4
D H_2CO_3 (2)

1.10 The conjugate base of HPO_4^{2-} is …

A OH^-
B PO_4^{3-}
C $H_2PO_4^-$
D H_3PO_4 (2)

[20]

REACTIONS

Neutralisation

The reaction of an acid with a base to form a **SALT** and water.

Acid + Base → Salt + Water

Hydrolysis

The reaction of a **SALT** with water

Salt + Water →

SALT

- Product of neutralisation
- Reactant of hydrolysis

A **SALT** is any ionic compound with **cation (positive ion) and anion (negative ion).**

When an ionic **SALT** dissolves in water, the ions in the **SALT** dissociate. One of the ions from a **SALT** reacts with water, forming either an acidic or basic or neutral solution.

SALT hydrolysis can be used to explain the pH of salt solutions/ to determine whether an acidic or basic or neutral solution will form

NEUTRALISATION

The reaction of an acid with a base to form a salt (ionic compound). and water.

Acid + Base → Salt + Water

Acid	Base		Salt	Water
$HC\ell(aq)$ +	$NaOH(aq)$	→	$NaC\ell(aq)$ +	$H_2O(\ell)$
Hydrochloric acid	Sodium Hydroxide		Sodium Chloride	

Sodium Chloride → Na^+ **Cation (positive ion)** and $C\ell^-$ **anion (negative ion)**

A **Salt** is any ionic compound whose **cation (positive ion) comes from a base** and whose **anion (negative ion) comes from an acid.**

Neutralisation

Acid + Base → Salt + Water

Strong Acid	+	Strong Base	→	Salt	+	Water
$HC\ell(aq)$	+	$NaOH(aq)$	→	$NaC\ell(aq)$	+	$H_2O(\ell)$

Weak Acid	+	Strong Base	→	Salt	+	Water
$CH_3COOH(aq)$	+	$NaOH(aq)$	→	$CH_3COONa(aq)$	+	$H_2O(\ell)$

Weak Acid	+	Strong Base	→	Salt	+	Water
$HC\ell(aq)$	+	$NH_4OH(aq)$	→	$NH_4C\ell(aq)$	+	$H_2O(\ell)$

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

Weak Acid — Strong Base — Salt — Water

SALT HYDROLYSIS

CH_3COO^- ⇐ CH_3COONa ⇒ Na^+

Anions of a weak acid, CH_3COOH

CH_3COO^- will undergo hydrolysis because it is an ion of a weak acid that ionises incompletely

A weak acid ionises incompletely and therefore its negative ion will hydrolyse

$$CH_3COO^- + H_2O \rightleftarrows CH_3COOH + OH^-$$

OH^- is formed

Basic(or Alkaline) Solution

pH > 7

Cations (positive ions) of a strong base, NaOH

Na^+ will not undergo hydrolysis because it is an ion of a strong base that dissociates completely

If the ion reacts with water, a strong base will be the product and will immediately dissociate because a strong base is completely dissociated.

$$Na^+ + H_2O \leftrightarrows NaOH + H_3O^+$$

$HC\ell(aq) + NH_4OH(aq) \rightarrow NH_4C\ell(aq) + H_2O(\ell)$

Strong Acid | Weak Base | Salt | Water

SALT HYDROLYSIS

NH_4^+ ⇐ $NH_4C\ell$ ⇒ $C\ell^-$

Cations of a weak base, NH_4OH

Anions of a strong acid, $HC\ell$

Acidic Solution

pH < 7

NH_4^+ will undergo hydrolysis because it is an ion of a weak base that dissociates incompletely

A weak bases dissociates incompletely and therefore its positive ion will hydrolyse.

$$NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$$

H_3O^+ is formed.

$C\ell^-$ will not undergo hydrolysis because it is an ion of a strong acid that ionises completely

If the ion reacts with water, a strong acid will be the product and will immediately ionise because a strong acid is completely ionised.

$$Cl^- + H_2O \leftrightarrows HCl + OH^-$$

$HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$

Strong Acid | Strong Base | Salt | Water

SALT HYDROLYSIS

Na^+ ⇐ $NaC\ell$ ⇒ $C\ell^-$

Cations (positive ions) of a strong base, NaOH

Anions of a strong acid, $HC\ell$

Neutral Solution

pH = 7

Na^+ will not undergo hydrolysis because it is an ion of a strong base that dissociates completely

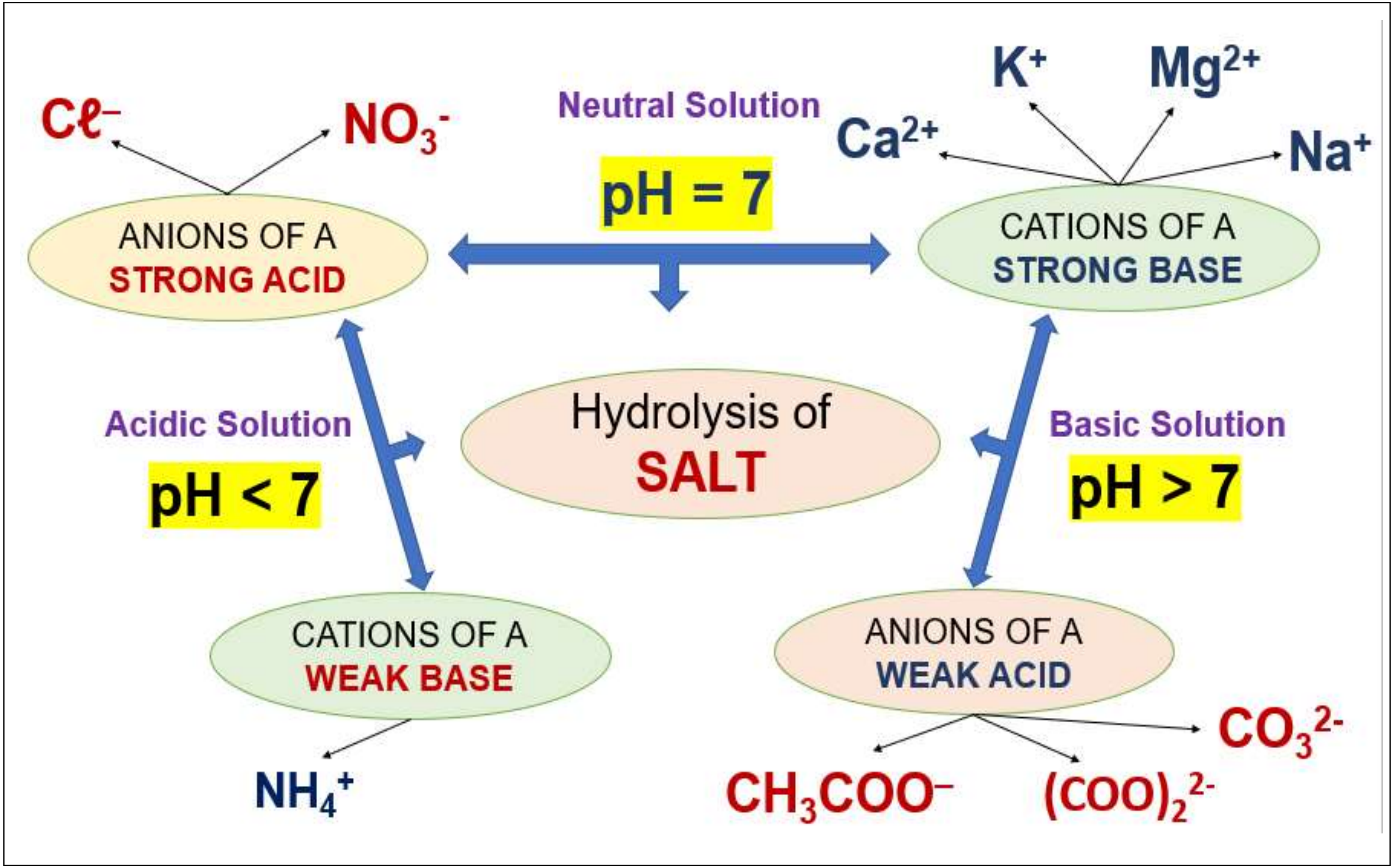
If the ion reacts with water, a strong base will be the product and will immediately dissociate because a strong base is completely dissociated.

$$Na^+ + H_2O \leftrightarrows NaOH + H_3O^+$$

$C\ell^-$ will not undergo hydrolysis because it is an ion of a strong acid that ionises completely

If the ion reacts with water, a strong acid will be the product and will immediately ionise because a strong acid is completely ionised.

$$Cl^- + H_2O \leftrightarrows HCl + OH^-$$


Cℓ⁻
NO3-
Neutral Solution
pH = 7
K+
Mg2+
Ca2+
Na+
ANIONS OF A
STRONG ACID
CATIONS OF A
STRONG BASE
Acidic Solution
pH < 7
Hydrolysis of
SALT
Basic Solution
pH > 7
CATIONS OF A
WEAK BASE
ANIONS OF A
WEAK ACID
NH4+
CH3COO⁻
(COO)2 2-
CO3 2-

ACTIVITY 2 **18 MARKS: 20 MINUTES**

A Grade 12 class wants to determine the percentage of ethanoic acid in a certain bottle of vinegar. They titrate a sample taken from the bottle of vinegar with a standard solution of sodium hydroxide. The equation for the reaction is:

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

2.1 The sodium ethanoate (CH_3COONa) formed during the above neutralisation reaction undergoes hydrolysis to form an alkaline solution. Write down an equation for this hydrolysis reaction. (3)

2.2 Ammonium chloride crystals, $NH_4C\ell(s)$, dissolve in water to form ammonium and chloride ions. The <u>ammonium ions react with water</u> according to the balanced equation below:

$$NH_4^+(aq) + H_2O(\ell) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$$

2.2.1 Write down the name of the process described by the underlined sentence. (1)

2.2.2 Is ammonium chloride ACIDIC or BASIC in aqueous solution? Give a reason for the answer. (2)

2.3 A learner dissolves ammonium chloride ($NH_4C\ell$) crystals in water and measures the pH of the solution.

2.3.1 Define the term *hydrolysis* of a salt. (2)

2.3.2 Will the pH of the solution be GREATER THAN, SMALLER THAN or EQUAL TO 7? Write a relevant equation to support your answer. (3)

2.4 Acid rain does not cause damage to lakes that have rocks containing limestone ($CaCO_3$). Hydrolysis of $CaCO_3$ results in the formation of ions, which neutralise the acid.

2.4.1 Explain, with the aid of the relevant HYDROLYSIS reaction, how limestone can neutralise the acid. (3)

Sodium ethanoate, $CH_3COONa(aq)$, forms when ethanoic acid reacts with sodium hydroxide.

2.4.2 Will the pH of a sodium ethanoate solution be GREATER THAN 7, LESS THAN 7 or EQUAL TO 7? (1)

2.4.3 Explain the answer to QUESTION 2.4.2 with the aid of a balanced chemical equation. (3)

Example 1

A hydrochloric acid solution has a concentration of 0,2 mol·dm^{-3} at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. pH of the solution.
3. OH^- concentration in the solution

Solution 1

Strong Acid
ionise completely in water to form **a high concentration of H_3O^+ ions**

HCl

Monoprotic Acid

An acid that can donate one proton.

Steps to follow when calculating the pH of monoprotic acid.					
Write down a balanced equation	**HCℓ**	**+ H_2O**	→	**H_3O^+**	**+ $Cℓ^-$**
1. Use ratios to calculate the concentration of [H_3O^+].	1 mol			1mol	
	1:1 ratio (Monoprotic acid) ∴ [H_3O^+] = [HCℓ] = 0,2 mol·dm^{-3}				
2. Substitute the concentration of [H_3O^+] in the formula, **pH = -log [H_3O^+],** to calculate the pH.	pH = -log [H_3O^+] ∴pH = -log (0,2) ∴pH = 0,70				
3. Substitute the concentration of [H_3O^+] in the formula, **K_w = [H_3O^+] [OH^-]= 1,0 x 10^{-14}** ,to calculate the OH^- concentration in the solution	K_w = [H_3O^+] [OH^-]= 1,0 x 10^{-14} ∴ (0,2) [OH^-] = 1,0 x 10^{-14} ∴ ∴ [OH^-]= $= \frac{1,0 \times 10^{-14}}{0,2}$ ∴ [OH^-]= 5 x 10^{-14} mol·dm^{-3}				

Example 2

A sulphuric acid solution has a concentration of 0,2 mol·dm^{-3} at 25 °C. Calculate

1. H_3O^+ concentration in the solution.
2. pH of the solution.
3. OH^- concentration in the solution.

Solution 2:

Strong Acid
ionise completely in water to form **a high concentration of H_3O^+ ions**

H_2SO_4

Diprotic Acid
An acid that can donate two protons.

Steps to follow when calculating the pH of diprotic acid.	
Write down a balanced equation	$H_2SO_4 + H_2O \rightarrow 2H_3O^+ + SO_4^{2-}$
	1 mol → 2mol
1. Use ratios to calculate the concentration of $[H_3O^+]$.	**1:2 ratio (Diprotic acid)** $\therefore [H_3O^+] = 2[H_2SO_4]$ $= 2(0,2)$ $= 0,4$ mol·dm^{-3}
2. Substitute the concentration of $[H_3O^+]$ in the formula, **$pH = -\log [H_3O^+]$,** to calculate the pH.	$pH = -\log [H_3O^+]$ $\therefore pH = -\log (0,4)$ $\therefore pH = 0,4$
3. Substitute the concentration of $[H_3O^+]$ in the formula, **$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$** to calculate the OH^- concentration in the solution	$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$ $\therefore (0,4)[OH^-] = 1,0 \times 10^{-14}$ $\therefore [OH^-] = \frac{1,0 \times 10^{-14}}{0,4}$ $\therefore [OH^-] = 2,5 \times 10^{-14}$ mol·dm^{-3}

Example 3

Sodium hydroxide solution has a concentration of 0,4 mol·dm^{-3} at 25 °C. Calculate

1. OH^- concentration in the solution.
2. H_3O^+ concentration in the solution.
3. pH of the solution.

Solution 2

NaOH

Strong Base
dissociates completely in water to form a high concentration of **OH^- ions**.

Steps to follow when calculating the pH of a base.				
Write down a balanced equation	**NaOH**	→	**Na^+**	**+ OH^-**
1. Use ratios to calculate the concentration of $[OH^-]$.	1 mol			1mol
	1:1 ratio ∴ $[OH^-] = [NaOH]$ $= 0,4$ mol·dm^{-3}			
2. Substitute the concentration of $[OH^-]$ in the formula, **$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$**, to calculate the OH^- concentration in the solution	$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$ ∴ $[H_3O^+](0,4) = 1,0 \times 10^{-14}$ ∴ $[H_3O^+] = \frac{1,0 \times 10^{-14}}{0,4}$ ∴ $[H_3O^+] = 2,5 \times 10^{-14}$ mol·dm^{-3}			
3. Substitute the concentration of $[H_3O^+]$ in the formula, **pH = -log $[H_3O^+]$**, to calculate the pH.	pH = -log $[H_3O^+]$ ∴pH = -log $(2,5 \times 10^{-14})$ ∴pH = 13,60			

Example 4

The pH of a hydrochloric acid solution is 4,5 at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. Concentration of HCl.

Solution 1

Strong Acid ionise completely in water to form **a high concentration of H_3O^+ ions**	⟷ **HCl** ⟷	**Monoprotic Acid** An acid that can donate one proton.

Steps to calculating the concentration of monoprotic acid if given the pH	
Write down a balanced equation.	$HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$
1. Substitute the pH value in the formula, **pH = -log [H_3O^+],** and calculate the concentration of [H_3O^+].	pH = -log [H_3O^+] ∴ 4,5 = -log [H_3O^+] ∴ [H_3O^+] = $10^{-4,5}$ ∴[H_3O^+] = $3,16 \times 10^{-5}$ mol·dm^{-3}
2. Use ratios to calculate the concentration of the HCl.	$HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$ 1 mol ... 1mol **1:1 ratio (Monoprotic acid)** ∴ [$HC\ell$] = [H_3O^+] =$3,16 \times 10^{-5}$ mol·dm^{-3}

Example 5

The pH of a sulphuric acid solution is 4,5 at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. Concentration of HCl.

Solution 2:

Strong Acid		Diprotic Acid
Strong Acid ionise completely in water to form **a high concentration of H_3O^+ ions**	⟵ H_2SO_4 ⟶	**Diprotic Acid** An acid that can donate two protons.

Steps to calculating the concentration of diprotic acid if given the pH					
Write down a balanced equation.	$\mathbf{H_2SO_4}$	**+ H_2O**	→	**$2H_3O^+$**	**+ SO_4^{2-}**
3. Substitute the pH value in the formula, **pH = -log [H_3O^+],** and calculate the concentration of [H_3O^+].	pH = -log [H_3O^+] ∴ 4,5 = -log [H_3O^+] ∴ [H_3O^+] = $10^{-4,5}$ ∴[H_3O^+] = $3,16 \times 10^{-5}$ mol·dm^{-3}				
4. Use ratios to calculate the concentration of the **H_2SO_4**.	$\mathbf{H_2SO_4}$	**+ H_2O**	→	**$2H_3O^+$**	**+ SO_4^{2-}**
	1 mol			2mol	
	1:2 ratio (Diprotic acid) ∴ [H_2SO_4] = $\frac{1}{2}$[H_3O^+] = $\frac{1}{2}$ ($3,16 \times 10^{-5}$) = $1,58 \times 10^{-5}$ mol·dm^{-3}				

ACTIVITY 3 **46 MARKS: 50 MINUTES**

3.1 Nitric acid (HNO_3), an important acid used in industry, is a strong acid. Calculate the pH of a 0,3 $mol·dm^{-3}$ nitric acid solution. (3)

3.2 A learner wishes to identify element X in the hydrogen carbonate, $XHCO_3$. To do this she dissolves 0,4 g of $XHCO_3$ in 100 cm^3 of water. She then titrates all this solution with a 0,2 mol dm^{-3} hydrochloric acid (HCℓ) solution. Methyl orange is used as the indicator during the titration.

3.2.1 Calculate the pH of the hydrochloric acid solution. (3)

3.3 Learners use the reaction of a 0,15 $mol·dm^{-3}$ sulphuric acid solution with a sodium hydroxide solution in two different experiments. The balanced equation for the reaction is:

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + H_2$$

3.3.1 Calculate the pH of sulphuric acid solution (3)

3.4 Calculate the pH of a 0,5 $mol·dm^{-3}$ sodium hydroxide solution at 25 °C. (4)

3.5 Ethanoic acid (CH_3COOH) is <u>an acid that ionises incompletely in water</u> according to the following balanced equation:

$$CH_3COOH\,(aq) + H2O(l) \rightarrow CH_3COO^-(aq) + H_3O^+(aq)$$

3.5.1 Write down the term used for the underlined phrase above. (1)

3.5.2 An ethanoic acid solution has a pH of 4 at 25 °C. Calculate the concentration of the hydronium ions, $H_3O^+(aq)$ in the solution. (3)

3.5.3 Is ethanoic acid a WEAK acid or a STRONG acid? Give a reason for the answer. (2)

3.6 The water in a certain lake has a pH of 5.

3.6.1 Calculate the concentration of the hydronium ions in the water. (3)

3.7 The pH of a hydrochloric acid solution, HCℓ(aq), is 1,02 at 25 °C.

3.7.1 Calculate the concentration of the HCℓ(aq). (3)

3.8 Carbonated water is an aqueous solution of carbonic acid, H_2CO_3.$H_2CO_3(aq)$ ionises in two steps when it dissolves in water.

3.8.1 The pH of a carbonic acid solution at 25 °C is 3,4. Calculate the hydroxide ion concentration in the solution. (5)

3.9 A sulphuric acid solution is prepared by dissolving 7,35 g of $H_2SO_4(\ell)$ in 500 cm^3 of water. Sodium hydroxide (NaOH) pellets are added to the 500 cm^3 H_2SO_4 solution.
The balanced equation for the reaction is

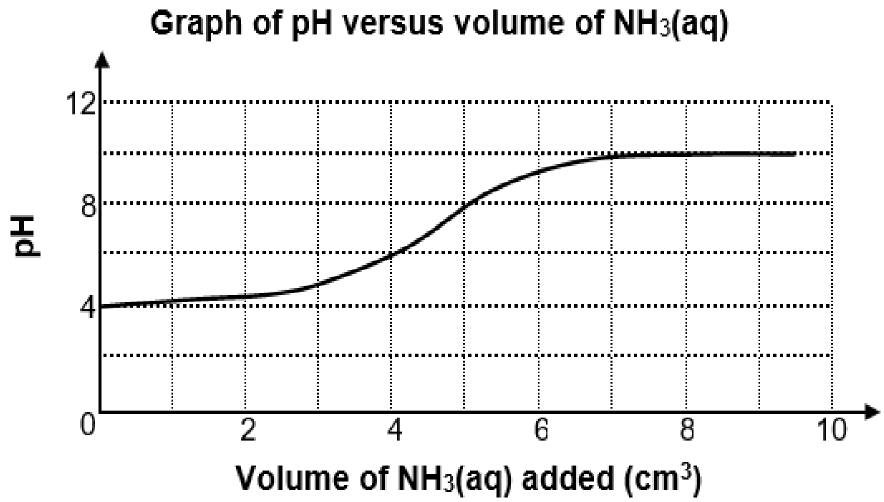
$$H_2SO_4(aq) + 2NaOH(s) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$$

After completion of the reaction, the pH of the solution was found to be 1,3. Assume complete ionisation of H_2SO_4.

3.9.1 Calculate the concentration of the H_2SO_4 (aq) (4)

3.10 A learner adds distilled water to a soil sample and then filters the mixture. The pH of the filtered liquid is then measured.

He then gradually adds an ammonia solution, $NH_3(aq)$, to this liquid and measures the pH of the solution at regular intervals. The graph below shows the results obtained.



3.10.1 Is the soil sample ACIDIC or BASIC? Refer to the graph above and give a reason for the answer. (2)

3.10.2 Calculate the concentration of the hydroxide ions (OH^-) in the reaction mixture after the addition of 4 cm^3 of $NH_3(aq)$. (4)

3.11 Like all equilibrium constants, the ionic product, K_w, of water changes its value as the temperature changes, as shown in the table below.

TEMPERATURE (° C)	K_w VALUE
25	$1,0 \times 10^{-14}$
65	$2,92 \times 10^{-14}$

3.11.1 Is the ionisation of water EXOTHERMIC or ENDOTHERMIC? (1)

3.11.2 Water is an ampholyte. Explain what this statement means. (1)

3.11.3 Show, by means of a suitable calculation, that the pH of water at 65 °C is 6,77. (4)

BASIC CALCULATIONS

MASS	SOLUTIONS
$n = \frac{m}{M}$	$c = \frac{n}{V}$ OR $c = \frac{m}{MV}$
n - is number of moles (mol) m - is mass (g) M - is molar mass ($g.mol^{-1}$)	c - is concentration ($mol.dm^{-3}$) v - is volume (dm^3)

EXAMPLE 1

A laboratory technician dissolves a 4,5 g sample of the magnesium oxide in 100 cm^3 hydrochloric acid of concentration 1,5 $mol{\cdot}dm^{-3}$ Calculate the number of moles of hydrochloric acid added to the magnesium oxide.

SOLUTION 1

SOLUTION 1

Choose the correct formula and copy formulae correctly from the data sheet.

Given Data:	n (HCl) =?
m (MgO) = 4,5 g Convert cm^3 to dm^3 by dividing the volume by 1000. V (HCl) = 100 cm^3 $\therefore$ V (HCl) = $\frac{100}{1000}$ = 0,1 dm^3 c (HCl) = 1,5 $mol{\cdot}dm^{-3}$	$c = \frac{n}{V}$ $1,5 = \frac{n}{0,1}$ $\therefore n\,(HCl) = 0,15\ mol$

EXAMPLE 2

A sulphuric acid solution is prepared by dissolving 7,35 g of $H_2SO_4(\ell)$ in 500 cm^3 of water. Calculate the number of moles of H_2SO_4 present in this solution.

Acid-base titrations

An acid-base titration is a procedure for determining the **amount of acid (or base) in asolution** by measuring the **volume of the base (or acid) of known concentration** tat will completely react with it.

$$\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$$

The solution of known concentration is called a **standard solution**.

The **equivalence point** of a titration is the point at which the acid/base has

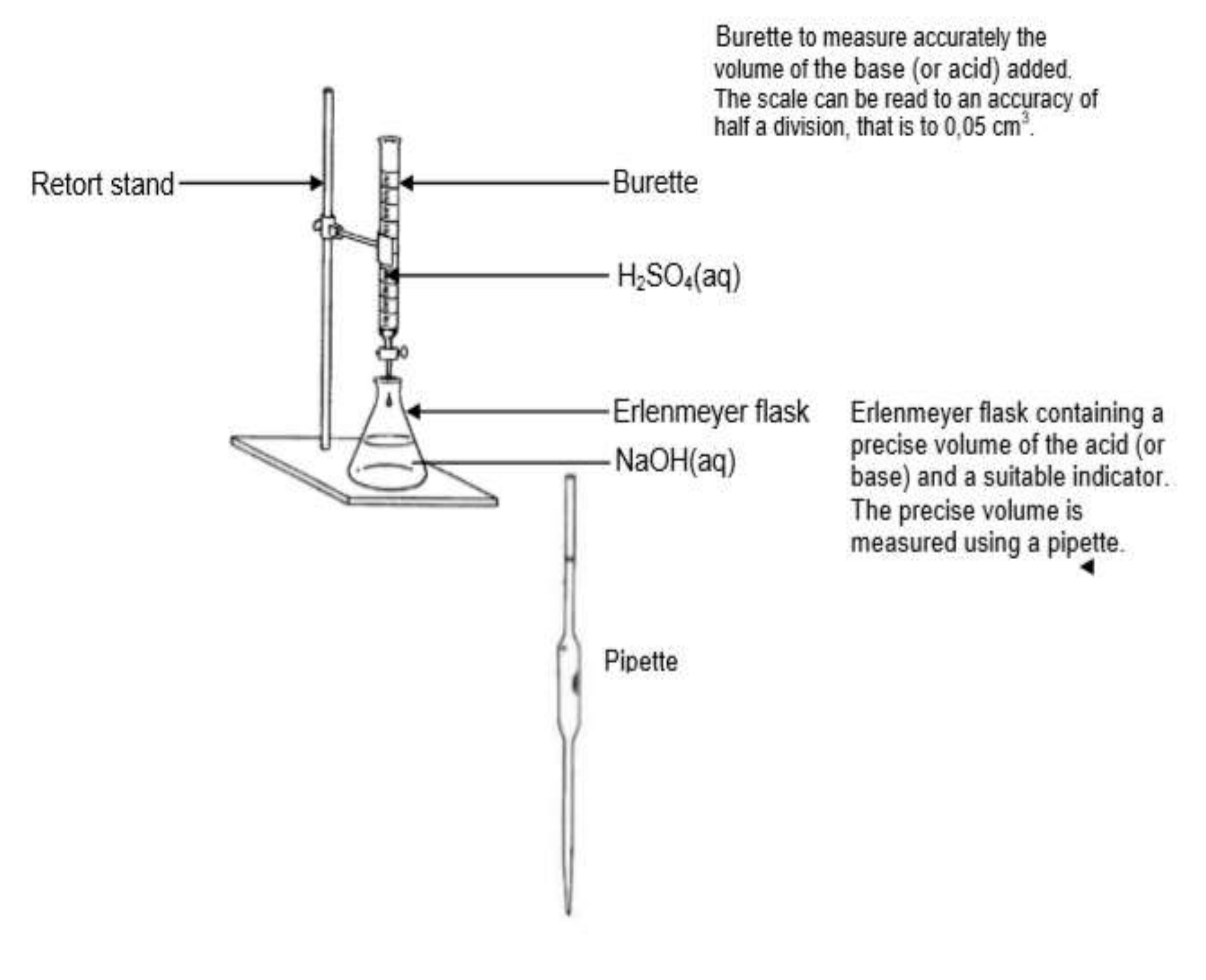
SOLUTION 2

Given Data: m (H_2SO_4) = 7,35 g Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 500 cm^3	n (H_2SO_4) =? M(H_2SO_4) = 2(1) + 32 + 4(16) = 98 $g.mol^{-1}$ $n = \frac{m}{M}$	**OR**	$c = \frac{m}{MV}$ $c = \frac{7,35}{(98)(0,5)}$ $c = 0,15\ mol{\cdot}dm^{-3}$

$\therefore$V (H_2SO_4) = $\frac{500}{1000}$ = 0,5 dm^3 n (H_2SO_4) =?	$n = \frac{7,35}{98}$ $\therefore n\ (H_2SO_4) = 0,08\ mol$	$c = \frac{n}{V}$ $0,15 = \frac{n}{0,5}$ $\therefore n\ (H_2SO_4) = 0,08\ mol$

completely reacted with the base/acid.

The **endpoint** of a titration is the point where the indicator changes colour.



Motivate the **choice of a specific indicator in a titration**. Choose from methyl orange, phenolphthalein, and bromothymol blue.

Titration of a strong acid and a strong base.

Acid	**Base**	**pH of the Salt formed**	**Indicator used**	**pH range of the indicator**
Strong Acid **Yellow**	strong base **Blue**	Neutral (pH =7)	bromothymol blue	6,0 – 7,8

- When a strong acid reacts with a stoichiometrically equivalent amount of a strong base, the resulting salt solution is neutral.
- The endpoint of the titration of a strong acid (e.g., $HC\ell$) with a strong base (e.g., NaOH) is at pH = 7.

- The best choice of indicator will be bromothymol blue because the pH at the endpoint of the titration falls within the range in which the indicator will change colour (yellow to blue) i.e., pH 6,0 - 7,8.

Titration of a strong acid with a weak base

Acid	Base	pH of the Salt formed	Indicator used	pH range of the indicator
Strong Acid **Red**	weak base **Yellow**	Acidic pH < 7	Methyl orange	3,1 - 4,4

- When a strong acid reacts with a stoichiometrically equivalent amount of a weak base, the resulting salt solution is acidic.
- The endpoint of the titration of a strong acid (e.g., HCℓ) with a weak base (e.g., Na_2CO_3) is at pH < 7.
- The best choice of indicator will be methyl orange because the pH at the endpoint of the titration falls within the range in which the indicator will change colour (red to orange to yellow) i.e., pH 3,1 – 4,4.

Titration of a weak acid and a strong base

Acid	Base	pH of the Salt formed	Indicator used	pH range of the indicator
Weak Acid **Clear**	strong base **Red**	Basic pH > 7	Phenolphthalein	8,3 – 10,0

- When a weak acid reacts with a stoichiometrically equivalent amount of a strong base, the resulting salt solution is basic.
- The endpoint of the titration of a weak acid (e.g., CH3COOH) with a strong acid (e.g., NaOH) is at pH > 7.
- The best choice of indicator will be phenolphthalein because the pH at the endpoint of the titration falls within the range in which the indicator will change colour i.e., pH 8,3 – 10,0.

EXAMPLE 3

Learners use the reaction of a 0,15 mol·dm^{-3} sulphuric acid solution with a sodium hydroxidesolution in two different experiments. The balanced equation for the reaction is:

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell)$$

They use 24 cm^3 of H_2SO_4(aq) in a titration to neutralise 26 cm^3 of NaOH(aq). Calculate theconcentration of the NaOH(aq).

SOLUTION 3

Given Data:	**Titration formula**
c_a = c(H_2SO_4) =0,15 mol·dm^{-3} Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 24 cm^3 $\therefore$V (H_2SO_4) = $\frac{24}{1000}$ = 0,024 dm^3 V (NaOH) = 26 cm^3 $\therefore$V (NaOH) = $\frac{26}{1000}$ = 0,026 dm^3 c (NaOH) = c_b =?	**$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell)$** 1 mol 2 mol $\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$ $\frac{(0{,}15)(0{,}024)}{c_b(0{,}026)} = \frac{1}{2}$ $c_b = 0{,}28\ mol.dm^{-3}$ $\therefore$c $(NaOH) = 0{,}28\ mol.dm^{-3}$ This formula should only be used for neutralisation reactions.

Given Data:	**Stoichiometric calculations**
c (H_2SO_4) =0,15 mol·dm^{-3} Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 24 cm^3 $\therefore$V (H_2SO_4) = $\frac{24}{1000}$ = 0,024 dm^3 V (NaOH) = 26 cm^3 $\therefore$V (NaOH) = $\frac{26}{1000}$ = 0,026 dm^3 c (NaOH) =? Label formulae when doing multistep calculations	**Step 1:** Calculate the number of moles of H_2SO_4. $c = \frac{n}{V}$ $0{,}15 = \frac{n}{0{,}024}$ $\therefore n\ (H_2SO_4) = 3{,}6 \times 10^{-3}\ mol$ **Step 2:** Use the mole ratio from the balanced equation to calculate the number of moles of the other substance required: **$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell)$** 1 mol 2 mol $\therefore$n(NaOH) = 2 n(H_2SO_4) = 2(3,6 x 10^{-3}) = 7,2 x 10^{-3} mol **Step 3:** Simply calculate the concentration of NaOH. $c = \frac{n}{V}$ $c = \frac{7{,}2 \times 10^{-3}}{0.026}$ $\therefore$c $(NaOH) = 0{,}28\ mol.dm^{-3}$

ACTIVITY 4 **50 MARKS: 50 MINUTES**

Learners prepare a <u>solution of known concentration</u> by dissolving 2 g pure sodium hydroxide crystals, NaOH, in water in a 250 cm3 volumetric flask.

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

4.2 Calculate the:

4.2.1 Concentration of the sodium hydroxide solution (4)

4.2.2 pH of the solution (4)

4.3 A learner wishes to identify element X in the hydrogen carbonate, $XHCO_3$. To do this she dissolves 0,4 g of $XHCO_3$ in 100 cm^3 of water. She then titrates all of this solution with a 0,2 mol dm^{-3} hydrochloric acid (HCℓ) solution. Methyl orange is used as the indicator during the titration.

4.3.1 Give a reason why methyl orange is a suitable indicator in this titration (2)

4.4 The K_a values for two weak acids, oxalic acid and carbonic acid, are as follows:

NAME	FORMULA	K_a
Oxalic acid	$(COOH)_2$	$5,6 \times 10^{-2}$
Carbonic acid	H_2CO_3	$4,3 \times 10^{-7}$

Learners prepare $2dm^3$ of a sodium hydroxide solution of concentration 0,1 $mol·dm^{-3}$. During a titration of the sodium hydroxide solution dilute oxalic acid, the learners find that 25,1 cm^3 of the NaOH(aq) neutralises exactly 14,2 cm^3 of the $(COOH)_2$(aq). The balanced equation for the reaction is as follows

$$2NaOH(aq) + (COOH)_2(aq) \rightarrow (COO)_2Na_2(aq) + 2H_2O(\ell)$$

4.4.1 Calculate the concentration of the oxalic acid solution. (5)

The following indicators are available for the titration:

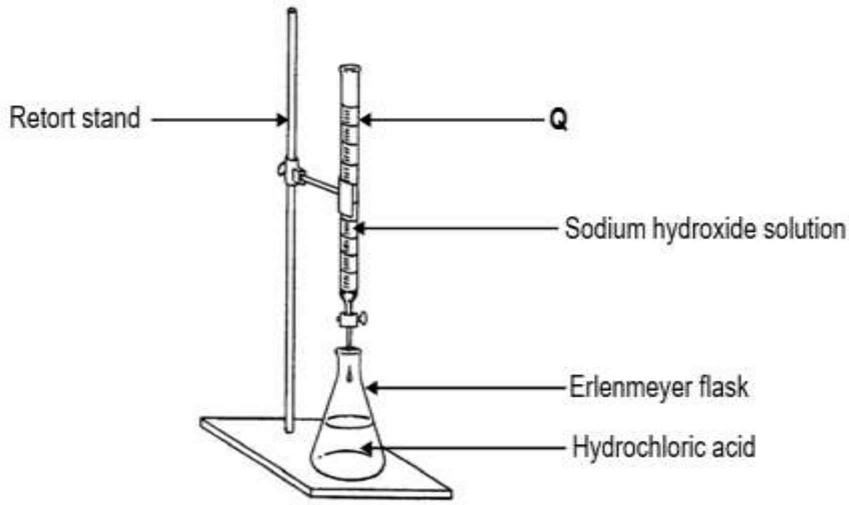
INDICATOR	pH RANGE
A	3,1–4,4
B	6,0–7,6
C	8,3–10,0

4.4.2 Which ONE of the indicators above is most suitable for this titration? Give a reason for the answer (2)

4.5 A laboratory technician wants to determine the percentage purity of magnesium oxide. He dissolves a 4,5 g sample of the magnesium oxide in 100 cm^3 hydrochloric acid of concentration 2 $mol·dm^{-3}$

4.5.1 Calculate the number of moles of hydrochloric acid added to the magnesium oxide. (3)

4.6 He then uses the apparatus below to titrate the EXCESS hydrochloric acid inthe above solution against a sodium hydroxide solution.



4.6.1 Write down the name of apparatus **Q** in the above diagram. (1)

4.6.2 The following indicators are available for the titration:

INDICATOR	pH RANGE
A	3,1 – 4,4
B	6,0 – 7,6
C	8,3 – 10,0

Which ONE of the above indicators (**A**, **B** or **C**) is most suitableto indicate the exact endpoint in this titration? Give a reason for the answer. (3)

4.6.3 During the titration, the technician uses distilled water to wash any sodium hydroxide spilled against the sides of the Erlenmeyer flask into the solution.
Give a reason why the addition of distilled water to the Erlenmeyer flask will not influence the results. (1)

4.7 **X** is a monoprotic acid.

4.7.1 State the meaning of the term *monoprotic.* (1)

A sample of acid **X** is titrated with a standard sodium hydroxidesolution using a suitable indicator.

4.7.2 At the endpoint it is found that 25 cm^3 of acid **X** is neutralised by27,5 cm^3 of the sodium hydroxide solution of concentration 0,1 $mol \cdot dm^{-3}$. Calculate the concentration of acid **X**. (5)

4.7.3 The concentration of H_3O^+ ions in the sample of acid **X** is 2,4 x 10^{-4} mol·dm^{-3}. Is acid **X** a WEAK or a STRONG acid? Explain the answer by referring to the answer in QUESTION 7.3.2. (3)

4.8 A standard solution of potassium hydroxide (KOH) is prepared in a 250 cm^3 volumetric flask. During a titration, 12,5 cm^3 of this solution neutralises 25 cm^{3}of a 0,16 mol·dm^{-3} ethanoic acid solution. The balanced equation for the reaction is:

$$CH_3COOH (aq) + KOH (aq) \rightarrow CH_3COOK (aq) + H_2O(\ell)$$

4.8.1 Calculate the mass of potassium hydroxide used to prepare the solution above in the 250 cm^3 volumetric flask. (7)

4.8.2 Will the pH of the solution in the conical flask at the end point be GREATER THAN 7, SMALLER THAN 7 or EQUAL TO 7? (1)

4.8.3 Explain the answer to QUESTION 7.2.3 with the aid of a balanced chemical equation. (3)

4.9 A learner accidentally spills some sulphuric acid of concentration 6 mol·dm ^{3} from a flask on the laboratory bench. Her teacher tells her to neutralise the spilled acid by sprinkling sodium hydrogen carbonate powder onto it. The reaction that takes place is: (Assume that the H_2SO_4 ionises completely).

$$H_2SO_4(aq) + 2NaHCO_3(s) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell) + 2CO_2(g)$$

The fizzing, due to the formation of carbon dioxide, stops after the learner hasadded 27 g sodium hydrogen carbonate to the spilled acid.

4.9.1 Calculate the volume of sulphuric acid that spilled. Assume that all the sodium hydrogen carbonate reacts with all the acid. (6)

The learner now dilutes some of the 6 mol·dm^{-3} sulphuric acid solution in the flask to 0,1 mol·dm^{-3}.

4.9.2 Calculate the volume of the 6 mol·dm^{-3} sulphuric acid solution needed to prepare 1 dm^3 of the dilute acid. (2)

PHYSICAL SCIENCES

GRADE 12

WINTER CLASSES

Topic: Rates of Reactions

TEACHER AND LEARNER CONTENT MANUAL

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 $\Delta H > 0$ for endothermic reactions, i.e. reactions in which energy is absorbed.
- State that $\Delta H < 0$ 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.

Rate and Extent of Reaction
(This section must be read in conjunction with the CAPS, p. 123–124.)

Rates of reaction and factors affecting rate

- **Define reaction rate as the change in concentration of reactants or products per unit time.**
- Calculate reaction rate from given data for reactants:
- List the factors that affect the rate of chemical reactions, i.e. nature of reacting substances, surface area, concentration (pressure for gases), temperature and thepresence of a catalyst.
- Explain in terms of the collision theory how the various factors affect the rate of chemical reactions. The collision theory is a model that explains reaction rate as the result of particles colliding with a certain minimum energy to form products.

Measuring rates of reaction

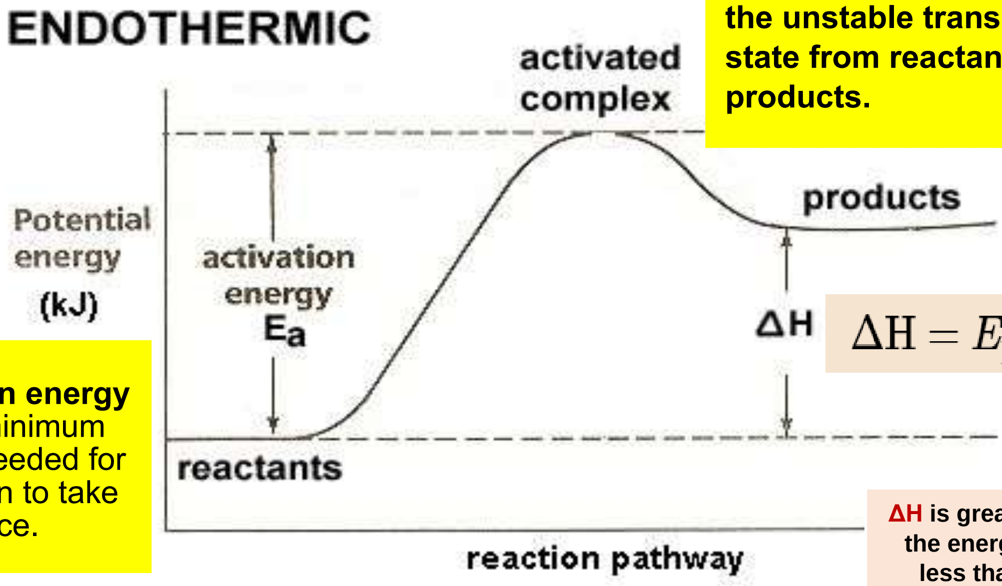
- Answer questions and interpret data (tables or graphs) on different experimental techniques for measuring the rate of a given reaction.

Mechanism of reaction and of catalysis

- Define the term catalyst as a substance that increases the rate of a chemical reactionwithout itself undergoing a permanent change.
- Explain that a catalyst increases the rate of a reaction by providing an alternative pathof lower activation energy. It therefore decreases the net activation energy.
- Interpret Maxwell-Boltzmann curves (number of particles against kinetic energy) toexplain the effect of a catalyst, temperature, and concentration on reaction rate.

TERMS AND DEFINITIONS	
Mole	One mole of a substance is the amount of substance having the same number of particles as there are atoms in 12 g carbon-12.
Molar gas volume at STP	The volume of one mole of a gas. (1 mole of any gas occupies 22,4 dm^3 at 0 °C (273 K) and 1 atmosphere (101,3 kPa).
Molar mass	The mass of one mole of a substance. Symbol: M Unit: $g{\cdot}mol^{-1}$
Avogadro's Law	Under the same conditions of temperature and pressure, the same number of moles of all gases occupy the same volume.
Concentration	The amount of solute per litre/cubic decimeter of solution. In symbols: $c = \frac{n}{V}$ Unit: $mol{\cdot}dm^{-3}$
Empirical formula	The simplest positive integer ratio of atoms presents in a compound.
Percentage yield	Yield is the amount of product obtained from a reaction. $percentage\ yield = \frac{actual\ mass\ obtained}{calculated\ mass}\ x\ 100$
Percentage purity	$percentage\ purity = \frac{mass\ of\ pure\ chamical}{total\ mass\ of\ sample}\ x\ 100$
Percentage composition	The percentage of each of the components in a substance. $percentage\ of\ component = \frac{mass\ contributed\ by\ component}{mass\ of\ all\ components}\ x\ 100$
Limiting reagents	The substance that is totally consumed when the chemical reaction is complete.
Heat of reaction (ΔH)	The energy absorbed or released in a chemical reaction.
Exothermic reactions	Reactions that release energy. ($\Delta H < 0$)
Endothermic reactions	Reactions that absorb energy. ($\Delta H > 0$)
Activation energy	The minimum energy needed for a reaction to take place.
Activated complex	The unstable transition state from reactants to products.
Reaction rate	The change in concentration of reactants or products per unit time. Rate at which reactants are used: $Rate = -\frac{\Delta c}{\Delta t}$ Unit: $mol{\cdot}dm^{-3}{\cdot}s^{-1}$ Rate at which products are formed: $Rate = \frac{\Delta c}{\Delta t}$ Unit: $mol{\cdot}dm^{-3}{\cdot}s^{-1}$ (When calculating reaction rate, the final answer is always positive!)
Collision theory	A model that explains reaction rate as the result of particles colliding with a certain minimum energy.
Catalyst	A substance that increases the rate of a chemical reaction without itself undergoing a permanent change. (A catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net/total activation energy.)
Factors that affect reaction rate	Nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.

Endothermic reaction is a reaction that absorbs energy.



Activated complex is the unstable transition state from reactants to products.

$$\Delta \mathrm{H} = E_{\mathrm{prod}} - E_{\mathrm{react}}$$

(ΔH>0)

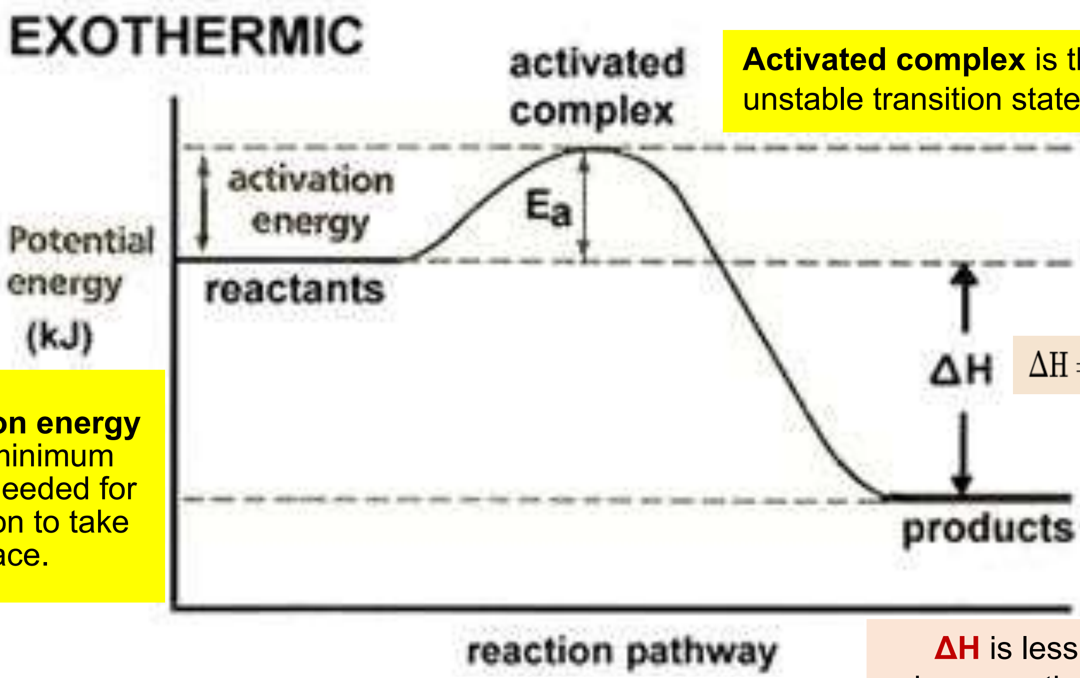
ΔH is positive.

Activation energy is the minimum energy needed for a reaction to take place.

ΔH **is greater than zero because the energy of the reactants is less than the energy of the products.**

Heat of reaction (ΔH) is **the energy absorbed in a chemical reaction.**

Exothermic reaction is a reaction that releases energy.



Activated complex is the unstable transition state from

$$\Delta \mathrm{H} = E_{\mathrm{prod}} - E_{\mathrm{react}}$$

(ΔH<0)

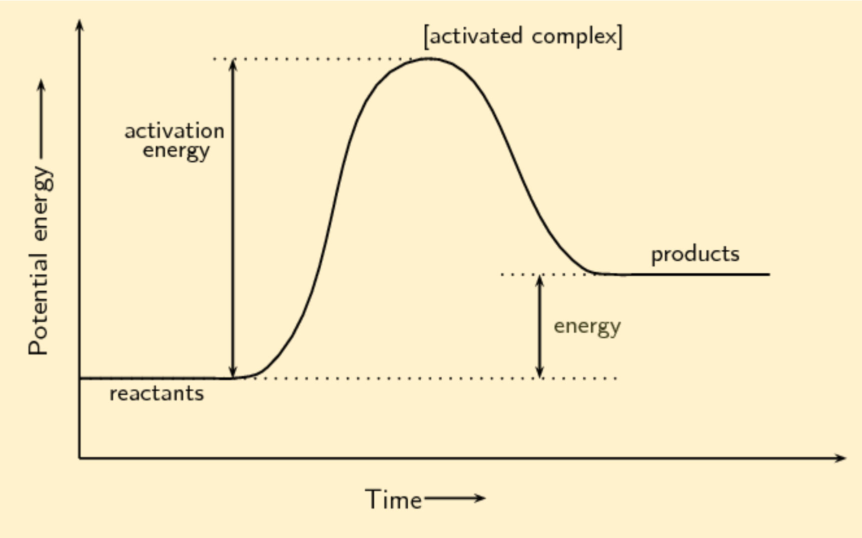
ΔH is negative.

Activation energy is the minimum energy needed for a reaction to take place.

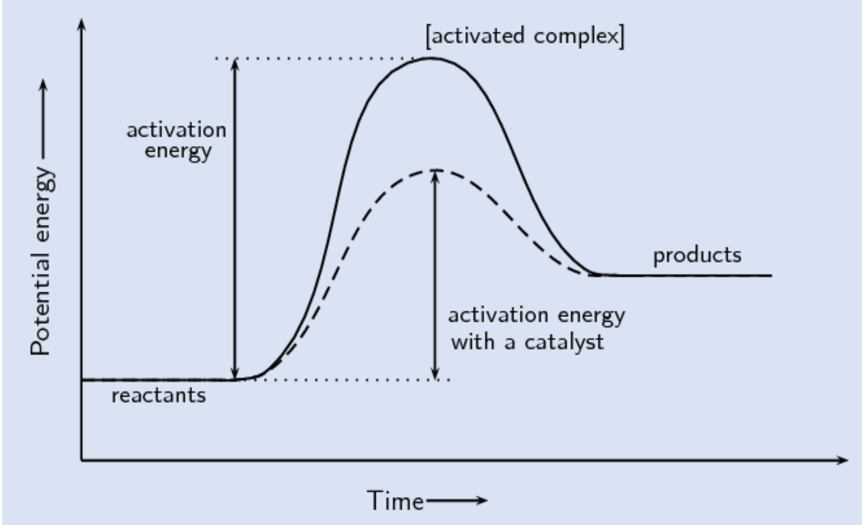
Heat of reaction (ΔH) is **the energy released in a chemical reaction.**

ΔH is less than zero because the **energy of the reactants is greater than the energy of the**

Uncatalysed endothermic reaction



Catalysed endothermic reaction.



Catalyst is a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.

The function of a **catalyst** is to **lower the activation energy** so that a greater proportion of the particles have enough energy to react.

RATE AND EXTENT OF REACTION

Reaction rate is the change in concentration of reactants or products per unit time.

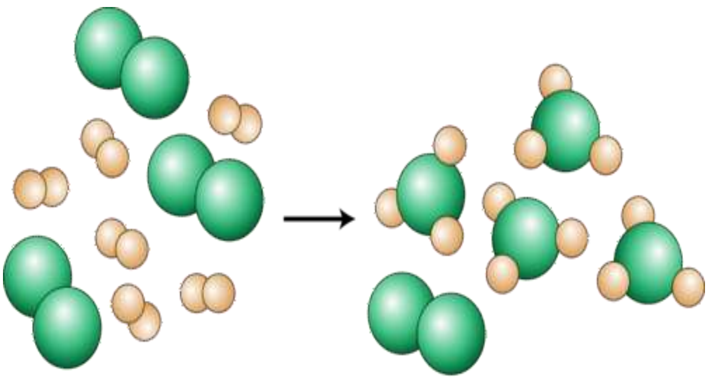
$$Rate = \frac{\Delta c}{\Delta t}$$

(Unit: $mol \cdot dm^{-3} \cdot s^{-1}$)

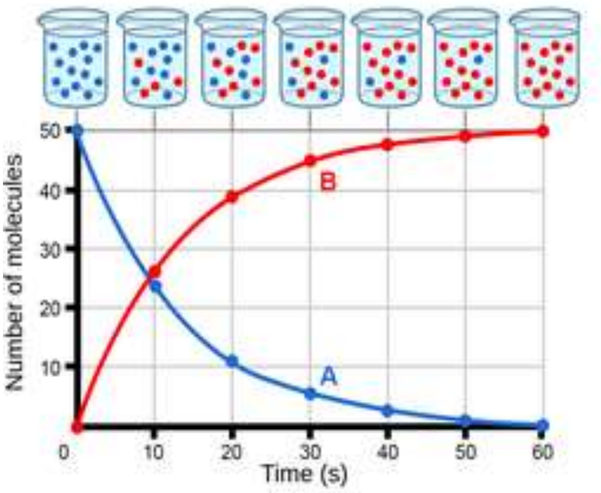
Average rate of a reaction describes

- How fast reactants are used up
- How fast products are formed

Reactants **Products**



	Reactants		Products
Before reaction	3 mol N_2	6 mol H_2	0 mol NH_3
After reaction	1 mol N_2	0 mol H_2	4 mol NH_3



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

Initially the concentration of reactants is high.

The initial concentration of products = 0

As the reactant particles react to form products, their number decreases.

As the reactant particles react, the number of product particles increase.

Questions may also include calculations of rate in terms of **change in mass/volume/ number of moles per time.**

Determine rate in terms of products	Rate = $\frac{\Delta c}{\Delta t}$	Rate = $\frac{\Delta m}{\Delta t}$	Rate = $\frac{\Delta V}{\Delta t}$	Rate = $\frac{\Delta n}{\Delta t}$
Determine rate in terms of reactants	Rate = $-\frac{\Delta c}{\Delta t}$	Rate = $-\frac{\Delta m}{\Delta t}$	Rate = $-\frac{\Delta V}{\Delta t}$	Rate = $-\frac{\Delta n}{\Delta t}$

CONCENTRATION OF PRODUCTS

- When calculating reaction rate for a reaction using the concentration of products, the following expression should be used:

$$\text{Average rate} = \frac{\Delta c}{\Delta t} = \frac{c_f - c_i}{t_f - t_i}.$$

- The concentration of products increases because products are formed and $c_f - c_i$ will be positive.
- The concentration can be substituted by number of moles (n) or mass (m) depending on the question.

CONCENTRATION OF REACTANTS

- When calculating reaction rate for a reaction using the concentration of reactants, the following expression should be used:

$$\text{Average rate} = -\frac{\Delta c}{\Delta t} = -\left(\frac{c_f - c_i}{t_f - t_i}\right)$$

- The concentration of reactants decreases because reactants are used and therefore $c_f - c_i$ will be negative.
- The minus sign ensures that a positive value is obtained for reaction rate.
- The concentration can be substituted by number of moles (n) or mass (m) depending on the question.

$$\text{Average rate} = -\left(\frac{\Delta n}{\Delta t}\right) = -\left(\frac{n_f - n_i}{t_f - t_i}\right)$$

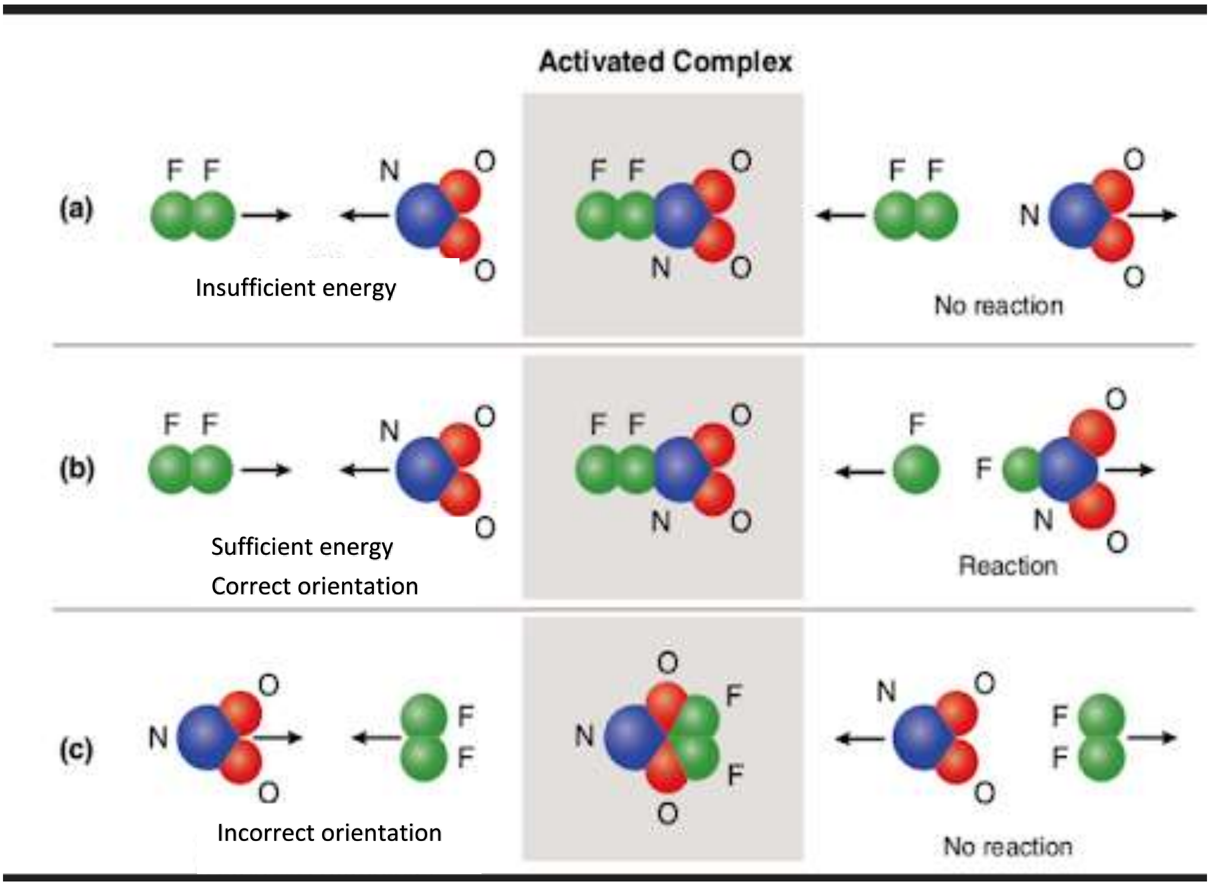
COLLISION THEORY

- Reactions take place when particles **collide.**
- **Not all collisions** lead to reactions.
- Those collisions that lead to reactions are called **effective collisions.**
- For a collision to be effective

Particles must….

- **Enough Energy** and
- **Correct Orientation**.
- **Higher energy collisions** are more effective.
- To **increase the rate of a reaction**, the number of possible effective collisions should be increased. In other words, the more often particles collide, the faster the reaction will take place.

- **Only Particles with $E_k \geq E_A$ collides effectively.**
- **Only Particles that collide with the correct orientation will result in reaction.**

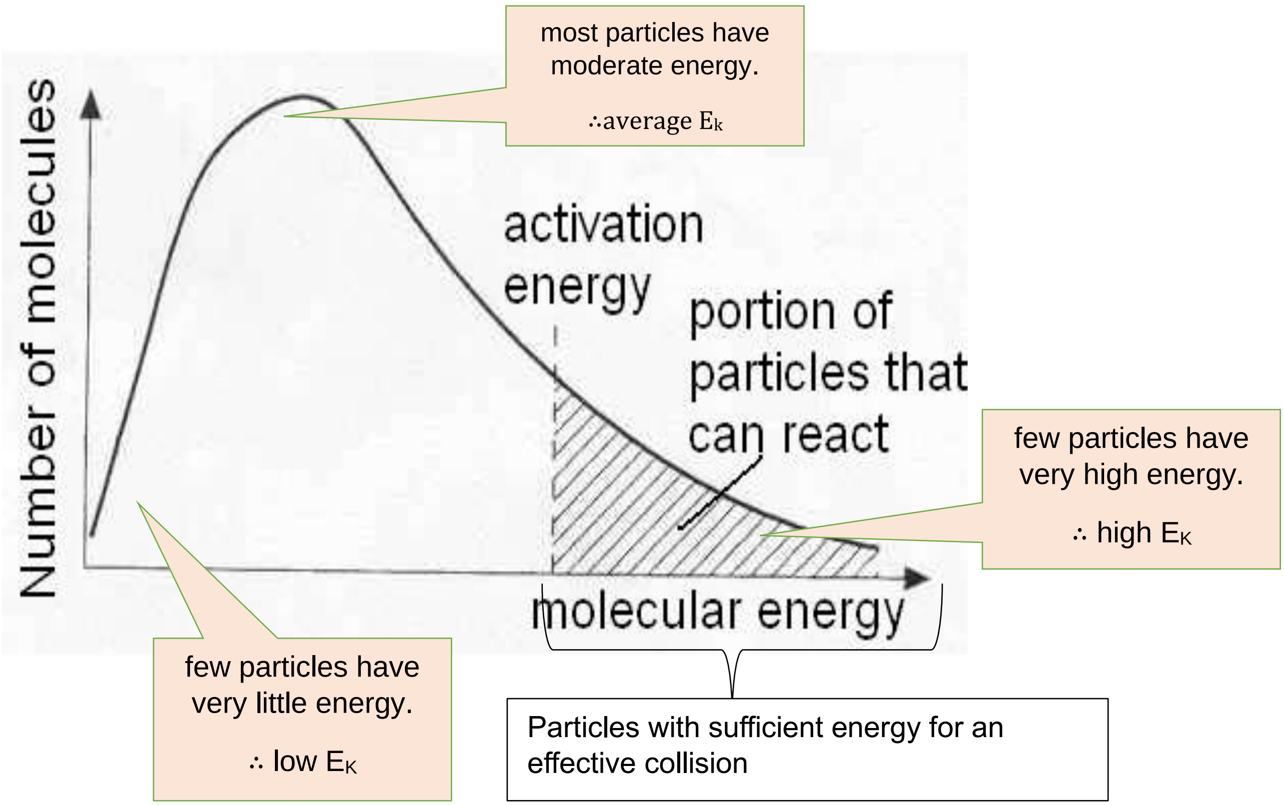


Factors that affect the rate of reactions

- **Temperature –** The faster the particles move, the more likely they are to collide, so the more likely they are to react.
- **Pressure (only in gases)** – The more you push the particles together, the more likely they are to collide, so the more likely they are to react.
- **Concentration (solutions and gases)** – the more particles squashed in per dm3, the more likely they are to collide, so the more likely they are to react.
- **State of division and size of reaction surface (solids)** – the more particles open to be reacted with, the more likely they are to collide, so the more likely they are to react.
- **Catalyst –** the activation energy is lowered for the reaction, making it easier for substances to react, so they react faster.
- **Nature of reacting substances** – different types of substances, by their very nature, react at different speeds. For example, iron oxidises (rusts) relatively slowly while carbon (coal) oxidises (burns) fairly fast.

Maxwell-Boltzman Distribution

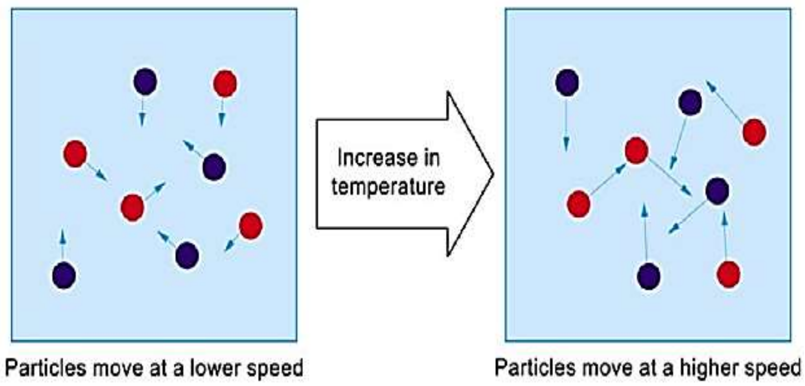
- The Maxwell-Boltzman distribution curve shows the distribution of the kinetic energy of molecules. The area under the graph to the right of the EA line represents the particles with sufficient kinetic energy



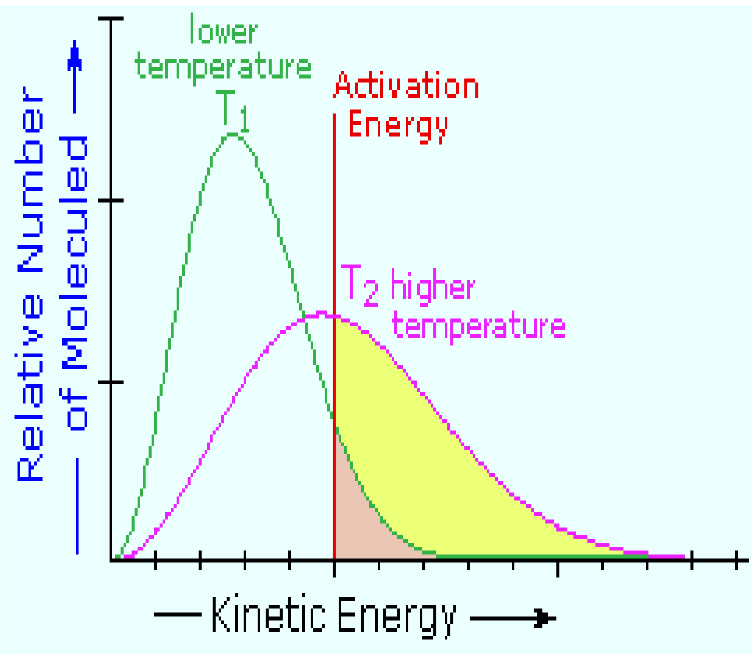
TEMPERATURE

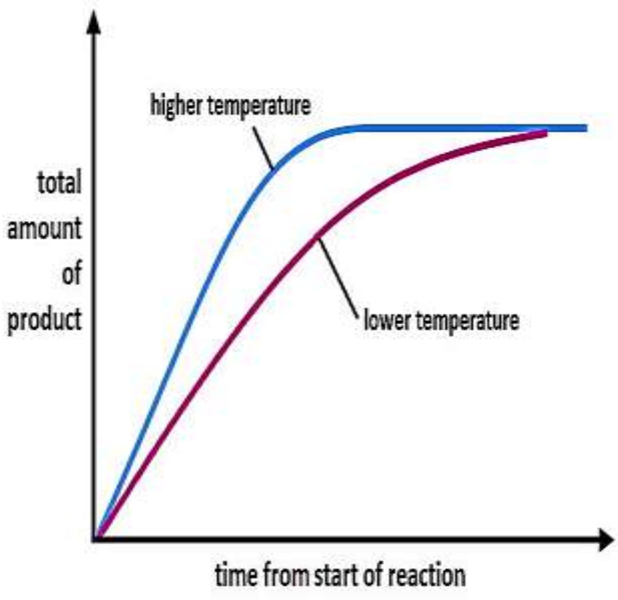
When the **temperature** of the reaction mixture is increased,

- the **average kinetic energy of particles is increases.**
- More molecules gain **sufficient/enough kinetic energy** OR more molecules have **kinetic energy greater than the activation energy.**
- More particles **collide with the correct orientation.**
- More **effective collisions per unit time**.
- Rate of reaction increases



- ❖ When reactants are heated, **more particles have kinetic energy > than the activation energy** (the yellow shaded area is bigger) and collide with correct orientation.
- ❖ More effective collisions take place per second and the collisions are more energetic.
- ❖ The reaction rate increases.

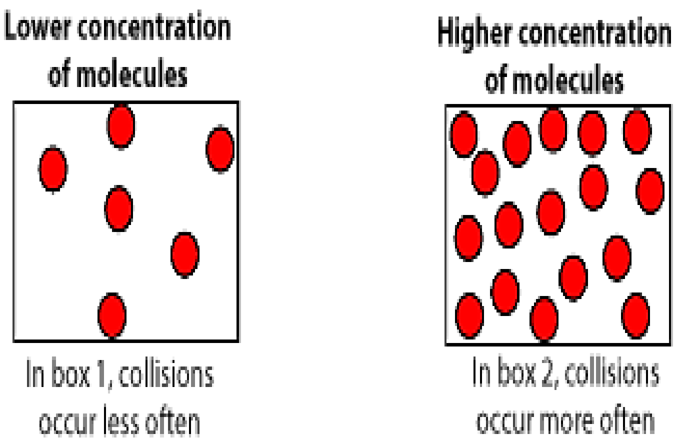


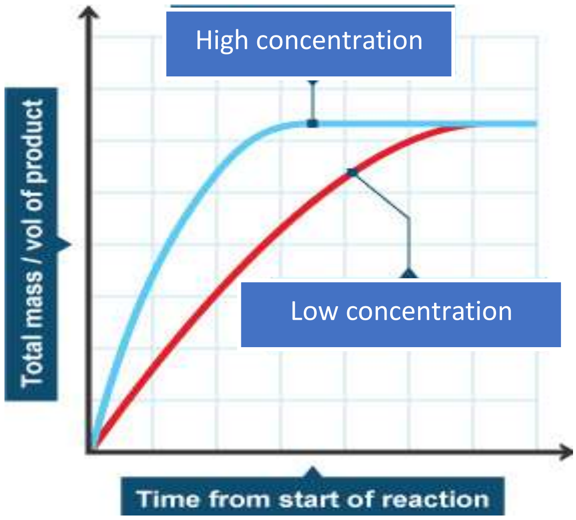


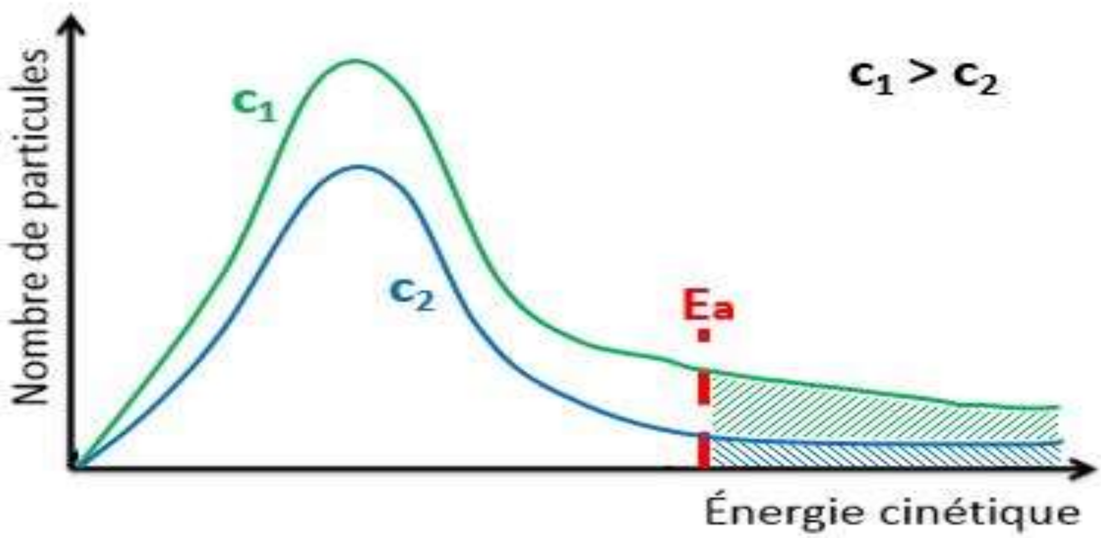
Concentration (solutions and gases)

An increase in **concentration of reactants**

- There are **more particles per unit volume**.
- More particles collide more frequently.
- More **effective collisions per unit time**
- The rate of reaction increases.





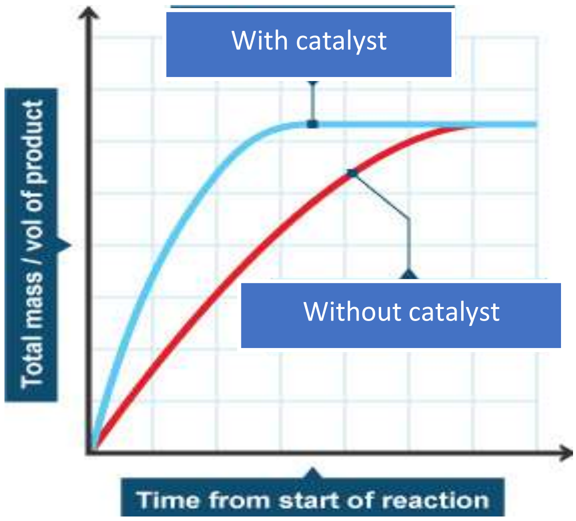


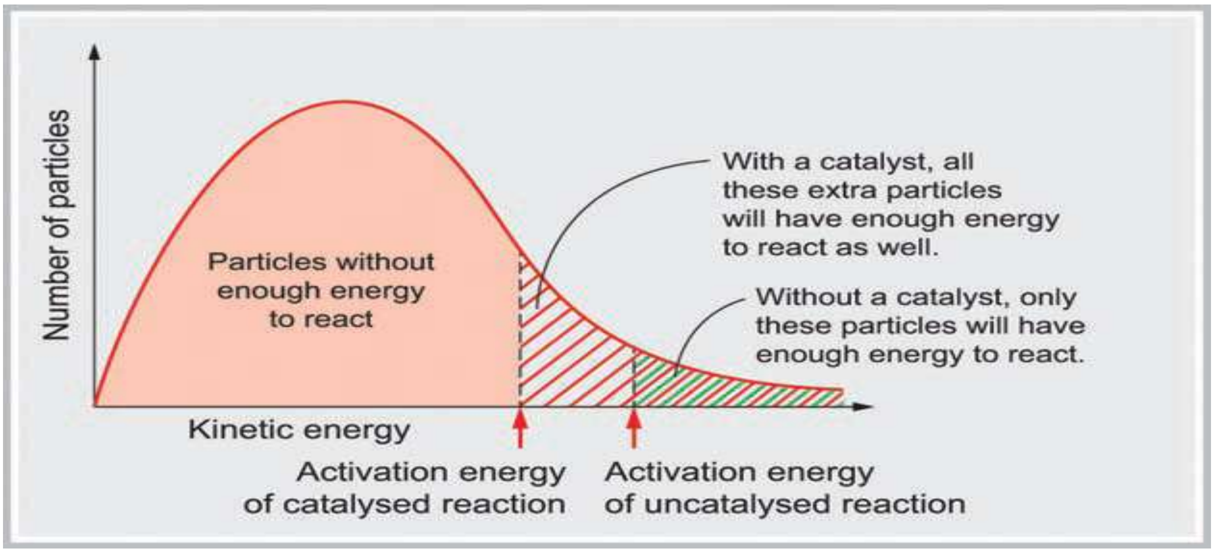
ADDITION OF A CATALYST

If a suitable catalyst is used during a reaction

- A catalyst provides an alternative **pathway of lower activation energy**.
- More molecules have **sufficient / enough kinetic energy.**
- More particles collide with **correct orientation.**
- More effective **collisions per unit time.**
- Rate of reaction increases.

- **Positive catalyst** as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.
- **Catalyst increases the rate of a reaction** by providing an alternative path of lower activation energy. It therefore decreases the **net/total activation energy.**

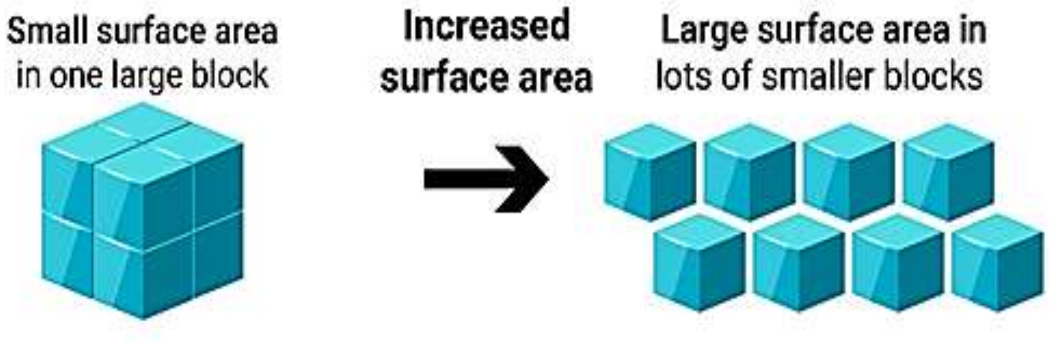




SURFACE AREA (of Solids reactants)

When a solid reactant is more finely divided,

- There is a greater surface area for collisions to occur.
- More particles with more contact points.
- More effective collisions per (unit) time.
- Rate of reaction increases.



NATURE OF REACTANTS

- Reactions between ionic compounds are usually much faster than those involving compounds where covalent bonds must be broken, and new ones formed.
- Many organic reactions are slow because of large number of covalent bonds involved.
- Organic molecules are large, which causes the number of effective collisions to be much lower.
- Metals that are higher up in the reactivity series (like Mg, Na) react faster than those lower down the reactivity series

Experimental Technique 1:
Measuring the volume of a gas product.

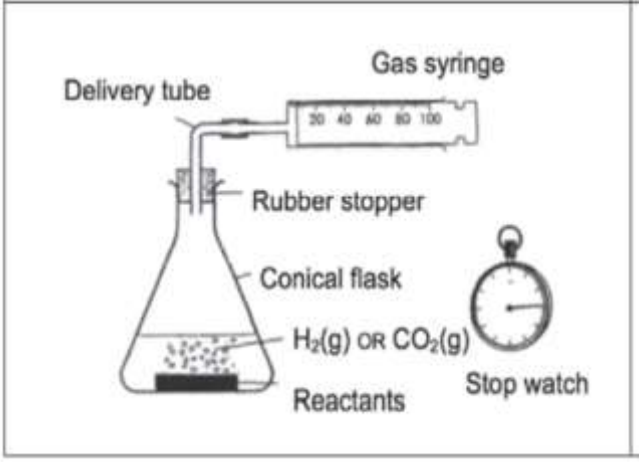
$$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$$

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

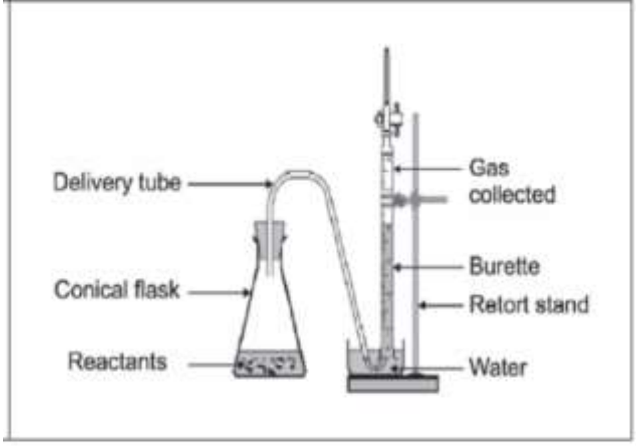
OR

$$2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$$

Measuring volume with a gas syringe:



Measuring volume by the downward displacement of water

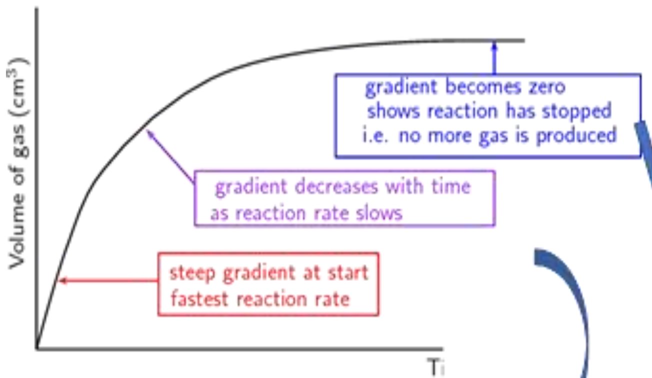


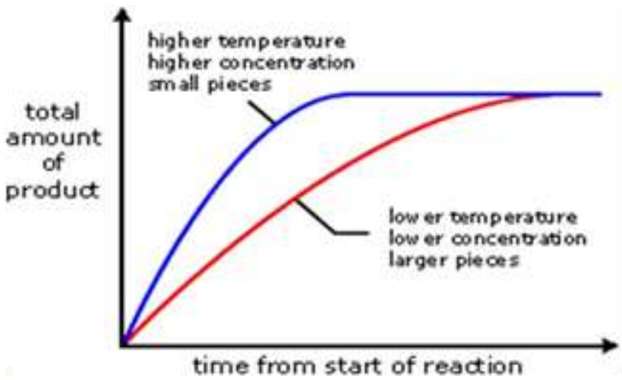
The rate of the reaction is determined by **measuring the volume of the gas produced** (the dependent variable) in specific time intervals (the independent variable).

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.

The volume of gas collected at set time intervals.





When the limiting reactant has been used up (all of it has reacted)

- the reaction is complete and
- no more products are produced so
- no more gas escapes from the system
- the mass remains constant

The gradients of the graphs indicate the rates of the reactions.

The steeper (more vertical) the gradient of the graph, the higher the reaction rate, because more happens in less time.

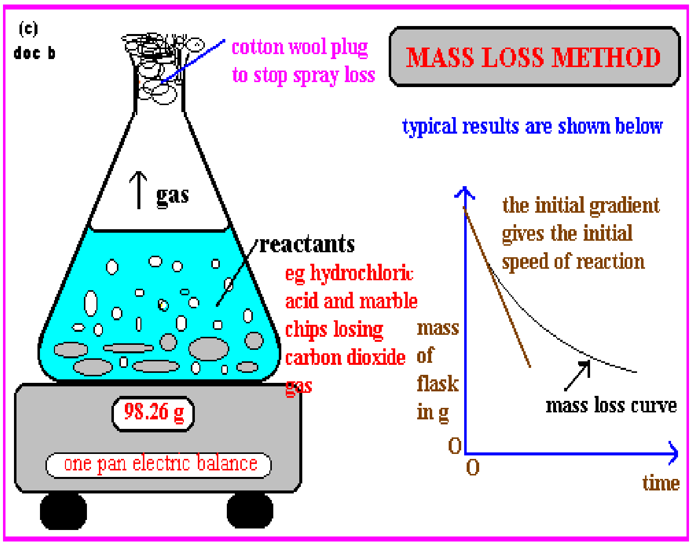
Experimental Technique 2:
Measuring the total mass of reactants and the mass loss:

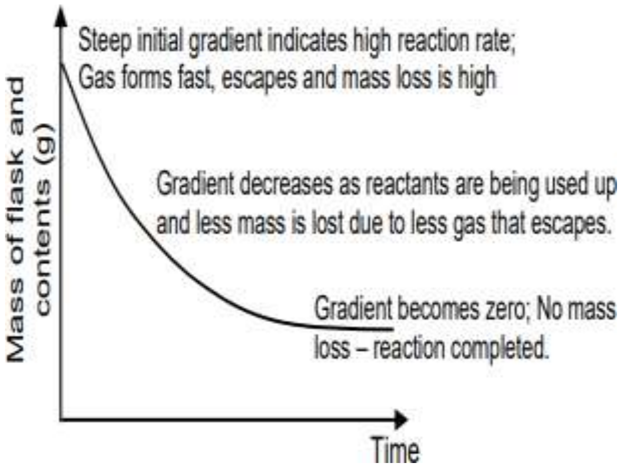
$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$

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

OR

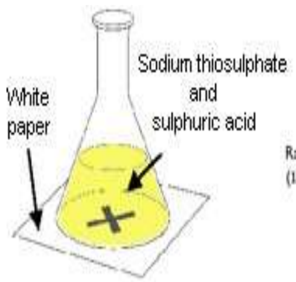
$2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$

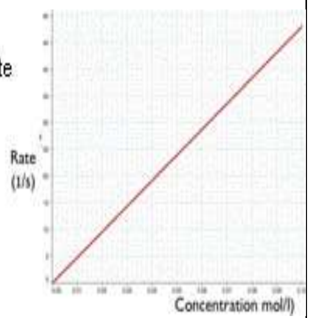


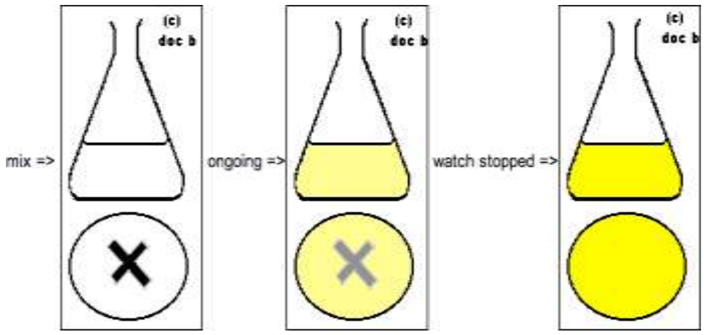


Experimental Technique 3:
Measuring turbidity.:

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





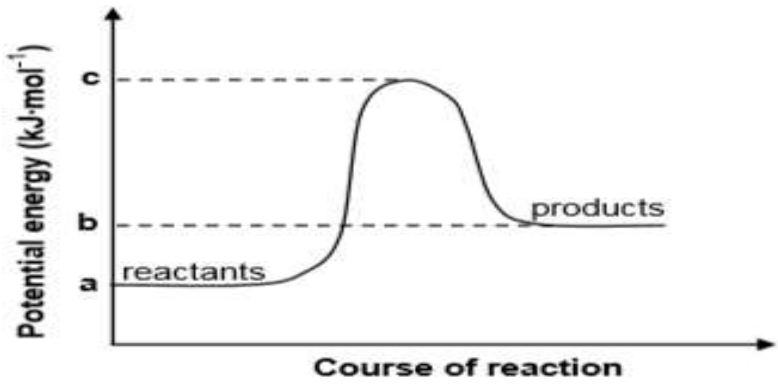


Sodium thiosulphate reacts with **diluted hydrochloric** acid to form a **yellow sulphur precipitate** (cloudysuspension).
The time taken for the formation of sulphur precipitate to cover the cross (mark X) until it disappears fromthe sight can be used to measure the rate of reaction.

ACTIVITY 1: MULTIPLE-CHOICE 12 Marks,12 minutes

Various options are provided as possible answers to the following questions. Choose the answer and write down only the letter (A–D) next to the question numbers (1.1 to 1.6) in the ANSWER BOOK, e.g. 1.5 D.

The potential energy graph for a hypothetical chemical reaction is shownbelow



1.1 What type of reaction is taking place and what are the correct methods to calculate ΔH and E_A?

	TYPE OF REACTION	△H	E_A
A	Exothermic	b – a	c – b
B	Endothermic	b – a	c – a
C	Endothermic	a – b	a – c
D	Exothermic	a – b	b – c

(2)

1.2 A potential energy diagram can be used to show the activation energy (E_A)
and the heat of reaction (ΔH) of a reaction.

Which ONE of the following combinations of values of E_A and ΔH CANNOT be obtained for any reaction?

	E_A ($kJ \cdot mol^{-1}$)	**ΔH ($kJ \cdot mol^{-1}$)**
A	50	-100
B	50	+100
C	100	+50
D	100	-50

(2)

Consider the balanced equation for the reaction between magnesium powder and EXCESS dilute hydrochloric acid, HCℓ(aq):

$$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$$

1.3 Which ONE of the following will NOT increase the rate of this reaction?

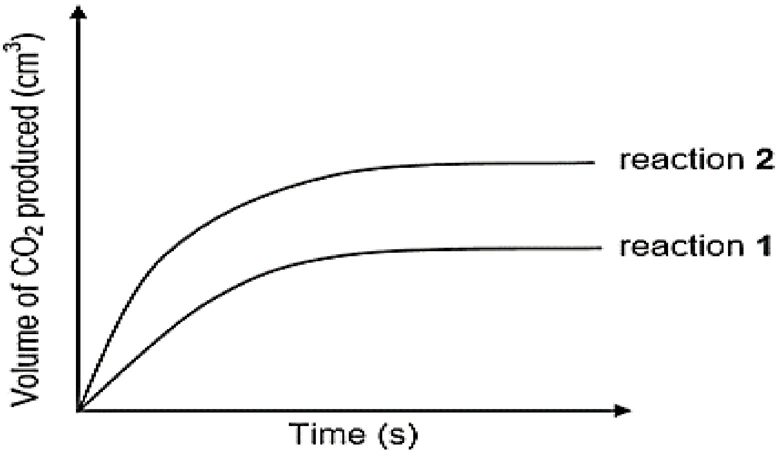
A Increasing the volume of HCℓ(aq)

B Increasing the temperature of HCℓ(aq)
C Increasing the concentration of HCℓ(aq)
D Adding more magnesium powder (2)

1.4 Which ONE of the following statements is the CORRECT definition for the rate of a reaction?

A The time taken for the reaction to take place
B The speed at which the reaction takes place
C The rate of change in concentration of the products or reactants
D The rate of change in concentration of the products or reactants per unit time (2)

1.5 Two DIFFERENT samples of IMPURE $CaCO_3$ of EQUAL masses react with0,1 mol·dm^{-3} H_2SO_4. Assume that the impurities do not react.
The graph below shows the volume of CO_2(g) produced for each reaction.



When compared to reaction **2**, which ONE of the following statements BEST explains the curve obtained for reaction **1**?

A The temperature is higher in reaction **1**.
B The surface area is greater in reaction **2**.
C The amount of impurities is greater in reaction **2**.
D The amount of impurities is greater in reaction **1**. (2)

1.6 The equation below represents a hypothetical reaction.

$$A(g) + B(g) \rightleftharpoons C(g) \quad \Delta H = -50 \text{ kJ·mol}^{-1}$$

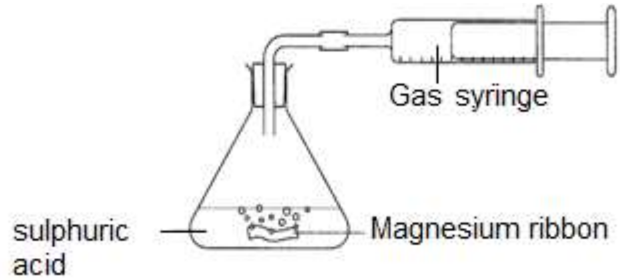
The activation energy for the REVERSE reaction is 110 kJ·mol^{-1}.
Which ONE of the following is the activation energy (in kJ·mol-1) for the FORWARD reaction?

A 50
B 60
C 110
D 160 (2)

ACTIVITY 1 **15 minutes**

Learners use the apparatus below to investigate how the surface area of a reactant affects the rate of reaction. They use magnesium metal and excess dilute sulphuric acid.

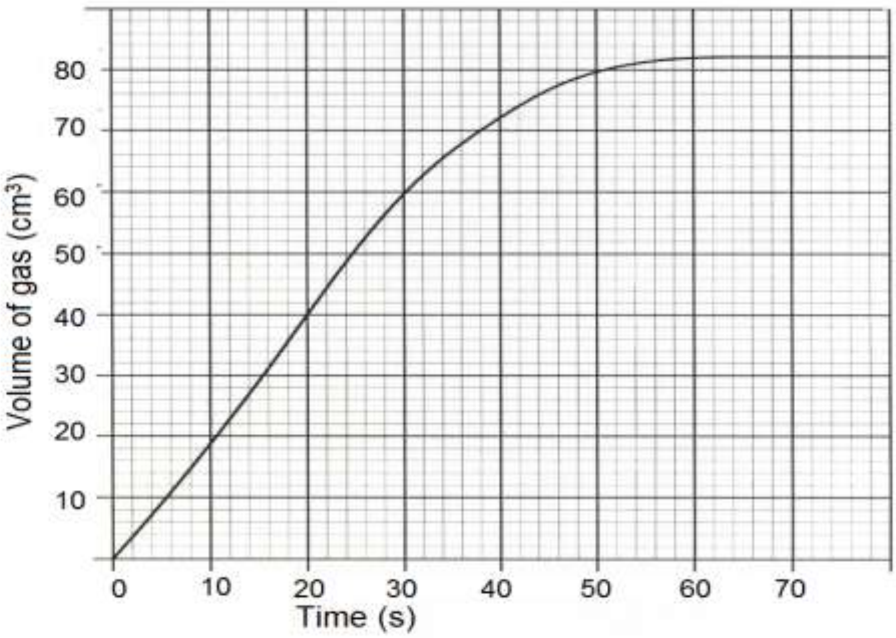
During the reaction, the gas that forms is collected in the gas syringe.



Experiment	Mass of Mg in grams	State of division of Mg
I	20	ribbon
II	20	powder

1.1 Write down the dependent variable for this investigation. (1)

The graph obtained for Experiment I is shown below.



1.2 Use the graph to calculate the rate of the reaction (in $cm^3 \cdot s^{-1}$) for the first 30 seconds. (3)

1.3 Will the rate of the reaction at 50 s be GREATER THAN, LESS THAN or EQUAL TO the rate calculated in QUESTION 5.2?
Write down a reason for the answer. (2)

1.4 Predict how the gradient of the results of EXPERIMENT **II** would compare to the gradient of the graph of EXPERIMENT **I,** plotted above, for the time interval between, t = 0 s and t = 30 s.
Write only INCREASE, DECREASE or NO CHANGE. (1)

1.5 Use the collision theory to explain how the increase in surface area of the magnesium metal affects the rate of the reaction. (3)

The balanced equation for the reaction is:

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$$

1.6 The 20 g of magnesium metal reacts with 100 cm^3 dilute sulphuric acid with a concentration of 1 $mol \cdot dm^{-3}$.
Calculate the mass of magnesium metal that remains after the reaction has run to completion (stopped). (5)
[15]

ACTIVITY 2 **13 minutes**

Learners use the reaction between sodium carbonate (Na_2CO_3) and a 0,1 $mol \cdot dm^{-3}$ sulphuric acid solution to investigate reaction rate.

They pour 150 cm^3 of the sulphuric acid solution into a beaker and add ENOUGH sodium carbonate powder to neutralise the acid. The temperature of the reaction mixture is kept at 0 °C.

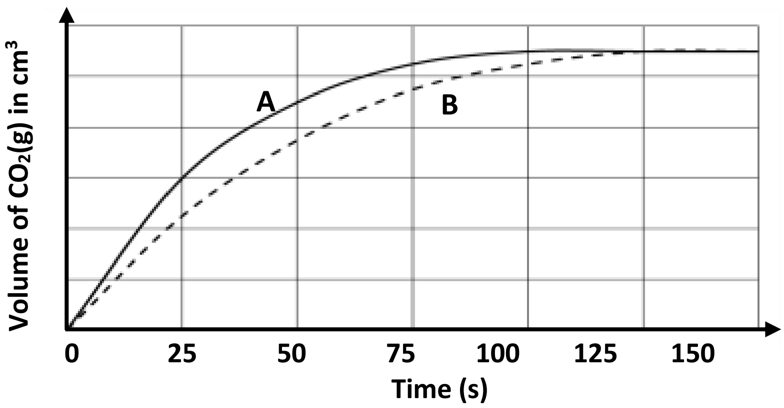
The balanced equation for the reaction is:

$$\mathbf{Na_2CO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell) + CO_2(g)}$$

2.1 Define the term *reaction rate* in words. (2)

Graph **A** (solid line) below shows the volume of $CO_2(g)$ formed as a function of time.

Graph of volume of $CO_2(g)$ formed versus time



2.2 How long (in seconds) did the reaction represented by graph **A** take to reach completion? (1)

2.3 How does the reaction rate of the reaction represented by graph **A** at t = 5 s compare to that at t = 25 s? Write down HIGHER THAN, LOWER THAN or EQUAL TO. Use the collision theory to explain the answer. (3)

2.4 Calculate the maximum volume of $CO_2(g)$, in dm^3, that can be produced by this reaction at STP. (5)

2.5 The same reaction is now repeated using the same mass of Na_2CO_3 and the same volume of the 0,1 $mol \cdot dm^{-3}$ H_2SO_4. The volume of $CO_2(g)$ formed as a function of time is represented by graph **B** above.

Write down TWO possible changes that could have been made to the reaction mixture. (2)

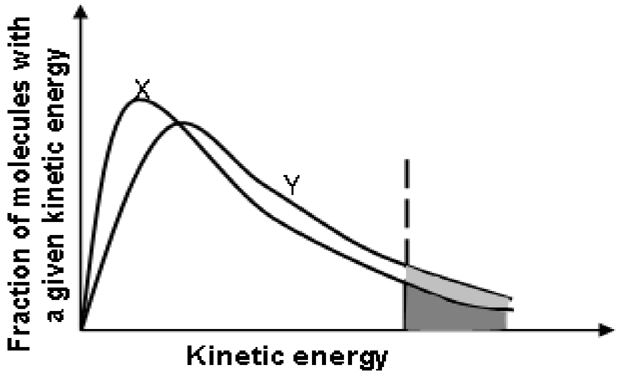
[13]

ACTIVITY 3 **9 minutes**

A learner investigates a way to increase the rate at which hydrogen gas develops in the reaction between zinc and hydrochloric acid.

3.1 By changing one reaction condition she obtains the graph below, in which:

- Curve X denotes the initial condition.
- Curve Y denotes the changed condition that produced a higher reaction rate

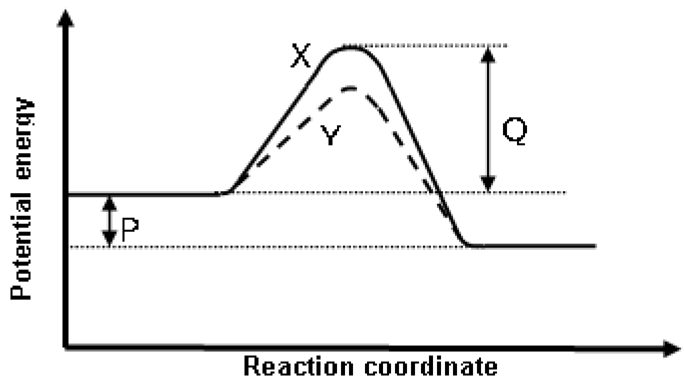


3.1.1 Which reaction condition did the learner change? (2)

3.1.2 Apply the collision theory and explain why the changed condition results in a higher reaction rate. (3)

3.2 She then changes another condition in which the effect is represented by the graph below. Once again:

- Curve X represents the initial condition.
- Curve Y represents the changed condition that resulted in a higher reaction rate



3.2.1 Which reaction condition did the learner change? (2)

3.2.2 What is the name of the energy value represented by the following:

P (1)

Q (1)

[9]

ACTIVITY 4 **17 minutes**

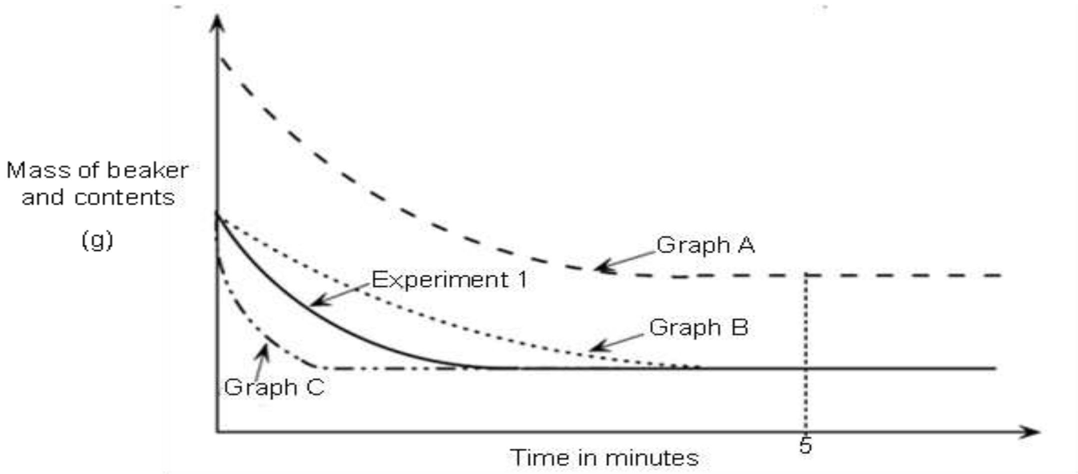
A learner investigates the various factors that influence the rate of chemical reactions. She places a sample of calcium carbonate in a beaker. The beaker is placed on a sensitive balance and an excess of hydrochloric acid (HCℓ) is added.

The learner repeats the experiment a number of times and under different conditions, always using the same volume of hydrochloric acid.

The table below summarises the different experimental conditions of four of her experiments (numbered 1 – 4)

Experiment	Mass of $CaCO_3$(g)	Concentration of HCℓ ($mol.dm^3$)	Temperature of HCℓ (^oC)	State of $CaCO_3$
1	10	2	25	granules
2	10	2	15	granules
3	20	2	25	granules
4	10	2	25	powder

During each experiment the mass of the beaker and its contents is recorded every minute. The graphs below indicate the changes in mass of the beaker and its contents during the reaction, as a function of time, for the four experiments.



4.1 Give a reason for the decrease in mass as each reaction progresses (1)

4.2 Why are all the graphs straight lines after five minutes? (2)

4.3 Use the graph and the data in the table to explain fully which ONE of the graphs, A, B or C, represents the results of

4.3.1 experiment 2? (3)

4.3.2 experiment 3? (3)

.3.3 experiment 4? (3)

4.4 Use collision theory to explain the initial shape of graph B compared to experiment 1. (3)

4.5 Explain why the mass indicated at 5 minutes in graph A is higher than the other graphs, while the other graphs indicate the same mass after 5 minutes (2)

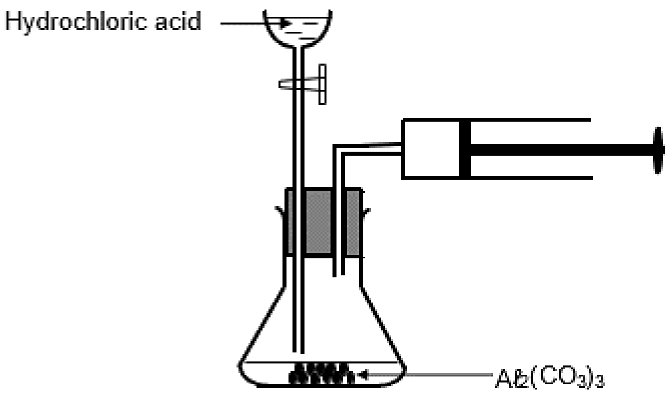
[17]

ACTIVITY 5 **26 minutes**

Two experiments, **I** and **II**, are conducted to investigate one of the factors that affects the rate of the reaction of aluminium carbonate, $Aℓ_2(CO_3)_3$, with EXCESS hydrochloric acid, HCℓ. The balanced equation for the reaction is:

$$Aℓ_2(CO_3)_3(s) + 6HCℓ(aq) \rightarrow 2AℓCℓ_3(aq) + 3H_2O(ℓ) + 3CO_2(g)$$

The apparatus used is shown below.



The reaction conditions used for each experiment are as follows:

Experiment I:
100 cm^3 of 1,5 $mol \cdot dm^{-3}$ HCℓ(aq) reacts with 0,016 mol $Aℓ_2(CO_3)_3$ granules at 25 °C

Experiment II:
50 cm^3 of 2 $mol \cdot dm^{-3}$ HCℓ(aq) reacts with 0,016 mol $Aℓ_2(CO_3)_3$ granules at 25 °C

5.1 Define the term *rate of a reaction* (2)

5.2 Using the experimental setup above, state the measurements that must be made to determine the rate of this reaction (2)

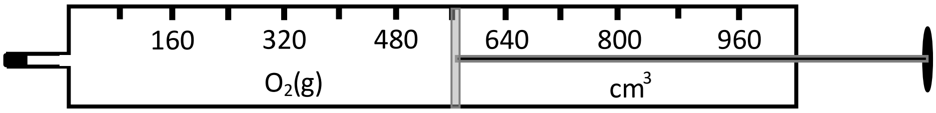
5.3 Use the collision theory to explain how the average reaction rate in **Experiment I** differs from the average reaction rate in **Experiment II**. (3)

The average rate of the reaction in **Experiment II** during the first 2,5 minutes is 4,4 x 10^{-3} $mol \cdot min^{1}$

5.4 Calculate the number of moles of $A\ell_2(CO_3)_3$ that remains in the flask after 2,5 minutes. (3)

5.5 Calculate the maximum volume of $CO_2(g)$ that can be prepared at 25 °C in **Experiment I**. Take molar gas volume at 25 °C as 24 000 $cm^3 \cdot mol^{-1}$ (3)

5.6 The volume of oxygen gas, $O_2(g)$, produced in experiment **B** during the first 36 s is collected in a syringe, as shown below.



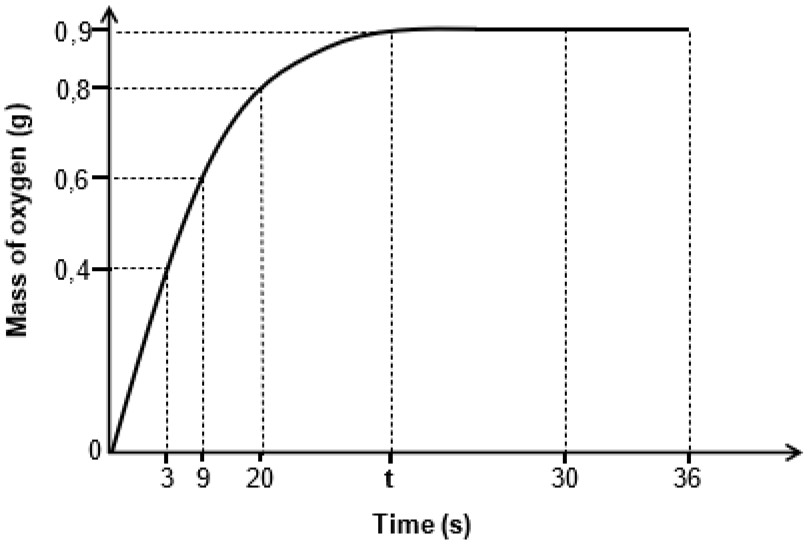
5.6.1 Write down the volume of $O_2(g)$ collected in the syringe.

The balanced equation for the reaction is:

$$2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$$

5.6.2 Calculate the mass of water, $H_2O(\ell)$, that was produced during the first 3,6 s. Take the molar gas volume to be 24 000 $cm^3 \cdot mol^{-1}$ at 25 °C.

5.7 The graph below, NOT drawn to scale, is obtained for the mass of oxygen gas produced over a period of time in experiment **A**.



Use the information in the graph to answer the following questions:

5.7.1 Write down the rate of production of oxygen gas for the interval 30 s to 36 s. (1)

5.7.2 Will the rate of the reaction in the interval 3 s to 9 s be GREATER THAN, SMALLER THAN or EQUAL TO the rate of the reaction in the interval 9 s to 20 s? (1)

5.7.2 The average rate of decomposition of hydrogen peroxide is 2,1 x

10^{-3} mol·s^{-1}. Calculate the value of time **t** on the graph. (5)

[26]

ACTIVITY 6 **16 minutes**

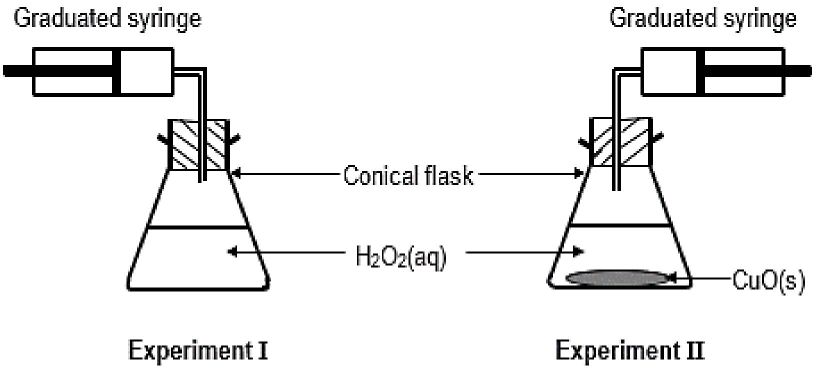
The apparatus below is used to investigate one of the factors that affects the rate of decomposition of hydrogen peroxide, H_2O_2. The balanced equation for the reaction is:

$$2H_2O_2(aq) \rightarrow 2H_2O(\ell) + O_2(g)$$

Two experiments are conducted. The reaction conditions are as follows:

Experiment I: 50 cm^3 of hydrogen peroxide is allowed to decompose at 30 °C.

Experiment II: 50 cm^3 of hydrogen peroxide decompose at 30 °C in the presence of copper (II) oxide powder (CuO).



The results of the investigation are summarised in the table below.

Experiment	Total volume of O_2 produced (dm^3)	Time taken for complete decomposition (min.)
I	0,4	12,3
II	0,4	5,8

6.1 For this investigation, write down the function of the:

For this investigation, write down the function of the:

6.1.1 Syringe (1)

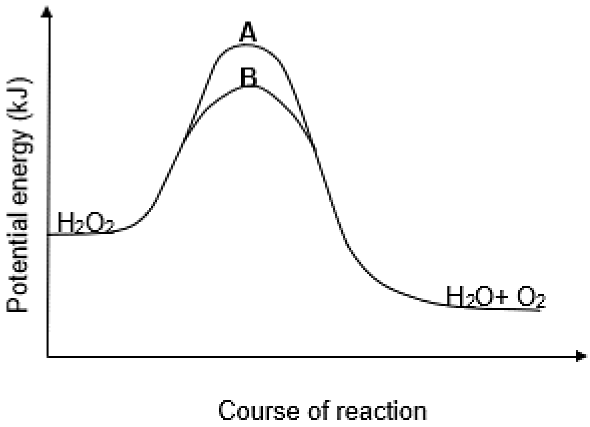
6.1.2 Copper (II) oxide (1)

6.2 How will you know when the reaction is completed? (1)

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

6.4 Use the collision theory to fully explain the difference in reaction rates of experiment I and experiment II. (3)

6.5 The graphs below show changes in the potential energy during the decomposition of hydrogen peroxide in experiment I and experiment II.



6.5.1 Is energy ABSORBED or RELEASED during this reaction? Give a reason for the answer. (2)

6.5.2 Which ONE of the curves, A or B, represents experiment II? (1)

6.6 Calculate the rate, in mol·dm^{-3}·min^{-1}, at which 50 cm^3 of hydrogen peroxide decomposes in experiment II. Assume that 1 mole of gas occupies a volume of 25 dm^3 at 30 °C. (6)

[16]

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