KWAZULU-NATAL PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS) SUPPORT DOCUMENT

GRADE 12

PHYSICAL SCIENCE

SUPPORT DOCUMENT

JIT

2021

FORCES AND NEWTON'S LAWS

At the end of the session learners must:

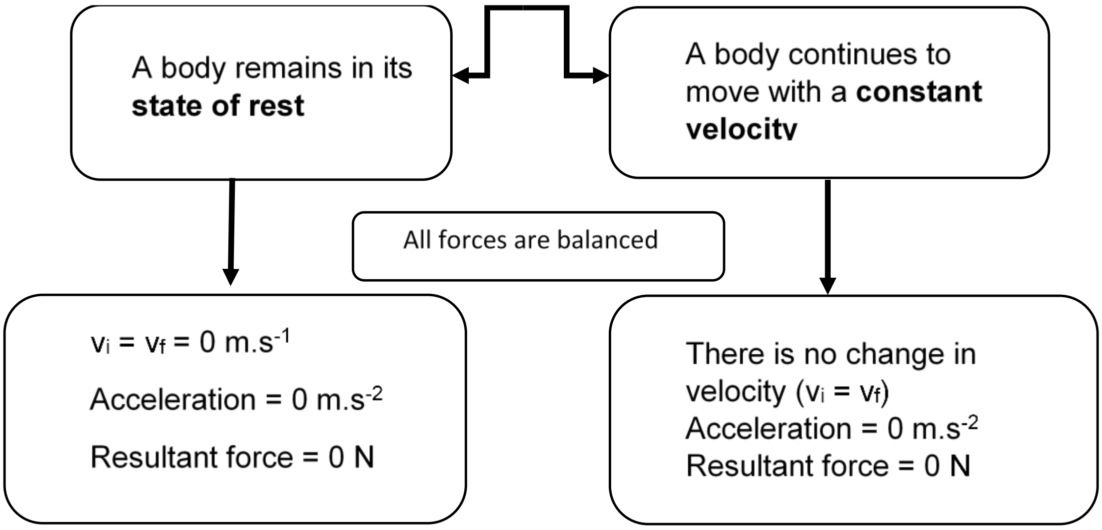
- Define normal force, frictional force, static frictional force and kinetic frictional force
- Solve problems using f = μN
- Draw the force diagram and free-body diagram
- Resolve a two-dimensional force into its parallel (x) and perpendicular (y) components
- Determine the resultant/net force of two or more forces.
- State Newton's first, second and third law of motion
- State Newton's Law of Universal Gravitation
- Calculate acceleration due to gravity on a planet
- Calculate the weight of an object on other planets with different values of gravitational acceleration
- Describe weight and mass
- Explain weightlessness

CORE CONCEPTS AND DEFINITIONS NB: (In relation to Examination guidelines)

- **Normal force, N**, as the force or the component of a force which a surface exerts on an object with which it is in contact with, and which is always perpendicular to the surface.
- **Frictional force, f**, as the force that opposes the motion of an object and which acts parallel to the surface.
- **Static frictional force, f_s**, as the force that opposes the tendency of motion of a stationary object relative to a surface.
- **Kinetic frictional force, f_k**, as the force that opposes the motion of a moving object relative to a surface.
- **Newton's First Law of Motion**, a body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it.
- **Newton's Second Law of Motion**, when a resultant/net force acts on an object, the object will accelerate in the direction of the force at an acceleration directly proportional to the force and inversely proportional to the mass of the object.
- **Newton's Third Law of Motion**, when object A exerts a force on object B, object B Simultaneously exerts an oppositely directed force of equal magnitude on object A
- **Newton's Law of Universal Gravitation**, each body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.
- **Weight**, as the gravitational force, in newton (N), exerted on an object.
- **Mass,** as the amount of matter in a body measured in kilogram (kg).
- **Weightlessness,** as the sensation experienced when all contact forces are removed i.e. no external objects touch one's body.

Newton's first Law of motion

A body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it.



Newton's Second Law of Motion

When a resultant/net force acts on an object, the object will accelerate in the direction of the force at an acceleration directly proportional to the force and inversely proportional to the mass of the object.

Mathematically expressed as: $\mathbf{F_{net} = ma}$

Where: ***F_{net}*** **- net force, measured in Newton's(N)**

***a*- acceleration, measured in metres per second squared (m·s^{-2})**

***m*-mass of the object, measured in kilograms (kg)**

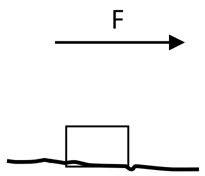
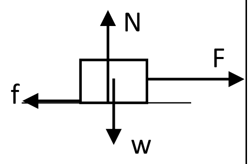
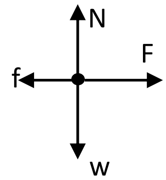
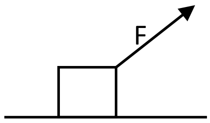
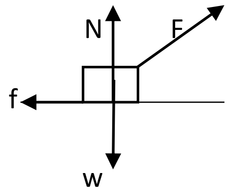
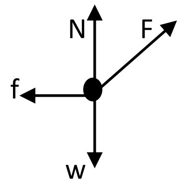
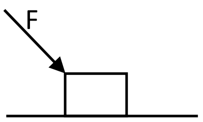
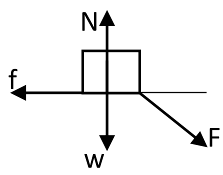
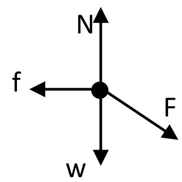
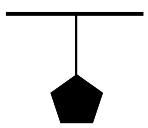
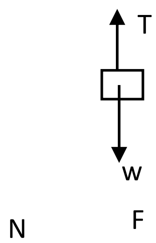
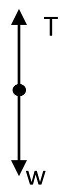
A net force acts on an object. $\mathbf{F_{net} \neq 0}$ **N** Forces acting on the object are not balanced Net force cause the object to accelerate in the direction of the force. Acceleration and net force go in the same direction. There is a change in velocity **($v_i \neq v_f$). a ≠ 0 m·s^{-2}**

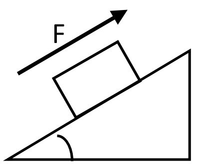
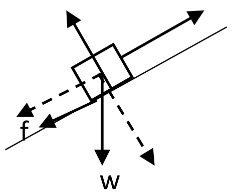
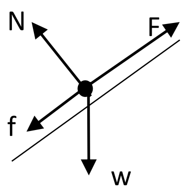
$\boldsymbol{a \; \alpha \; F_{net}}$ When the net force increases, the acceleration also increases. vice versa

$\boldsymbol{a \; \alpha \; \frac{1}{m}}$ When the mass increases, the acceleration decreases.

FREE BODY DIAGRAMS/FORCE DIAGRAMS VS THE NET FORCE

The learners understanding of how to draw either a force diagram or a free body diagram indicating forces acting on an object, must go together with an understanding on how to expressed F_{net} in terms of the forces drawn in the diagram.

Plane	**Diagram**	**Force diagram**	**Free-body diagram**	**F_{net}=ma**
Horizontal				F_{net}=ma F+(-f)=ma **(N=w=mg)**
Horizontal at an angle				F_{net}=ma $F_{//}$-f=ma **(N=w-$F_{\perp}$)**
				F_{net}=ma $F_{//}$-f=ma **(N=w+$F_{\perp}$)**
Vertical				F_{net}=ma w-T=ma

Inclined				F_{net}=ma
				F-f-$w_{//}$=ma
				$w_{//}$=mgSinθ
				$w_{\perp}$=mgCosθ
				(N=$w_{\perp}$=mgCosθ)

Newton's Third Law of Motion

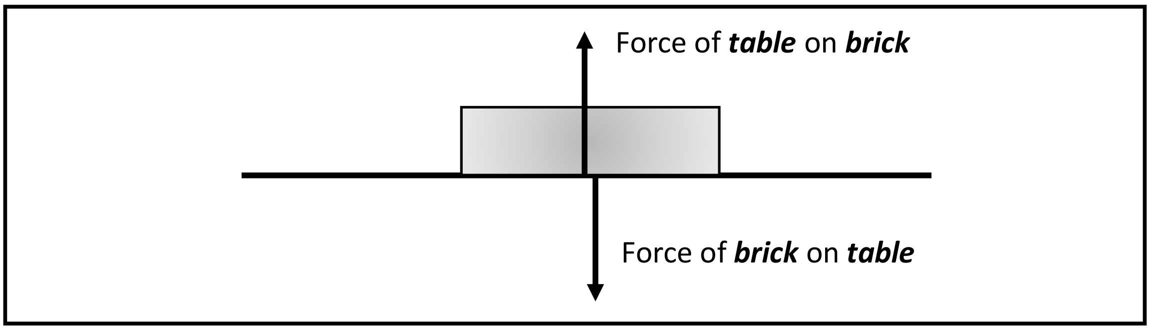
When object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A.

- The forces are **equal in magnitude**
- The forces act in the same straight line but in the **opposite directions** on different objects
- The forces do not cancel each other, as they act on **different objects**

For any two objects **A** and **B**: $F_{AonB} = -F_{BonA}$

Example

The force diagram shows the pair of forces when a brick rests on the table



Newton's Law of Universal Gravitation

Each body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

$$F = G\frac{m_1 m_2}{r^2}$$

Where:

F-force between objects, measured in Newtons(N)

G-Universal Gravitational constant ($G = 6.67\times10^{-11}\ Nm^2kg^{-2}$)

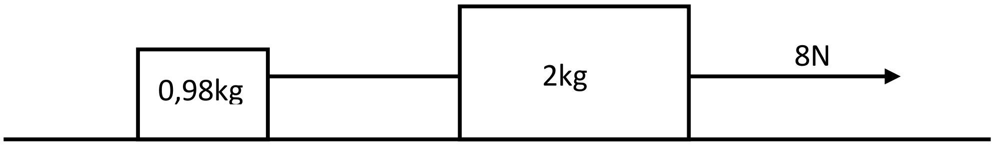
m_1m_2-masses of objects in kilograms(kg)

r-distance between the objects in metres(m)

WORKED EXAMPLES

EXAMPLE 1

A 8 N force pulls horizontally on a block of mass 2 kg. The block slides on a smooth horizontal surface. The first block is connected by a horizontal weightless inelastic string to a second block of mass 0,98 kg on the same surface.



1.1 Draw a free-body diagram for each block. (7)

1.2 Determine the acceleration of the blocks (7)

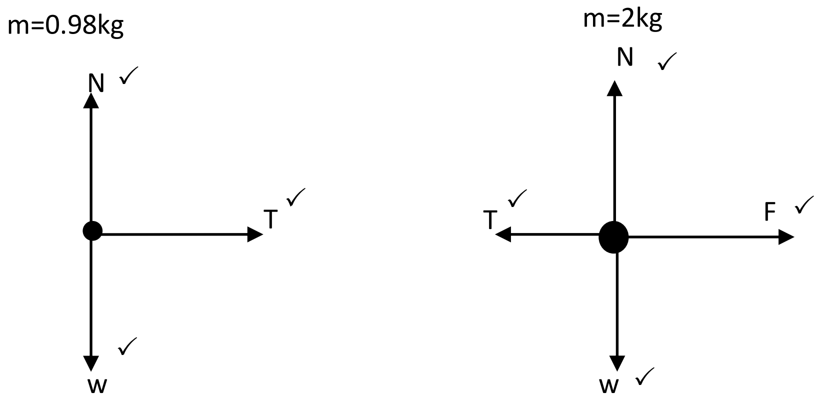
1.3 Determine the tension in the string. (3)

1.4 The mass of the first block is increased. State whether the tension in the string will INCREASE, DECREASE OR STAY THE SAME. (1)

[18]

SOLUTIONS:

1.1.



(7)

1.2. $F_{net}=ma$ ✓

For 0.98kg block

$T=ma$

$T=(0.98)a$---------(1) ✓

For 2kg block

$F-T=ma$

$F_{net}=ma$

$F_{net}=(m_1+m_2)\ a$

$8 = (0.98+2)\ a$

$8 = 2.98a$

$a = 2.68\ m.s^{-2}$

8-T=(2)a-----------(2) ✓

(1) To (2)

(8-0,98a ✓ = 2a ✓

a = 2.68 m.s^{-2} ✓✓ (7)

1.3. m=0,98kg block

T = ma ✓

T = (0,98)(2,68) ✓

T = 2,63N ✓

m = 2kg block

F_{net} = ma

F-T = ma

8-T = (2) (2,68)

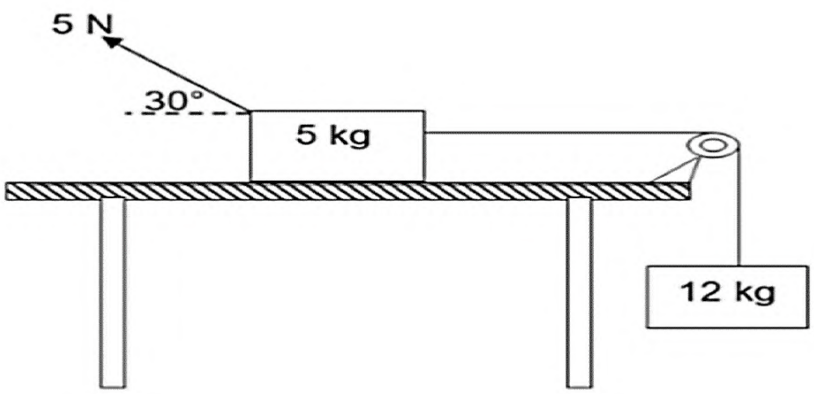
-T = -2,63N

T = 2,63N (3)

1.4. Stays the same. ✓ (1)

EXAMPLE 2

A 5 kg block, resting on a rough horizontal table, is connected to a 12 kg block by a light inextensible string that passes over a light frictionless pulley. A 5 N force is applied to the 5 kg block at 30° to the horizontal as shown in the diagram below.



2.1. Draw a labelled free-body diagram showing ALL the forces acting on the 5kg. The coefficient of kinetic friction (μk) between the 5 kg block and the surface is 0,2. Use Newton's Laws to calculate the magnitude of the: (5)

2.2. Normal force acting on the 5 kg block. (3)

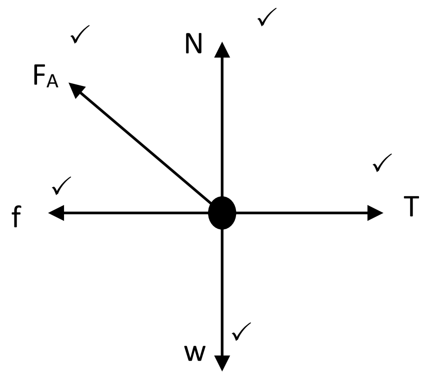
2.3. Kinetic frictional force acting on the 5 kg block. (3)

2.4. Acceleration of the 5 kg block. (4)

[15]

SOLUTIONS

2.1.



(5)

2.2. $F_N + F_{AY} = w$

$F_N + (5\times\sin30^0)$ ✓ = (5)(9,8) ✓

F_N = 46,5 N ✓ (3)

2.3. $f_k = \mu N$ ✓

$f_k = 0,2\times46,5$ ✓

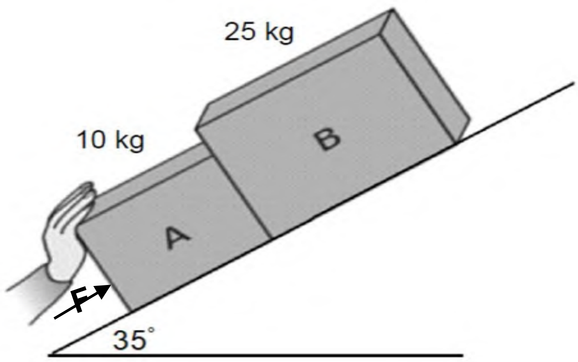
f_k = 9,3 N ✓ (3)

2.4.

At 5 kg block B:	At 12 kg block A
Fnet = ma	W + (-T) = ma
T + (-f) + (-F_{AX}) = ma	mg – T = 12 × a
T = 5 × a ✓	12 × 9,8 – T = 12 × a
T = 5a + 9,3 + 5 cos30°✓..(1)	T = 117,6 – 12a✓.. (2)
103,96987 = 17a	(1) = (2):
	117,6 –12a = 5a + 4,9 + 5cos30°
	117,6 – (9,3+ 5cos30°)=5a + 12a
	a = 6,12 m•s^{-2} ✓

EXAMPLE 3

Two blocks, **A** and **B**, are placed on an inclined rough surface that makes an angle of 35° with the horizontal. A force, **F**, is applied on block **A** to push the system up the incline. Block **B** experiences a frictional force of 15 N.



3.1. State Newton's Third law of motion in words. (2)

3.2. If the system accelerates at 1,5 m·s^{-2} up the force exerted by block B on block A. (6)

3.3. Draw a labelled free-body diagram of all the forces acting on block B. (4)

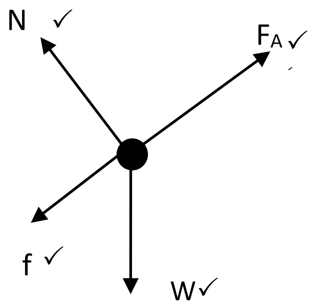
3.4. If block A experiences a frictional force of 4,5 N when the system was accelerating at 1,5 m·s^{-2}, calculate magnitude of the applied force, **F**. (4)

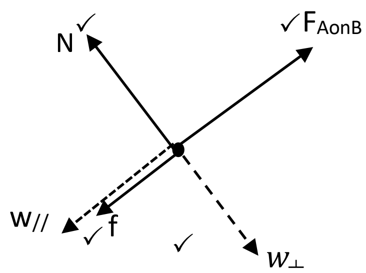
[16]

SOLUTIONS

3.1. When object A exerts a force on object B, <u>object B **simultaneously** exerts an oppositely directed force</u> of <u>equal magnitude</u> on object A.✓✓ (2)

3.2. OPTION 1 OPTION 2





$F_{net} = ma$ ✓ (4)

3.3. $F_{AonB} + f_B + w_{//} = ma$

$F_{AonB} + (-15) + (-25\times 9.8\times 0,574)$✓ $= 25\times 1,5$ ✓

$F_{AonB} – 155,63 = 37,50$

$F_{AonB} = 193,13$ N✓

$F_{AonB} = -F_{BonA}$

$F_{BonA} = -193,13$ N (6)

$F_{BonA} = 193,13$ N✓ down the slope ✓

3.4. $F_{net} = ma$

$F_{Nceba} + F_{BonA} + f_A + w_{//} = ma$ ✓

$F_{Nceba} + (-193,13) + (-4,5) + (-10×9,8×0,574)$✓ $= 10×1,5$ ✓

$F_{Nceba} – 253,88 = 15$

$F = 268,88$ N ✓ (4)

MULTIPLE CHOICE QUESTIONS

1.1 A constant net force, F, is applied to a crate which moves along a frictionless horizontal surface. Which ONE the following quantities remains constant while force F acts on the crate?

A The rate of change of velocity

B The change in momentum

C The work done on the crate

D The change in kinetic energy (2)

1.2 A spaceship experiences a weight of X on earth. It is sent into space and lands on a planet which has a mass twice that of the earth and a radius ½ that of the earth. The weight of the spaceship will be...

A 8X

B ½X

C X

D ¼X (2)

1.3 A car is moving at a constant speed. Which ONE of the following statements about the forces acting on the car is CORRECT?

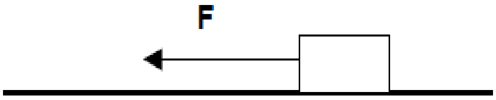
A The net force acting on the car is zero.

B There are no forces acting on the car.

C The weight of the car is equal to the normal force acting on the car.

D There is a non-zero net force acting on the car. (2)

1.4. A block, being pulled by a force **F**, and moving to the left on a rough horizontal surface, is slowing down.

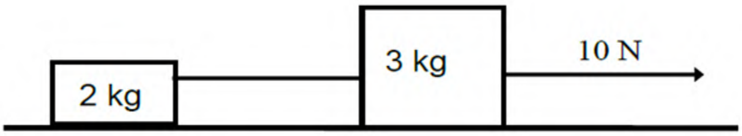


	DIRECTION OF RESULTANT FORCE	DIRECTION OF ACCELERATION
A	to the right	to the left
B	to the right	to the right
C	to the left	to the left
D	to the left	to the right

(2)

ACTIVITIES

1. Two wooden blocks of masses 2 kg and 3 kg respectively are placed on a rough horizontal surface. They are connected by a string. A constant horizontal force of 10 N is applied to the second string attached to 3 kg mass as shown in the diagram below. Assume that both strings are inextensible.



The system moves towards the right with a CONSTANT VELOCITY.

1.1. Define the term kinetic frictional force. (2)

1.2. What is the magnitude of the net force acting on the system? (1)

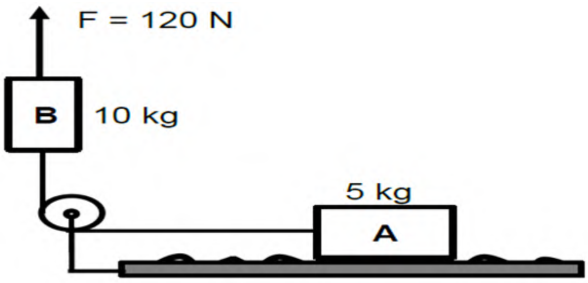
1.3. Draw a labelled free-body diagram showing ALL the forces acting on the 3 kg block as it moves towards the right. (5)

1.4. Calculate the coefficient of kinetic friction between the surface and the two wooden blocks. (4)

1.5. The 10N force is increased to 30 N so that the system now accelerates. (5)

Calculate the acceleration of the system. **[17]**

2. A block **A** of mass 5 kg, at rest on a rough horizontal table, is connected to another block **B** of mass 10 kg by means of a light inextensible string which passes over a light frictionless pulley. A force of 120 N is applied vertically upwards on block **B** as shown in the diagram below.



The coefficient of kinetic friction between the surface and block **A** is 0,3. Ignore the effects of air friction.

2.1. State *Newton's Second Law* in words (2)

2.2. Draw a labelled free-body diagram of ALL forces acting on block **B** (3)

2.3 Calculate the magnitude of the:

2.3.1 Friction force acting on block **A** (3)

2.3.2. Tension force acting on block **B** (6)

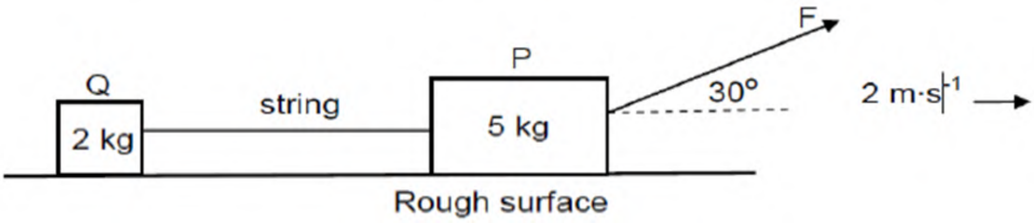
2.4 A man on the surface of planet **Y** weighs HALF his weight compared to his weight on the surface of the Earth. The mass of planet **Y** is TWICE that of the Earth.

2.4.1. State Newton's Law of Universal Gravitation in words (2)

2.4.2. Calculate the radius of planet **Y** in terms of the radius of the Earth (4)

[20]

3. Two boxes, P and Q, resting on a rough horizontal surface, are connected by a light inextensible string. The boxes have masses 5 kg and 2 kg respectively. A constant force F, acting at an angle of 30° to the horizontal, is applied to the 5 kg box, as shown below. The two boxes now move to the right at a **constant speed** of 2 m·s^{-1}.



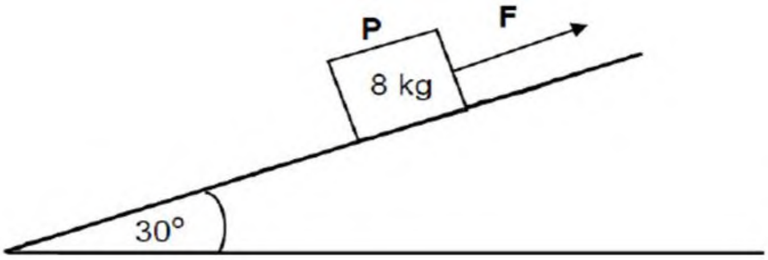
3.1. State Newton's First Law of Motion in words (2)

3.2. Draw a labeled free-body diagram for box Q (4)

3.3. Box P experiences a constant frictional force of 5 N and box Q a constant frictional force of 3 N. Calculate the magnitude of force F. (6)

[12]

4. An 8 kg block, P, is being pulled by constant force F up a rough inclined plane at an angle of 30° to the horizontal, at **CONSTANT SPEED**. Force F is parallel to the inclined plane, as shown in the diagram below.



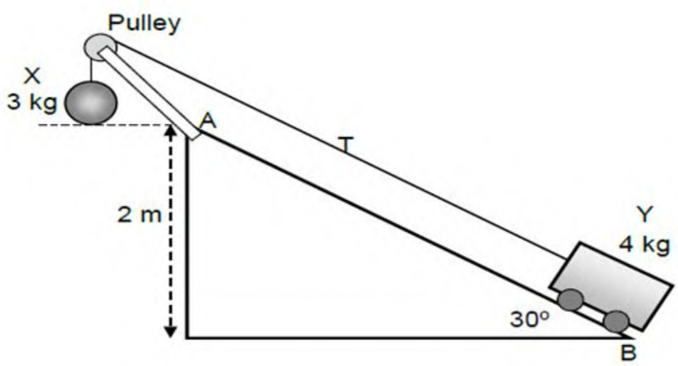
4.1. Draw a labelled free-body for block P. (4)

4.2. The kinetic frictional force between the block and the surface of the inclined plane is 20,37N. Calculate the magnitude of force F. (5)

4.3. Force F is now removed and the block ACCELERATES down the plane. The kinetic frictional force remains 20, 37N. Calculate the magnitude of the acceleration of the block. (4)

[13]

5. Ball X of mass 3 kg is attached to trolley Y of mass 4 kg by a light string which passes over a frictionless pulley as shown in the diagram. Initially the trolley is at rest on a slope AB, which makes an angle of 30° with the horizontal. When the ball is released it falls to the ground and the trolley moves 2 m up the slope accelerating at 0,43 $m \cdot s^{-2}$.



5.1. Draw a labelled free body diagram to show ALL the forces acting on the trolley as it moves up the slope. (4)

5.2. Show that a friction force of 6,79 N acts on the trolley as it moves up the slope (3)

5.3. State Newton's Second Law of motion in words. (2)

5.4. Calculate the tension T in the string (5)

5.5. Calculate the speed with which the 3 kg ball strikes the ground. (4)

VERTICAL PROJECTILE MOTION

Definitions and Key Concepts

- A **projectile** is an object which has been given an initial velocity and then it moves under the influence of the gravitational force only.
- **Free fall** is motion in which an object is moving under the influence of gravitational force only where there is no air resistance.

EQUATIONS OF MOTIONS

$v_f = v_i + a\Delta t$

$v_f^2 = v_i^2 + 2a\Delta y$

$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

$\Delta y = (\frac{v_i + v_f}{2})\Delta t$

REMEMBER:
1. Draw a sketch diagram
2. Write down given variables
3. Choose one direction of motion as positive
4. Solve

Where:

Δy= displacement in meters (m)

Δt = time in seconds (s)

v_i = initial velocity in meters per seconds (m·s^{-1})

v_f = final velocity in meters per seconds (m·s^{-1})

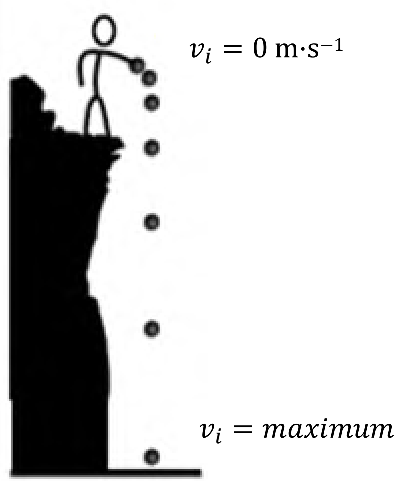
a = acceleration in meters per seconds squared (m·s^{-2})

(**NB:** $a = 9{,}8$ m·s^{-2} downwards)

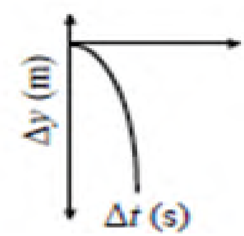
Describe the motion

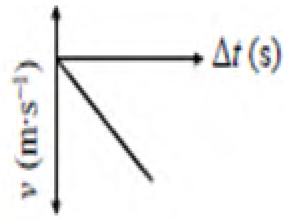
- Free falling objects dropped or released objects, has $v_i = 0$ m.s^{-1} ;depending on the velocity of the host

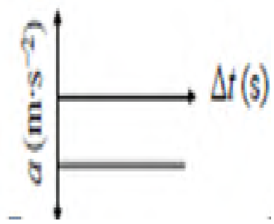
OBJECT DROPPED /RELEASED FROM A CERTAIN HEIGHT



UP AS POSITIVE

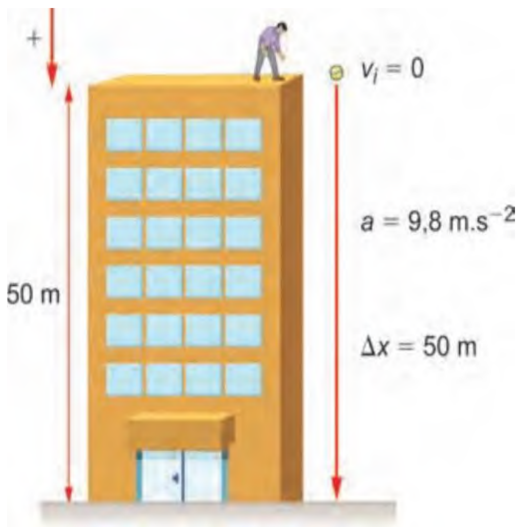






EXAMPLE 1

1. A ball is dropped from a building which is 50 m high as shown in Figure 2.6. Calculate the ball's velocity just before it hits the ground. Ignore the effects of air resistance.



SOLUTION

Given data: $v_i = 0$ m·s^{-1}

$a = +\,9{,}8$ m·s^{-2}

$\Delta y = 50$ m

$v_f = ?$

$v_f^2 = v_i^2 + 2a\Delta y$

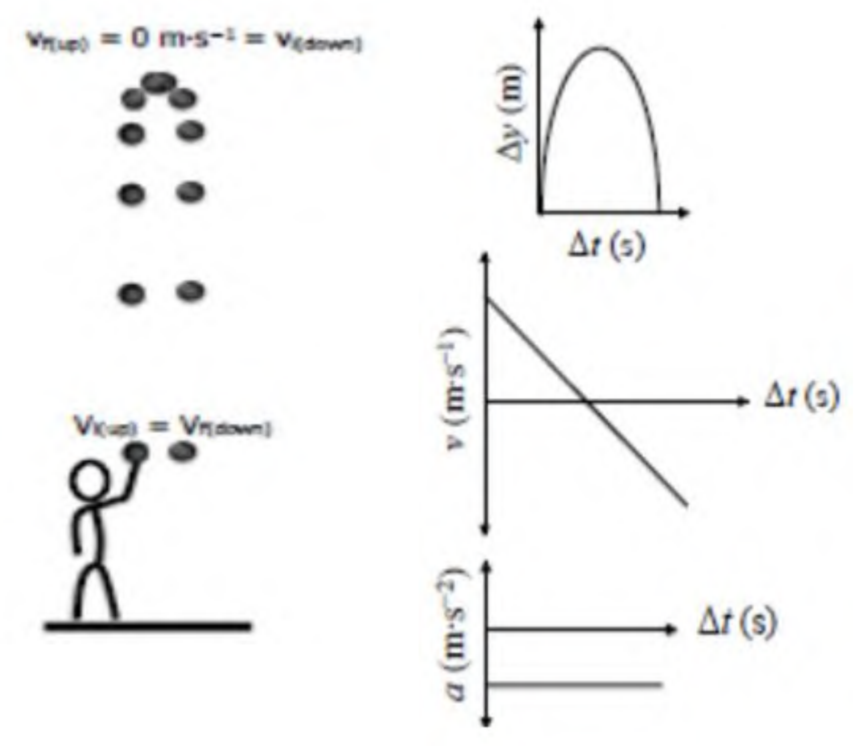
$= (0^2) + 2\,(9{,}8)(50)$

$= 980$

$v_f = 31{,}30$ m·s^{-1} downward

OBJECT THROUWN VERTICALLY UPWARD AND RETURNS TO THE SAME POSITION

- The object slows down as it is moving up in the air.
- The final velocity of the object when it reaches the throwers hand is the same in magnitude but opposite in direction as when it left the throwers hand.
- The time taken from the point of projection to maximum height is equal to the time taken from the maximum height back to the point of projection.
- The object momentarily stops at the maximum height; v = 0 m.s^{-1}



EXAMPLE 2:

An object is projected vertically upwards. 4 seconds later, it is caught at the same height (point of release) on its way downwards. Ignore all effect of friction

2.1 Calculate the velocity with which the object was projected upwards.

2.2 What is the magnitude and direction of the acceleration at the maximum height reached by the object?

SOLUTIONS

2.1 $v_f = v_i + a\Delta t$

$0 = v_i + (9,8)(2)$

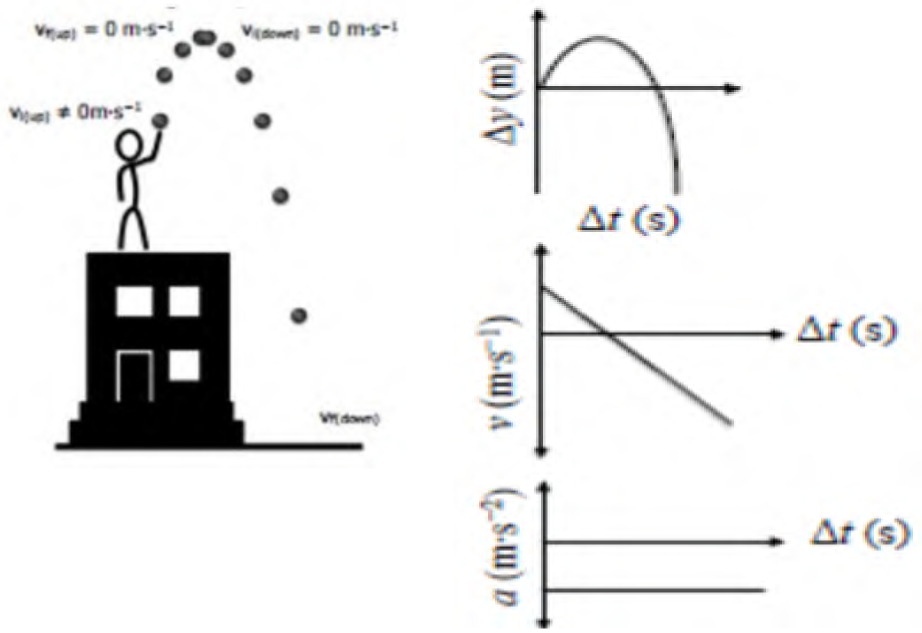
$v_i = -19,6$

$\therefore v_i = 19,6\ m\cdot s^{-1}$ upwards

2.2 $9,8\ m\cdot s^{-2}$ downwards

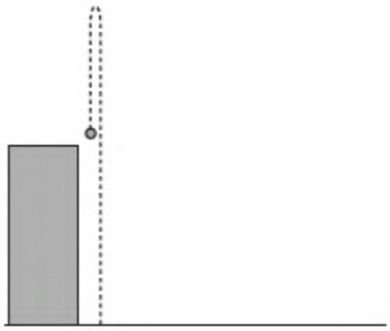
OBJECT THROWN VERTICALLY UPWARD AND PASSES THE POINT OF PROJECTION

- If the object goes beyond throwers hand, then v_f **>** v_i.
- If the object goes beyond throwers hand, time taken as it moves up is not equal to time taken as it moves down.



EXAMPLE 3

A child throws a coin vertically upwards from the window of a high building with an initial velocity of 15 m.s^{-1}. It strikes the ground travelling at 35 m.s$^{-1.}$ Ignore the effects of air resistance.



3.1 Describe the motion of the coin.

3.2 Calculate the time taken for the coin to reach its maximum height above the ground.

3.3 Calculate the time taken for the coin to reach the ground.

3.4 Calculate the height of the building.

3.5 Calculate the distance that the coin has travelled when it hits the ground.

3.6 The position of the coin relative to the top of the building at 4 s.

SOLUTIONS

3.1 Constant (uniform) acceleration downwards.

3.2 **Take up as positive**

$v_f = v_i + a\Delta t$

$0 = +15 + (-9,8)\ \Delta t$

$0-15 = (-9,8)\ \Delta t$

$\Delta t = 1,53\ s$

3.3 $v_f = v_i + a\Delta t$

$-35 = +15 + (-9,8)\ \Delta t$

$-50 = -9,8\ \Delta t$

$\Delta t = 5,10$ s

3.4 $v_f^2 = v_i^2 + 2a\Delta y$

$(-35^2) = (+15)^2 + 2(-9,8)\Delta y$

$1225 = 225 - 19,6\Delta y$

$\Delta y = -51$

$\therefore$ Height = 51 m

3.5 $v_f^2 = v_i^2 + 2a\Delta y$

$0 = 15^2 + 2(-9,8)\Delta y$

$0 = 225 - 19,6\ \Delta y$

$0 - 225 = -19,6\ \Delta y$

$\Delta y = 11,48$ m

$\therefore$ distance travelled = 11,48 + 11,48 + 51 = 73,96 m

3.6 Reference point is the top of the building:

$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

$$= (15)(5,10) + \frac{1}{2}(9,8)(5,10)^2$$

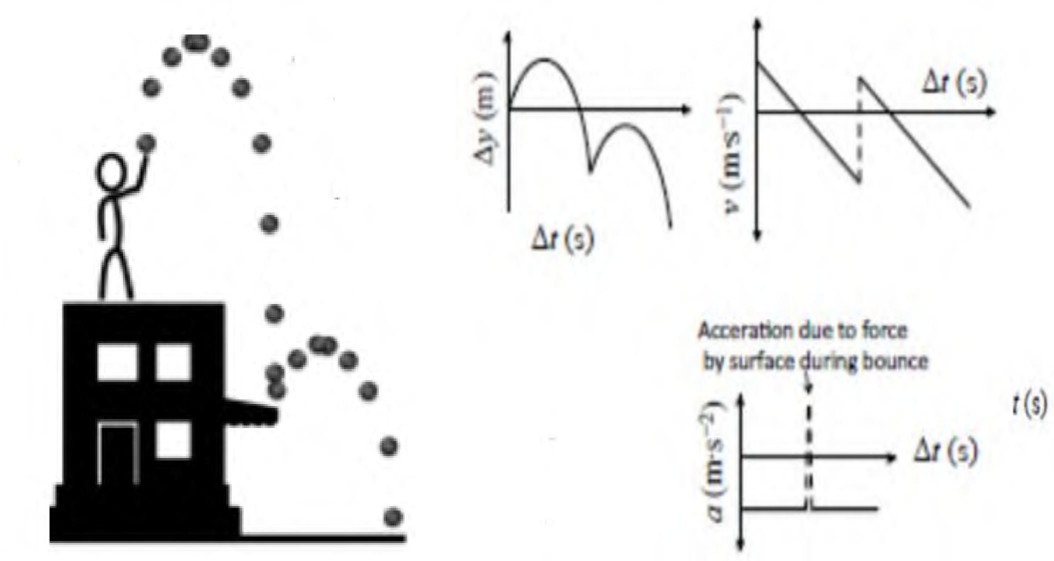
$$= 60 - 78,4$$

$\Delta y = -18,4$

$\Delta y = 18,4$ m below the top of the building

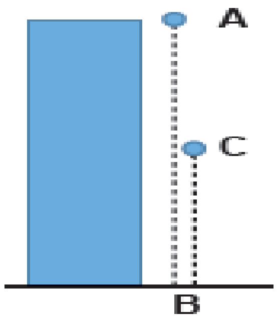
OBJECT THROWN VERTICALLY UPWARD AND PASSES THE POINT OF PROJECTION AND BOUNCES

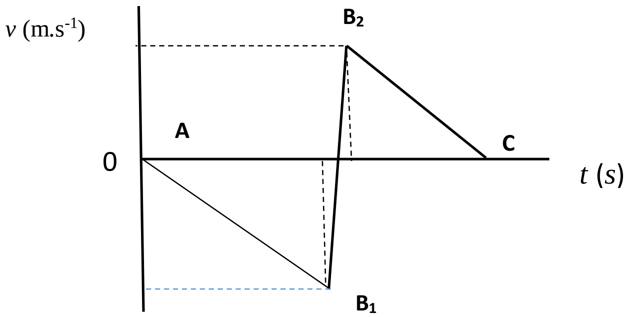
- Bouncing object changes direction after the first bounce.



OBJECT DROPPED FROM A CERTAIN HEIGHT AND BOUNCES

- During the **contact time** velocity of an object changes in magnitude and direction

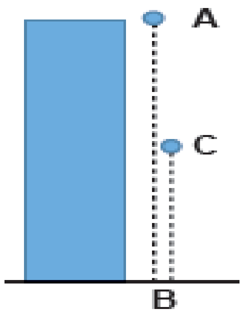


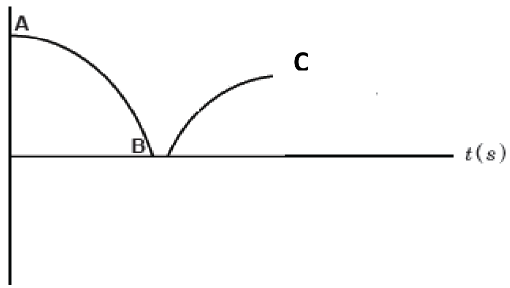


At point:

- **B_1** ,the ball is in contact with the ground.
- **B_2** , the bal leaves the ground with a positive velocity.
- Between **B_2-C,** the ball is moving upwards, velocities are positive and decreasing.
- **C,** the ball has reached its maximum height after the bounce.

- Due to the change in velocity of an object, the maximum height reached after the first bounce is different.

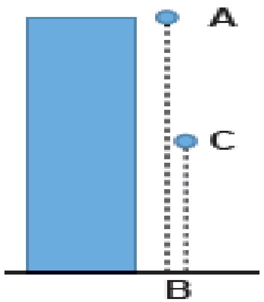


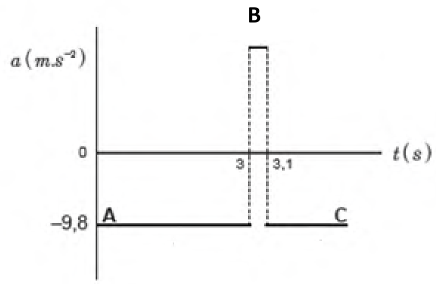


At point:

- Between **B-C:**
  - velocities are positive (UPWARDS); therefore, the gradient must be positive.
  - Velocities are decreasing; therefore, the gradient must decrease.
- **C**, the ball has reached its maximum height after the bounce

- Acceleration remains constant (in magnitude and direction) throughout motion of an object.



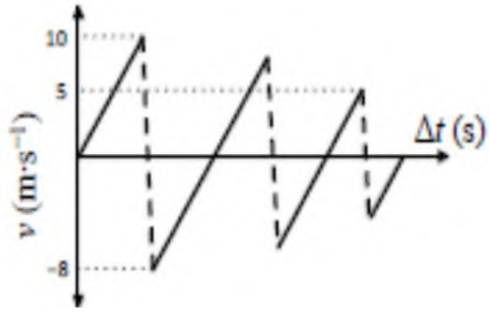


At point:

- **A** , constant negative acceleration BEFORE the bounce.
- **B** , UPWARD acceleration During the bounce (for 0,1s).
- **C** , constant negative acceleration AFTER the bounce.

EXAMPLE 4

The velocity-time graph below represents the bouncing movement of a 0,1 kg ball. Use the graph to answer the questions that follow:



4.1 Which direction of movement is positive?

4.2 How many times did the ball bounce?

4.3 What does the gradient of the graph represent?

4.4 Are the collisions between the ball and ground elastic or inelastic?

4.5 If the ball is in contact with the ground for a duration of 0,08 s, determine the impulse on the ball

4.6 Predict why the ball stopped moving.

4.7 Calculate the time taken for the ball to reach the ground for the first time.

4.8 Hence, without using the equations of motion, calculate the height from which the ball was initially dropped.

SOLUTIONS

4.1 Downwards

4.2 3 times

4.3 Acceleration of the ball

4.4 After each bounce there is a change is the velocity of the ball, and therefore a change in kinetic energy. The collisions are inelastic as kinetic energy is not conserved

4.5 $F_{net}\Delta t = \Delta p$

$= m(v_f - v_i)$

$= (0{,}1)(-8 - 10)$

$= -1{,}80$

∴ Impulse = 1,80 N·s upwards

4.6 It stops on the apex, ∴ it was most likely caught.

4.7 $v_f = v_i + a\Delta t$

$10 = 0 + (9{,}8)\ \Delta t$

$\Delta t = 1{,}02\ s$

∴time taken$= 1.02s$

4.8 $Area = \frac{1}{2} b \times h$

$= \frac{1}{2}(1{,}02)(10)$

= 5,1

∴ height = 5,1 m above the ground

IMPORTANT TO REMEMBER

- At the starting point its displacement is ZERO, $\Delta y = 0$ m.
    - All displacements for upward motion or downward motion stay positive above starting point.
    - The magnitude of upward displacement from starting position to its highest point is equal to the magnitude of downward displacement from the height point back to the starting point.
- At all times the object accelerates downwards due to the force of gravity.
- At any point during the journey the acceleration of the object is equal to the gravitational acceleration, g.
    - a = 9,8 $m.s^{-2}$ downwards. The velocity of the object changes by 9.8$m.s^{-2}$ in one second throughout the motion.
    - g is independent of the mass of the object.
    - g is dependent upon the distance from the centre of the earth.

ACTIVITIES: VERTICAL PROJECTILE MOTION

QUESTION 1

USE THE INFORMATION BELOW TO ANSWER QUESTION 1.1 AND QUESTION 1.2

An object is thrown upwards with a velocity of 5 $m.s^{-1}$

1.1 Which ONE of the following gives the magnitude of the velocity of the object at its maximum height?

A 0

B 5

C 4,9

D 9,8 (2)

1.2 The height reached by the object when its velocity is 2 $m.s^{-1}$ can be determined in ONE single step. The equation below that can be used to find this is ….

A $v_f = v_i + a\Delta t$

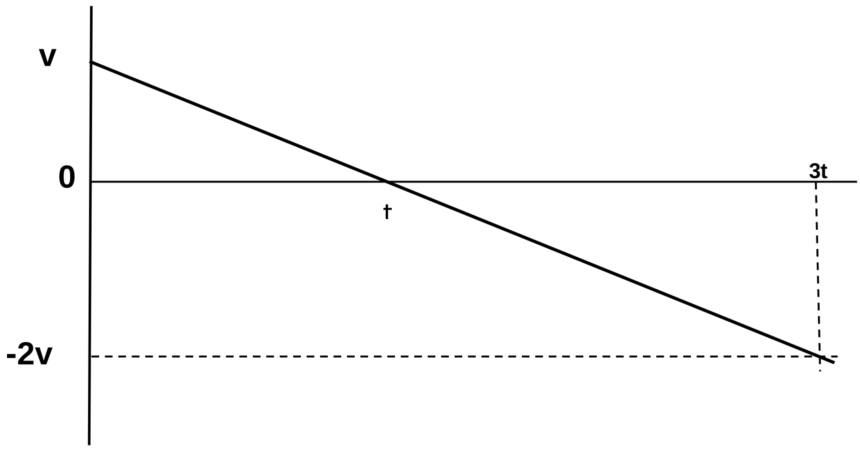
B $v_f^2 = v_i^2 + 2a\Delta y$

C $\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

D $\Delta y = \left(\frac{V_f + V_i}{2}\right)\Delta t$

(2)

1.3 The velocity versus time graph below represents the movement of an object under the influence of gravitational force.



The displacement of the object in time **3t** is …

A **vt**.

B Zero.

C **-vt**.

D $-\frac{3}{2}$**v t**.

1.5 An object is free falling towards the surface of the earth.

Which ONE of the following best describes the direction of **acceleration** of the object?

A The acceleration is 9,8 $m.s^{-2}$ downward.

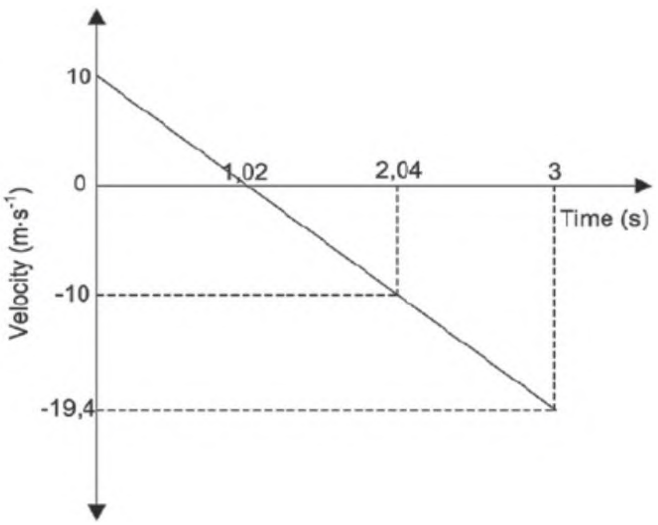
B The acceleration is 9,8 $m.s^{-2}$ upward.

C The acceleration is less than 9,8 $m.s^{-2}$ downward.

D The acceleration is less than 9,8 $m.s^{-2}$ upward. (2)

QUESTION 2

Lerato throws a stone vertically into the air from the top of a cliff. The stone strikes the ground below after 3 s. The velocity vs. time graph below shows the motion of the stone. Ignore the effect of air resistance.



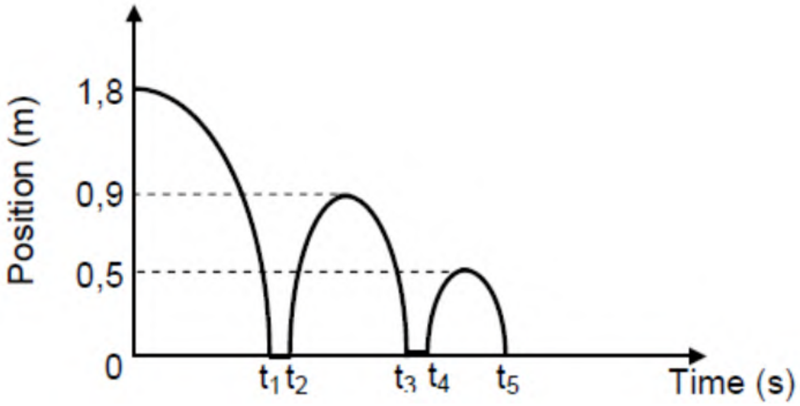
2.1 How long does the stone take to fall from the height of the cliff to the ground below? (2)

2.2 What is the maximum height that the stone reaches above the ground? (Hint: calculate the height the stone reaches above the cliff, then calculate the height of the cliff, and add these two numbers). (4)

2.3 Draw a graph of position versus time. Use upwards as negative. (6)

QUESTION 3

A ball of mass 0,5 kg is projected vertically downwards towards the ground from a height of 1,8 m at a velocity of 2 m.s^{-1} The position-time graph for the motion of the ball is shown below.



3.1 What is the maximum vertical height reached by the ball after the second bounce? (1)

3.2 Calculate the magnitude of the time t_1 indicated on the graph. (5)

3.3 Velocity with which the ball rebounds from the ground during the first bounce. (4)

The ball is in contact with the ground for 0,2 s during the first bounce.

3.4 Calculate the magnitude of the force exerted by the ground on the ball during the first bounce if the ball strikes the ground at 6,27 m·s^{-1}. (4)

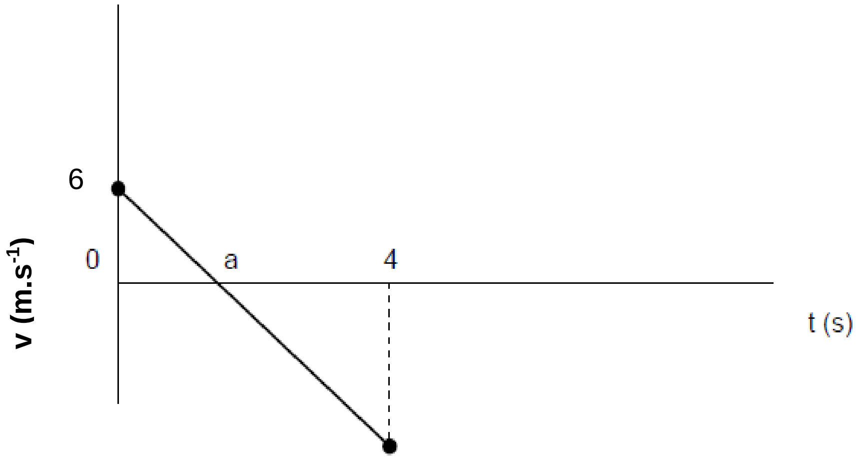
3.5 Draw a velocity-time graph for the motion of the ball from the time that it is projected to the time when it rebounds to a height of 0,9 m.

Clearly show the following on your graph:

- The time when the ball hits the ground
- The velocity of the ball when it hits the ground
- The velocity of the ball when it rebounds from the ground (7)

QUESTION 4

A helicopter is rising vertically at constant velocity. When the helicopter is at a height of 100 m above the ground, a girl accidentally drops her camera out of the window of the helicopter.The velocity-time graph below represents the motion of the camera from the moment it is released from the helicopter until it strikes the ground. Ignore air-Resistance.



4.1 What is the value of the slope (gradient) of the graph? (2)

4.2 Use the gradient to calculate the time *a* on the time axis (5)

4.3 Which point on the path of the camera corresponds to time *a*? (1)

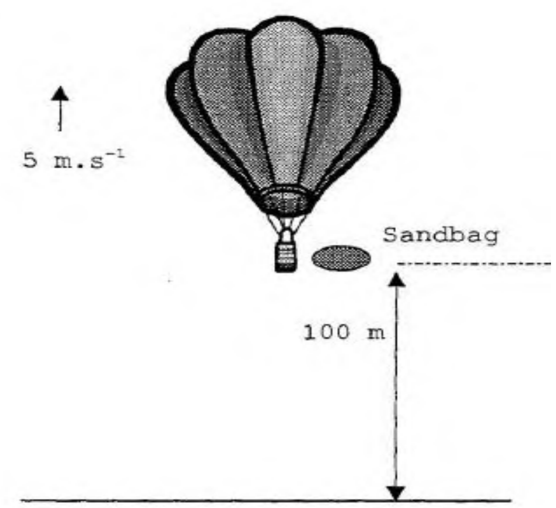
4.4 **Use an equation of motion** to calculate the magnitude of the velocity of the camera as it reaches the ground at 4 s. (4)

4.5 **Use the graph** to calculate the maximum height reached by the camera. (5)

4.6 Draw a rough displacement-time graph **and** an acceleration-time graph to represent the motion of the camera from the moment it was released until it hit the ground.Time values must be shown but y-axis values need not be shown. (8)

QUESTION 5

5.1 A hot-air balloon is rising upwards at a constant velocity of 5 m·s-1. When the balloon is 100 m above the ground, a sandbag is thrown upward from it at 15m.s^{-1}. Ignore air resistance.



What is the acceleration of:

5.1.1 The hot-air balloon while the sandbag is in it? (1)

5.1.2 The sandbag the moment it is thrown from the hot-air balloon? (2)

5.2 Determine the maximum height P, **above the ground**, reached by the sandbag after it is thrown from the hot-air balloon. (3)

5.3 Calculate the time taken for the sandbag to reach this maximum height after it has been released. (3)

5.4 Calculate the total time taken for the sandbag to reach the ground after it has been released. (4)

5.5 Will the velocity of the hot-air balloon **INCREASE**, **DECREASE** or **REMAIN THE SAME** immediately after the sandbag has been released? Explain fully. (4)

5.6 Draw the position time graph for the motion of the sandbag from the moment it was thrown to the time it

Was got to the ground. Take height it was thrown as reference.

Show the following on the graph:

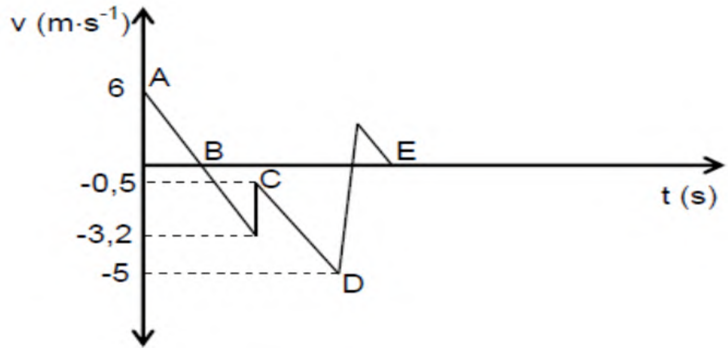
- Time taken to reach maximum height
- Time taken to return to the ground
- Maximum height reached (5)

QUESTION 6

The velocity-time sketch graph for a ball of mass 160 g, thrown vertically upwards with a velocity of 6 m·s^{-1} from a certain height above the ground ,is shown below.

On the way down the ball crashes through a thin horizontal glass pane and then continues downward, eventually bouncing on the ground.

Ignore all effects of air friction and assume none of the broken pieces of glass sticks to the ball.



6.1 Write down the magnitude and direction of the acceleration of the ball when it reaches position B as indicated on the graph. (2)

6.2 How many times did the ball bounce on the ground? (1)

6.3 According to the graph, which direction, DOWNWARDS or UPWARDS is taken as the positive direction? (1)

6.4 Calculate the distance between the pane of glass and the initial position from which the ball was thrown. (4)

6.5 Draw a rough position-time graph for the motion of the ball. Show the points **A** to **E** on the graph. Do not show any displacement or time values on the graph. (5)

Take the initial position of the ball as zero.

QUESTION 7

Ball B is projected vertically upwards at a velocity of 30 m.s^{-1} from the ground. Ignore the effects of air friction. Use the ground as ZERO POSITION.

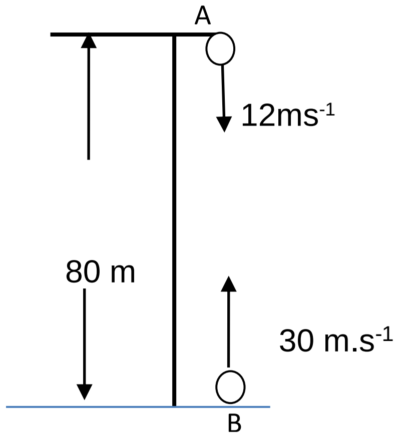
7.1 Calculate the time taken by the ball B to return to the ground. (5)

7.2 Sketch a velocity-time graph for ball B.

Show the following on the graph:

- Initial velocity of ball B.
- Time taken to reach the highest point of the motion.
- Time taken to return to the ground.

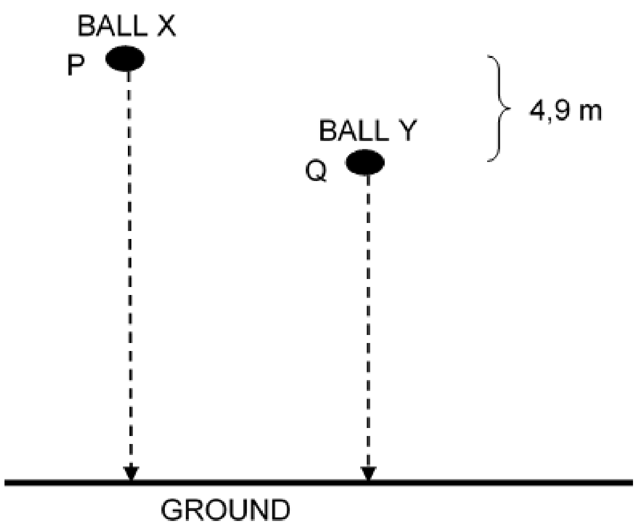
One second after ball B is projected upwards, a second ball, A, is thrown vertically downwards at a velocity of 12m·s^{-1} from a balcony 80m above the ground. Refer to the diagram below.



7.3 Calculate how high above the ground ball B will be the instant the two balls pass each other (6)

QUESTION 8

A ball, X, is thrown vertically downwards, with an initial speed of 2,5 m.s^{-1}, from a point P located above the ground. At the same instant a second identical ball, Y, is dropped from a point Q which is located 4,9 m below point P.



Both balls hit the ground at the same time.

In answering the following questions ignore the effects of air friction. Take downward motion as positive.

8.1 Once in motion both balls are said to be in free fall. Give a reason to support this statement. (1)

8.2 Calculate the time taken by ball Y to hit the ground. (5)

8.3 Calculate the velocity with which ball, X, strikes the ground. (4)

8.4 Use the answer obtained in question 2.3 to calculate the height of point Q above the ground. (4)

8.5 Will ball Y strike the ground with a velocity GREATER THAN, LESS THAN or EQUAL TO, the velocity with which ball X strikes the ground? (1)

8.6 On the same system of axes, sketch the relevant velocity-time graph for the entire motion of both balls X and Y. Indicate on your graph the corresponding velocity and time values. Label your graphs. (4)

MOMENTUM AND IMPULSE

MOMENTUM

- Is the product of mass and velocity
- Is a vector quantity
- Any object that is moving has momentum
- The symbol is p
- Unit of measurement is kg·m·s^{-1}
- Can be calculated using : p = mv
  Where: p - momentum in kg·m·s^{-1}
  M -mass in kg
  v - velocity in m·s^{-1}

Linear momentum is a vector quantity with the same direction as the velocity of the object

Class activity

1. A dancer of mass 50kg leaps into the air and lands feet first on the ground with a velocity of 3 m·s^{-1} . Calculate the momentum of which the dancer reaches the ground.

2. Clay with a mass of 0,06 kg, is dropped straight down and hit the roof of a car with a velocity of 15 m·s^{-1} . Calculate the momentum of the clay.

3. A skater with a mass of 54kg moves with a velocity of 3 m·s^{-1} . What is its momentum?

VECTOR NATURE OF MOMENTUM

Momentum is a **vector quantity** and has both magnitude and direction. It is therefore important to **always include direction** in all momentum calculations.

EXAMPLE 1:

A golf ball of mass 0,02 kg leaves a golf club at a velocity of 100 m·s^{-1} in an easterly direction. Calculate the momentum of the golf ball.

SOLUTION:

$p = mv$

= (0, 02) (100)

= 2,00 kg·m·s^{-1} east

EXAMPLE 2:

A toy car of mass 150 g has a momentum of 0,45 kg· m·s^{-1} left. Calculate the velocity of the toy car.

SOLUTION:

$P = mv$

0,45 = (0, 015) (v)

V = 3,00 m·s^{-1} to the left

CHANGE IN MOMENTUM

When a moving object comes into contact with another object (moving or stationary) it results in a change in velocity for both objects and therefore a change in momentum (p) for each one. The change in momentum can be calculated by using:

$$\Delta p = p_f - p_i$$

Δp = change in momentum ($kg \cdot m \cdot s^{-1}$)

Δp_f = final momentum ($kg \cdot m \cdot s^{-1}$)

Δp_i = initial momentum ($kg \cdot m \cdot s^{-1}$)

Due to the vector nature of momentum, it is very important to choose a positive direction.

EXAMPLE 1:

A 1000 kg car initially moving at a constant velocity of 16 $m \cdot s^{-1}$ in an easterly direction approaches a stop street, starts breaking and comes to a complete standstill. Calculate the change in the car's momentum.

SOLUTION:

Choosing east as positive:

$\Delta p = p_f - p_i$

$\Delta p = mv_f - mv_i$

$\Delta p = (1000)(0) - (1000)(16)$

$\Delta p = -1600$

$\therefore \Delta p = 1\ 600\ kg \cdot m \cdot s^{-1}$ west

EXAMPLE 2:

A cricket ball with a mass of 0,2 kg approaches a cricket bat at a velocity of 40 $m \cdot s^{-1}$ east and leaves the cricket bat at a velocity of 50 $m \cdot s^{-1}$ west.

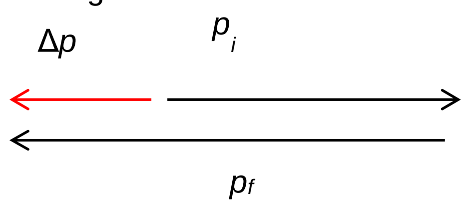
1. Calculate the change in the ball's momentum during its contact with the cricket bat.
2. Draw a vector diagram showing the change in momentum of the cricket ball.

SOLUTION:

Choosing east as positive:

1. $\Delta p = p_f - p_i$ $\Delta p = mv_f - mv_i$
   $\Delta p = (0{,}2)(-50) - (0{,}2)(40)$
   $\Delta p = -18$
   $\therefore \Delta p = 18\ kg \cdot m \cdot s^{-1}$ west

2.



NEWTON'S SECOND LAW OF MOTION

Newton's second law in terms of momentum: The net force acting on an object is equal to the rate of change of momentum.

According to Newton's Second Law, a resultant force applied to an object will cause the object to accelerate. When the net force on an object changes, so does its velocity and hence the momentum.

$$F_{net} = \frac{\Delta p}{\Delta t}$$

F_{net} = resultant force (N)

Δp = change in momentum ($kg \cdot m \cdot s^{-1}$)

Δt = time (s)

IMPULSE

Impulse: the product of the net force and the contact time.

By rearranging Newton's second law in terms of momentum, we find that impulse is equal to the change in momentum of an object according to the impulse-momentum theorem:

Impulse = $F\Delta t$
Impulse = Δp $m\Delta v$
= Δp

Impulse, $F\Delta t$, is measured in N·s.

Δp is measured in $kg \cdot m \cdot s^{-1}$

The change in momentum is directly dependent on the magnitude of the resultant force and the duration for which the force is applied. Impulse is a vector, therefore must have direction.

EXAMPLE 1:

A golf ball with a mass of 0,1 kg is driven from the tee. The golf ball experiences a force of 1000 N while in contact with the golf club and moves away from the golf club at 30 m·s^{-1}. For how long was the golf club in contact with the ball?

SOLUTION:

$F_{net}\Delta t = m\Delta v$

$1000t = (0,1)\ (30 - 0)$

$t = 3 \times 10^{-3}$ s

EXAMPLE 2:

Why can airbags be useful during a collision? State your answer by using the impulse-momentum theorem.

SOLUTION:

From the impulse-momentum theorem **($F_{net}\Delta t = m\Delta v$)**:

an airbag increases contact time **(t)** during the accident, thereby decreasing the force **(F_{net})** to be exerted on the passenger, because according the resultant force experienced is inversely proportional to the contact time **($F_{net}\ \alpha 1/t$).**

NB: the explanation applies to seatbelts, arrestor beds and crumble zones.

EXAMPLE 3:

Initially a girl on a roller skate is at rest on a smooth horizontal pavement. The girl throws the parcel of mass 8 kg, horizontally to the right at a speed of 4 m·s^{-1}. Immediately after the parcel has been thrown, the girl-roller skate combination moves at a speed of 0.6 m·s^{-1}.

Calculate the impulse of the parcel

2. Without any further calculations, write down the change in momentum experienced by the girl while the parcel is being thrown.

SOLUTION:

Choose right as positive

$F_{net}\Delta t = mv_f - mv_i$ $F_{net}\Delta t = 8(4) - 8(0)$

$F_{net}\Delta t = 32.00$ N·s

Impulse = 32.00 N·s to the right

32 kg·m·s^{-1} to the left.

COLLISIONS

●Objects move off/ stick together/ combine

When objects collide and move off together, their masses can be added as one object.

Objects that are stationary (B) have an initial velocity of zero.

Σpbefore = Σpafter

$m_Av_{iA} + m_Bv_{iB} = (m_A + m_B)v_f$

●Objects Collide and rebounds

Objects can collide and move off separately

$\Sigma p_{before} = \Sigma p_{after}$

$m_Av_{iA} + m_Bv_{iB} = m_Av_{fA} + m_Bv_{fB}$

NB: The velocity and momentum are vectors (i.e. direction specific). Velocity substitution must take direction into account.

●Object dropped vertically on a moving object

Example: A stuntman jumps off a bridge and lands on a truck.

Linear momentum= momentum along one axis.

A dropped object has a horizontal velocity of zero, v_{iB}= 0 m•s^{-1}

Σpbefore = Σpafter

$m_Av_{iA} + m_Bv_{iB} = (m_A + m_B)v_f$

NEWTON'S THIRD LAW AND MOMENTUM

During a collision, the objects involved will exert forces on each other. Therefore, according to Newton's third law, if object A exerts a force on object B, object B will exert a force on object A where the two forces are equal in magnitude, but opposite in direction.

The magnitude of the force, the contact time and therefore the impulse on both objects are equal in magnitude.

Forces are applied between objects during:

Collisions: Move off together, collide and deflect, object dropped vertically on moving object.

Explosions: Explosions, springs, firearms

EXPLOSIONS

●Explosions

Objects that experience the same explosion will experience the same force.

The acceleration, velocity and momentum of the object is dependent on the mass.

Objects that are stationary (A+B) have an initial velocity of zero.

$\Sigma p_{before} = \Sigma p_{after}$

$(m_A + m_B)v_i = m_A v_{fA} + m_B v_{fB}$

●Springs

The spring will exert the same force on both objects (Newton's Third Law).

The acceleration, velocity and momentum of the object is dependent on the mass.

Objects that are stationary (A+B) have a velocity of zero.

$\Sigma p_{before} = \Sigma p_{after}$

$(m_A + m_B)v_i = m_A v_{fA} + m_B v_f$

●Firearms/ cannons

The gun and bullet will experience the same force.

The acceleration of the weapon is significantly less than the bullet due to mass difference.

Recoil can be reduced by increasing the mass of the weapon.

MOMENTUM AND ENERGY

ELASTIC VS INELASTIC COLLISIONS

Elastic collision: a collision in which both momentum and kinetic energy are conserved.

Inelastic collision: a collision in which only momentum is conserved. Kinetic energy is not conserved i.e. the total kinetic energy before collision or explosion is not equal to the total kinetic energy after collision.

In an isolated system, MOMENTUM WILL ALWAYS BE CONSERVED. To prove that a collision is elastic, we only have to prove that kinetic energy is conserved.

Kinetic energy can be calculated using the mass and velocity of an object:

$EK = ½mv^2$

EK = kinetic energy (J) m = mass (kg) v = velocity ($m.s^{-1}$)

Elastic collision: Ek(before) = Ek(after)

Inelastic collision: Ek(before) ≠ Ek(after)

(SOME ENERGY IS LOST AS SOUND OR HEAT)

APPLICATION OF IMPULSE IN REAL LIFE SITUATIONS

- **Airbags/Seatbelts**

- Save thousands of lives
- They increase the time of contact
- According to $F_{net} = \Delta p/ \Delta t$, if time of contact increases the net force will decrease and that will reduce injury

- **Arrestor beds**

Two design features:

1. The surface must have sufficient friction
2. The surface must be long enough for the truck to stop

They decrease a truck's momentum to zero over a fairly long time interval and the force exerted on the truck is small enough not to harm the truck driver.

ACTIVITY

1. A toy train, mass 0,5 kg is moving along a toy track to the right with a speed of 2 $m.s^{-1}$. It collides with another stationary train that also has a mass of 0,5 kg. As a result of the collision, the first train remains stationary.

1.1 Use the principle of conservation of momentum to find the velocity of the second train after the collision.

1.2 Calculate the total kinetic energy before and after the collision. How do they compare with each other?

2. A bullet of mass 50g is fired horizontally into a stationary wooden block of mass 8kg lying on a rough horizontal surface. The bullet strikes the wooden block at a velocity of 196 $m.s^{-1}$. The impact causes the block–bullet system to slide a distance of 40cm from its original position before coming to rest. Assume the block experiences a constant frictional force.

2.1 Name and state the law in words that can be used to calculate the velocity of the block–bullet system immediately after impact. (3)

2.2 Calculate the magnitude of the velocity of the block–bullet system immediately after the impact. (5)

2.3 Draw a labeled sketch to illustrate all the forces acting on the block-bullet system while it is moving. (3)

2.4 Is the collision elastic? Show by a calculation to prove your answer.

2.5 Assume that block-bullet system experiences a constant acceleration of –1,86 ms^{-2} while it is moving. Calculate the co-efficient of kinetic friction (μ_k) between the wooden block and the surface.

3. The most common reasons for rear-end collisions are too short a following distance, speeding and failing brakes. Car A of mass 1 000 kg, stationary at a traffic light, is hit from behind by Car B of mass 1 200 kg, travelling at 18 $m·s^{-1}$. Immediately after the collision Car A moves forward at 12 $m·s^{-1}$.

3.1 Calculate the speed of car B immediately after collision.

3.2 Show by a calculation that this collision is inelastic.

STRUCTURED PROBLEMS

QUESTION 1

Dancers have to learn many skills, including how to land correctly. A dancer of mass 50 kg leaps into the air and lands feet first on the ground. She lands on the ground with a velocity of 5 $m·s^{-1}$. As she lands, she bends her knees and comes to a complete stop in 0,2 seconds.

1.1 Calculate the momentum with which the dancer reaches the ground. (3)

1.2 Define the term impulse (2)

1.3 Calculate the magnitude of the net force acting on the dancer as she lands. (3)

Assume that the dancer performs the same jump as before but lands without bending her knees.

1.4 Will the force now be GREATER THAN, SMALLER THAN or EQUAL TO the force calculated in QUESTION 1.3? (1)

1.5 Give a reason for the answer to QUESTION 1.4. (3)

[12]

QUESTION 2

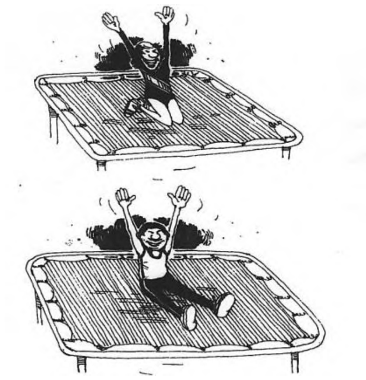
A cricket ball of mass 450 g is bowled towards a batsman at a speed of 37,5 $m.s^{-1}$. The batsman misses the ball and the wicket keeper catches the ball.

2.1 Calculate the average force exerted by the wicket keeper on the ball, if he stops the ball in 0,5 s. (5)

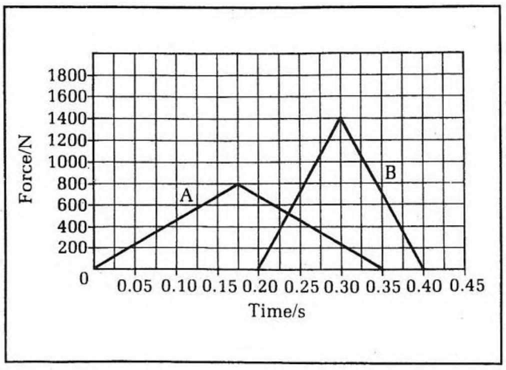
2.2 Use the equation $Fnet = \frac{\Delta p}{\Delta t}$ to explain why the wicket keeper should pull his hands back when catching a fast moving cricket ball. (3)

QUESTION 3

The pictures below show a girl of mass 45 kg and boy of mass 65 kg, bouncing off separate, identical trampolines at a fun fair.



The graphs below show how the forces exerted by the trampolines on the children vary with time during one bounce. Graph A represents the force exerted on the girl by the trampoline and Graph B represents the force exerted on the boy by the trampoline.



3.1 Define IMPULSE. (2)

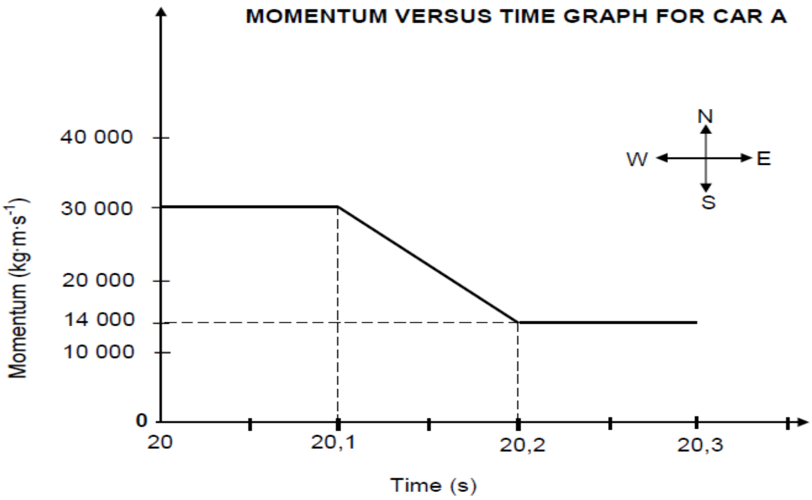
3.2 Show with the aid of relevant calculations that the impulse of the boy is equal in magnitude to the impulse of the girl. (5)

3.3 If the boy and girl jumped onto their trampolines from the same height, Which ONE of the two will rebound with a greater speed? (1)

QUESTION 4

The graph below shows how the momentum of car **A** changes with time *just before* and *just after* a head-on collision with car **B**.

Car **A** has a mass of 1 500 kg, while the mass of car **B** is 900 kg.
Car **B** was travelling at a constant velocity of 15 $m \cdot s^{-1}$ west before the collision.
Take east as positive and consider the system as isolated.



4.1 What do you understand by the term isolated system as used in physics? (1)

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

4.2 Calculate the:

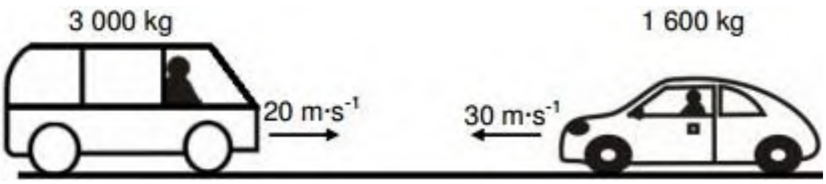
4.2.1 Magnitude of the velocity of car A just before the collision (3)

4.2.2 Velocity of car B just after the collision (5)

4.2.3 Magnitude of the net average force acting on car A during the collision (4)

QUESTION 5

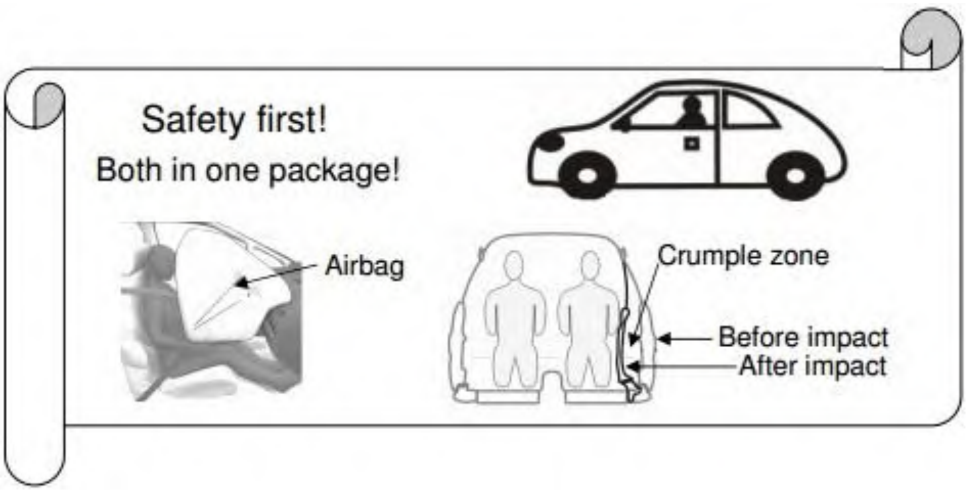
Collisions happen on the roads in our country daily. In one of these collisions, a car of mass 1600 kg, travelling at a speed of $30 m.s^{-1}$ to the left, collides head-on with a minibus of mass 3000 kg, travelling at $20 m.s^{-1}$ to the right. The two vehicles move together as a unit in a straight line after the collision.



5.1 Calculate the velocity of the two vehicles after the collision. (6)

5.2 Do the necessary calculations to show that the collision was inelastic. (6)

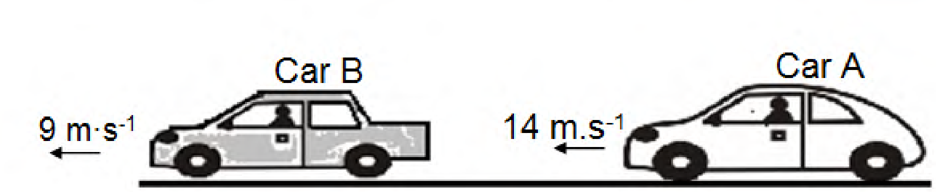
5.3 The billboard below advertises a car from a certain manufacturer.



Use your knowledge of momentum and impulse to justify how the safety features mentioned in the advertisement contribute to the safety of passengers. (3)

QUESTION 6

In the sketch below car A of mass 1250 kg is travelling at 14 $m.s^{-1}$. At the same time car B of mass 800 kg is travelling in the same direction as car A but in front of car A at 9 $m.s^{-1}$.



Car A collides with car B. Immediately after the collision car A continues to move in its original direction at 12 $m.s^{-1}$.

6.1 Assume that the linear momentum is conserved during this collision and calculate the speed of car B immediately after the collision. (4)

6.2 Explain why the assumption made in question 3.1 may not be valid if both cars A and B are designed to crumple partially on impact. (2)

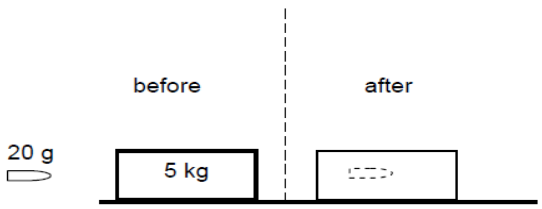
6.3 Consider the following statement: “The risk of injury for passengers in a lighter car is greater than the risk of injury for passengers in a heavier car during a head-on collision”. Use principles of Physics to explain the validity of this statement. (4)

QUESTION 7

A bullet of mass 20 g is fired from a stationary rifle of mass 3 kg. Assume that the bullet moves horizontally. Immediately after firing, the rifle recoils (moves back) with a velocity of 1,4 $m·s^{-1}$.

7.1 Calculate the speed at which the bullet leaves the rifle. (4)

The bullet strikes a stationary 5 kg wooden block fixed to a flat, horizontal table. The bullet is brought to rest after travelling for 0,04s into the block. Refer to the diagram below.

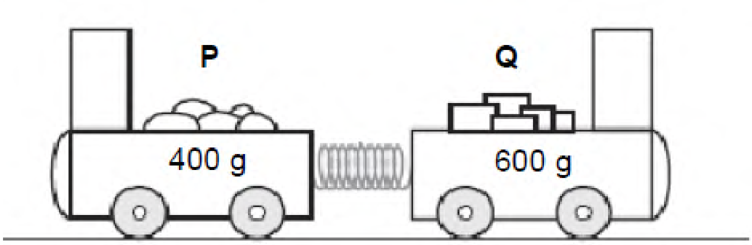


7.2 Calculate the magnitude of the average force exerted by the block on the bullet (5)

7.3 How does the magnitude of the force calculated in QUESTION 7.2 compare to the magnitude of the force exerted by the bullet on the `block? Write down only LARGER THAN, SMALLER THAN or THE SAME. (1)

QUESTION 8

The diagram below shows two trolleys, P and Q, held together by means of a compressed spring on a flat, frictionless horizontal track. The masses of P and Q are 400 g and 600 g respectively.



When the trolleys are released, it takes 0,3 s for the spring to unwind to its natural length. Trolley Q then moves to the right at 4 $m \cdot s^{-1}$.

8.1 State the principle of conservation of linear momentum in words. (2)

8.2 Calculate the:

8.2.1 Velocity of trolley P after the trolleys are released (4)

8.2.2 Magnitude of the average force exerted by the spring on trolley Q (4)

8.3 Is this an elastic collision? Only answer YES or NO. (1)

WORK, ENERGY AND POWER

Key Concepts:

- What is Work?
- Work done on an object by a constant force
- Work done on an object by conservative forces
- Work done on an object by non-conservative forces
- Work-energy theorem
- Conservation of Mechanical Energy
- Power

Prerequisites:

Some familiarity with the following concepts would be helpful in understanding the information in this topic

- Vectors
- Different kinds of forces
- Drawing free-body diagram
- Newton's Laws of Motion
- Energy and Conservation of Mechanical Energy
- Momentum and conservation of momentum

EXAM GUIDELINES

- Define the work done on an object by a constant force as the product of the force and the displacement.
- Give examples of when an applied force does and does not do work on an object.
- Calculate the work done by an object when a force ***F*** applied at angle θ to the direction of motion causes the object to move a distance, using

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

Know that an object with larger potential energy has a greater capacity to do work.

- Positive net work done on system will increase energy of the system
- Negative net work done on system will decrease energy of the system
- *State the 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.
- Solve problems using the work energy theorem, i.e. the work done on an object by a net force is equal to the change in the object's kinetic energy, using:

$$Wnet = \Delta Ek = Ekf - Eki$$

- Define Conservative forces as a force for which work done in moving an object between two points is independent of the path taken e.g. *gravitational force, elastic force and electrostatic force*).
- Non-conservative forces as a force for which work done in moving object between two points depends on the path taken. e.g. *air resistance, friction, tension, applied forces)*

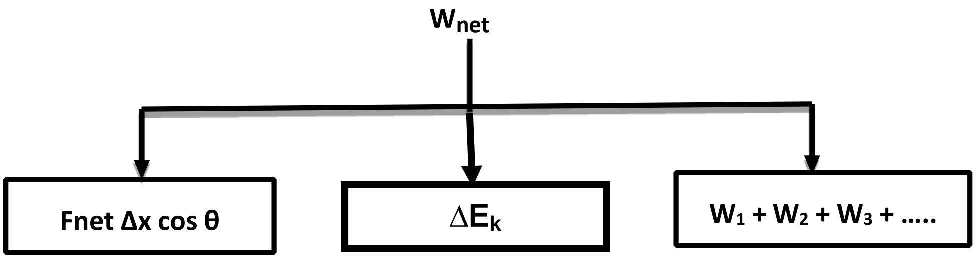
Know that when:

- Only conservative forces are present, mechanical energy is conserved
- Non conservative forces are present, mechanical energy (sum of kinetic and potential) is not conserved, but total energy (of the system) is still conserved.
- State the **Principle of Conservation of mechanical energy:** the total mechanical energy in an isolated system remains constant.
  Note: a system is isolated when net external force acting on the system is zero.
- Solve conservation of energy problems using the equation:

$$Wnc = \Delta Ek + \Delta Ep$$

- Define power as the rate at which work is done.
  In symbols : P = $\frac{W}{\Delta t}$
  Calculate:
- Power involved when work is done
- Minimum power required of an electric motor to pump water from a borehole of a depth at a particular rate using :
  $W_{nc} = \Delta E_k + \Delta E_p$
- Average power, $P_{av} = Fv_{av}$

STRATEGY FOR SOVING PROBLEMS USING THE WORK-ENERGY THEOREM



1. Draw a force or free body diagram showing all forces acting on the object.
2. Write down the equation: $W_{net} = \Delta E_k$
3. If the equation in 2 cannot solve the problem, write the following:
   $F_{net} \Delta x \cos \theta = \Delta E_k$
4. If the equation in 3 cannot solve the problem, write the following:

$$W_1 + W_2 + \ldots = \Delta E_k$$

To use equations in 3 or 4 you will need the following information:

5. Find the resultant force (Fnet) acting on the object. Use a free body diagram to help you. OR identify the individual forces for which F_{net} is the SUM.
6. Find the angle θ between F_{net} (OR each force acting on the object) and Δx. It can ONLY be 0^0 OR 180^0

Note: When …

$\theta = 0^0$: F and Δx have the same direction. F does positive work

θ is between 0^0 and 90^0, F does positive work

$\theta = 90^0$ or 270^0: F is perpendicular to Δx. F does no work on the object.

θ is between 90^0 and 270^0, F does negative work.

$\theta = 180^0$: F and Δx have opposite directions. F does negative work

7. If an object moves at a **constant velocity**,
   Wnet = 0, $\Delta E_k = 0$, Fnet = 0, a = 0

NB. Find the Sum of All the Work Done on the object and equate them to zero and then find the unknown. Always check your answer for correctness.

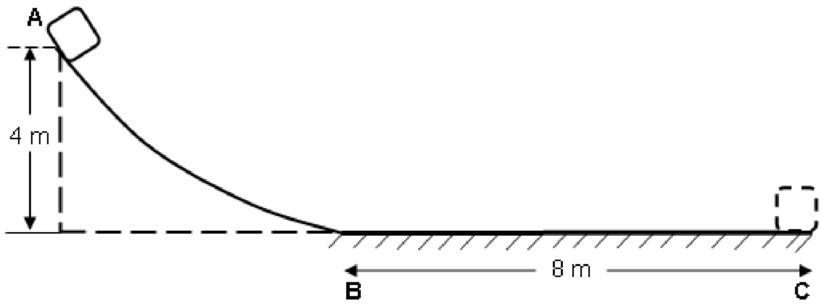
8. If you are not restricted to use the Work-Energy Theorem, then in addition to the above formulae, apply the relevant formula from the list below to solve the problem:

- $v_f^2 = v_i^2 + 2a\Delta x$ (When acceleration is uniform)
- $0 = \Delta U + \Delta K$ (When mechanical energy is conserved)
- $(U + K)_{top} = (U + K)_{bottom}$ (When mechanical energy is conserved)
- $W_{nc} = \Delta U + \Delta K$ (When mechanical energy is not conserved i.e. when non-conservative forces act on the object)

WORKED EXAMPLES

WORKED EXAMPLE 1

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



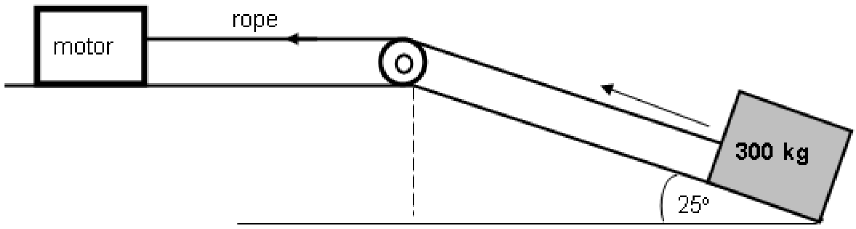
An object of mass 10 kg is released from point A which is 4 m above the ground. It slides down the track and comes to rest at point C.

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

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

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

1.2 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.



1.2.1 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 $m \cdot s^{-1}$.

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

[18]

SOLUTION

1.1.1 In an isolated/closed system, the total mechanical energy is conserved (2)

1.1.2 No (1)

1.1.3 $(E_p + E_k)_A = (E_p + E_k)_B$

$(mgh + ½\ mv^2)_A = (mgh + ½\ mv^2)_B$

$(10)(9{,}8)(4) + 0 = 0 + ½\ (10)\ v_f^2$

$v_f = 8{,}85\ m{\cdot}s^{-1}$

$W_{net} = \Delta K$

$f\Delta x \cos\theta = \Delta K$

$f(8)\cos 180^o = ½\ (10)(0 – 8{,}85^2)$

$f = 48{,}95\ N$ (6)

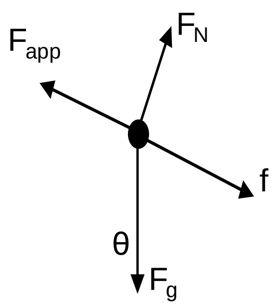
1.2.1 $f_k = \mu_k N$

$= \mu_k mg\cos\theta$

$= (0{,}19)(300)(9{,}8) \cos 25^o$

$= 506{,}26\ N$ (3)

1.2.2



$F_{net} = 0$ ✓

$F_{app} + (-F_g \sin\theta) + (-f) = 0$

$F_{app} - (300)(9{,}8)\sin 25^o$ ✓ $- 506{,}26$ ✓ $= 0$

$F_{app} = 1\ 748{,}76\ N$

$P_{ave} = Fv_{ave}$ ✓

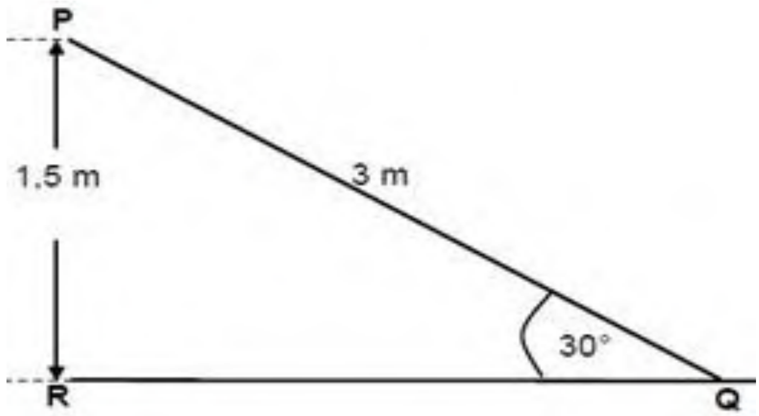
$= 1748{,}76 \times 0{,}5$ ✓

$= 874{,}38\ W$ ✓ (6)

[18]

WORKED EXAMPLE 2

PQ is a slide at a playground. The slide is 3 m long and 1,5 m high. A boy of mass 40 kg and a girl of mass 22 kg stand at the top of the slide at P. The girl accelerates uniformly from rest down the slide. She experiences a constant frictional force of 1,9 N. The boy falls vertically down from the top of the slide through the height PR of 1,5 m. Ignore the effects of air friction.



2.1 Write down the principle of conservation of mechanical energy in words. (2)

2.2 Draw a labelled free-body diagram to show ALL the forces acting on the …

a) Boy while falling vertically downwards (1)

b) Girl as she slides down the slide (3)

2.3 Use the principle of CONSERVATION OF MECHANICAL ENERGY to calculate the speed of the boy when he reaches the ground at R. (2)

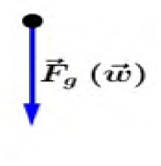
2.4 Use the WORK-ENERGY THEOREM to calculate the speed of the girl when she reaches the end of the slide at Q.

2.5 How would the velocity of the girl at Q compare to that of the boy at R if the slide exerts no frictional force on the girl? Write down only GREATER THAN, LESS THAN or EQUAL TO.

SOLUTIONS

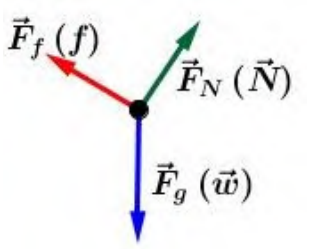
2.1 The total mechanical energy in an isolated system remains the same (2)

2.2 a)



(1)

b)



(3)

2.3 $(Ek + Ep)_P = (Ek + Ep)_R$

$0 + (40)(9,8)(1,5) = (40)v^2 + 0$

$v = 5,422\ m\ s^{-1}$ (4)

2.4 There are two forces acting on the girl – gravity and friction

$Wnet = \Delta Ek$

$F_{g||}.\Delta\ x \cos(\theta) + F_f.\Delta x \cos(\theta)\ x \cos(\theta) = ½\ m(v_f^2 - v_i^2)$

$(22)(9,8)\sin(30^0)(3)\cos 0^0 + (1,9)(3)\cos(180^0) = ½\ (22)(v_f^2 - 0)$

$v_f = 5,374\ m\ s^{-1}$

2.5 With no friction acting, the girl would have the same final velocity as the boy

WORKED EXAMPLE 3

During a fire extinguishing operation, a helicopter remains stationary (hovers) above a dam while filling a bucket with water. The bucket, of mass 80 kg, is filled with 1 600 kg of water. It is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 2 m·s^{-1}. The tension in the cable is 17 000 N. Assume there is no sideways motion during the lift. Air friction is NOT ignored.

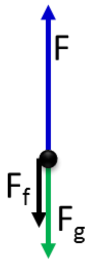
3.1 Draw a labelled free body diagram showing ALL the forces acting on the bucket of water, while being lifted upwards. (3)

3.2 Use the WORK ENERGY THEOREM to calculate the work done by air friction on the bucket of water after moving through the height of 20 m. (5)

[8]

SOLUTION

3.1



(3)

3.2 Wnet = ΔE_k

$\Delta W_F + \Delta W_{Fg} + \Delta W_f = \Delta E_k$

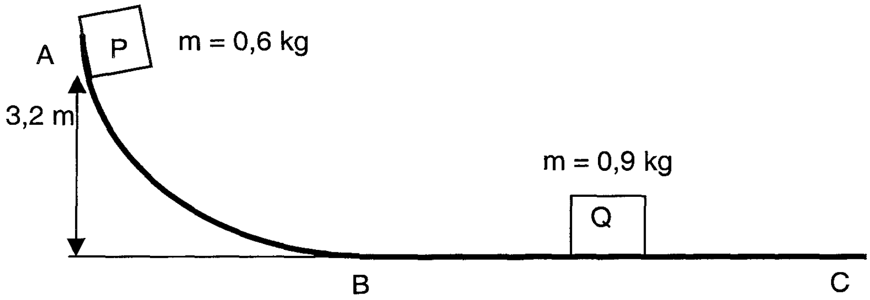
$17000.\ 20.\ \text{Cos}\ (0^0) + (1600 + 80)\ (9, 8)\ 20.\ \cos(180\ ) + Wf = 0$

Wf = - 10720 J (5)

PRACTICE QUESTIONS

QUESTION 1

The track consists of a curved **SECTION AB** and a horizontal **SECTION BC**. The track is frictionless. Body **Q**, mass 0,9 kg, is stationary on **SECTIONBC**. A second body **P**, mass 0,6 kg, is placed at point **A**, which is 3,2 m vertically above the horizontal section. It is released and slides down **SECTION AB**.



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

1.2 Use the energy principles to show that **P** moves at a velocity of 7,92 $m.s^{-1}$ when it reaches body **Q**. (4)

Body P collides with body Q. Immediately after collision, Body Q moves towards C at a velocity of 4, 4 $m.s^{-1}$.

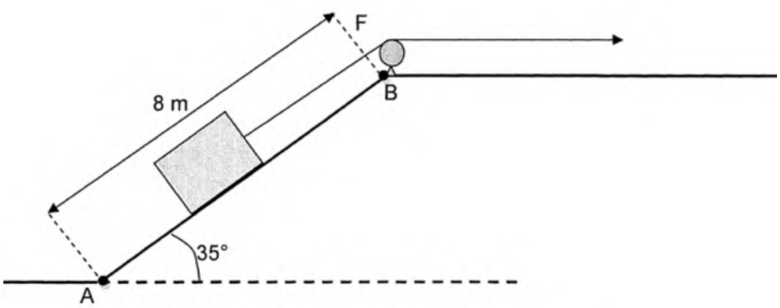
1.3 Calculate the velocity of **P** immediately after the collision. (5)

1.4 Calculate the average force that **Q** exerts on **P** if the two bodies remain in contact for 0, 8 seconds. (5)

[16]

QUESTION 2

The diagram below shows a crate of mass 50 kg being pulled up a slope from point **A** to point **B** at CONSTANT VELOCITY. The slope makes an angle of 35^0 with the horizontal. The frictional force that the surface exerts on the crate is 250 N.



2.1 Draw a labelled free body diagram showing all the forces acting on the crate. (4)

2.2 Calculate the:

2.2.1 Force F applied to pull the crate up the slope from point **A** to point **B**. (4)

2.2.2 Work done by force **F** upon reaching point **B**. (3)

2.2.3 Power due to force **F** if it takes 2 minutes to move the crate from point **A** to point **B**. (4)

[15]

QUESTION 3

A rescue helicopter is stationary (hovering) above the water to rescue a man in difficulties off the Clifton beachfront (**FIGURE 1**). It lowers a a lifebuoy with a mass 2 kg onto the water for the man to cling to it while the crew prepare to bring him aboard the helicopter (**FIGURE 2**). When the buoy is at a height of 10 m above the ground it has a velocity of 1,5 $m \cdot s^{-1}$. A buoy is then lowered at a constant acceleration onto the water with a cable, where it eventually comes to rest. Assume there is no sideways motion during the descent. Air friction is NOT to be ignored.

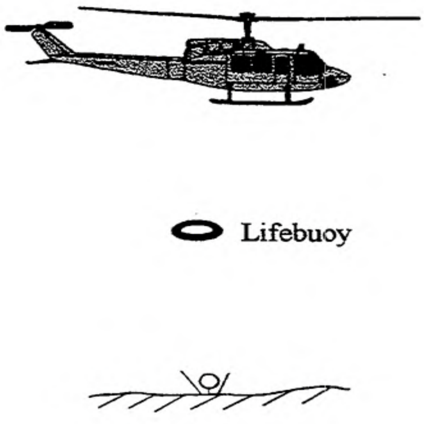


FIGURE 1

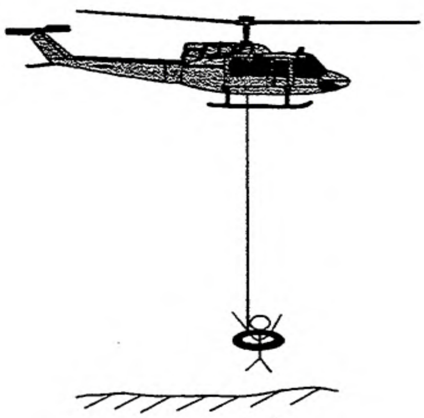


FIGURE 2

3.1 Define a *non-conservative force*. (2)

3.2 Identify TWO *non-conservative forces* acting on the buoy during its downward descent (motion). (2)

3.3 Write down the name of a *non-contact force* that acts on the man while he is out of the water and being hoisted upwards. (1)

3.4 Draw a free-body diagram showing ALL the forces acting on the buoy while it is being lowered to the water. (3)

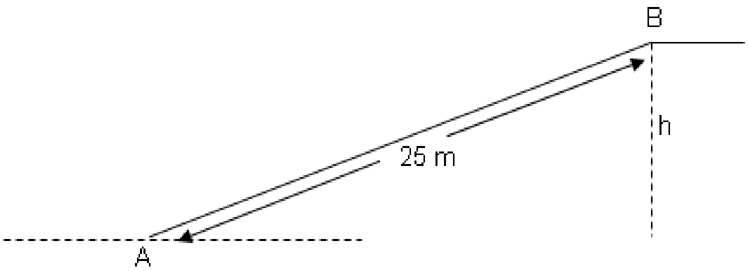
3.5 Write down the WORK-ENERGY THEOREM in words. (2)

3.6 Use the work-energy theorem to calculate the acceleration of the buoy as it is lowered to the water. (6)

[16]

QUESTION 4

The diagram below shows a truck of mass, 12 000 kg free-wheeling,(engine of the truck does no work on the truck) up a straight inclined road of length 25 m. The truck experiences a constant frictional force of magnitude 3 400 N as it moves up the incline. The truck enters the bottom of the incline, point A, with a speed of 25 m·s^{-1} and reaches the top of the incline, point B, with a speed of 20 m·s^{-1}.



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

4.2 Draw a labelled force diagram showing all the forces acting on the truck as it moves up the incline. (3)

4.3 Calculate the net work done on the truck on moving from the bottom of the incline to the top of the incline. (4)

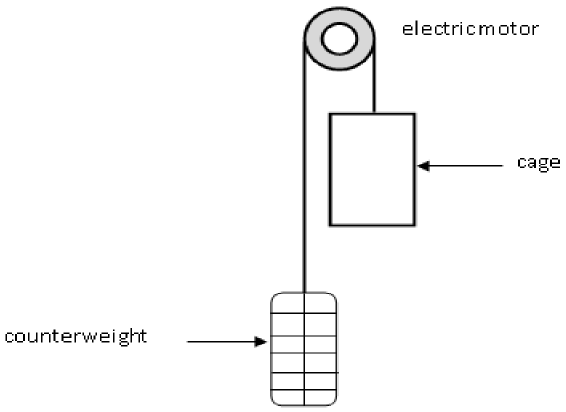
4.4 What is meant by a non-conservative force? (2)

4.5 Show that the work done by the non-conservative force is – 85 000 J. (3)

4.6 Hence calculate the height, h, reached by the truck at the top of the incline. (5)

QUESTION 5

A lift arrangement comprises an electric motor, a cage and its counterweight. The counterweight moves vertically downwards as the cage moves upwards. The cage and counterweight move at the same constant speed. Refer to the diagram below



The cage, carrying passengers, moves vertically upwards at a constant speed, covering 55 m in 3 minutes. The counterweight has a mass of 950 kg. The total mass of the cage and passengers is 1 200 kg. The electric motor provides the power needed to operate the lift system. Ignore the effects of friction.

5.1 Define the term power in words. (2)

5.2 Calculate the work done by the:

5.2.1 Gravitational force on the cage (3)

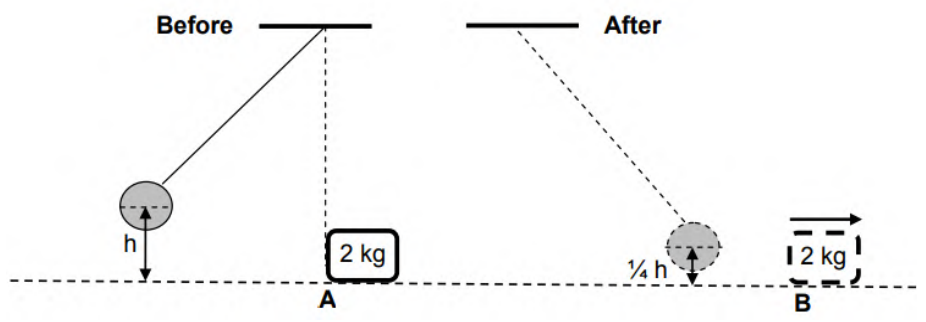
5.2.2 Counterweight on the cage (2)

5.3 Calculate the average power required by the motor to operate the lift arrangement in 3 minutes. Assume that there are no energy losses due to heat and sound (6)

[13]

QUESTION 6

A pendulum with a bob of mass 5 kg is held stationary at a height h metres above the ground. When released, it collides with a block of mass 2 kg which is stationary at point A. The bob swings past A and comes to rest momentarily at a position ¼ h above the ground. The diagrams below are NOT drawn to scale.



Immediately after the collision the 2 kg block begins to move from A to B at a constant speed of 4,95 $m \cdot s^{-1}$. Ignore frictional effects and assume that no loss of mechanical energy occurs during the collision.

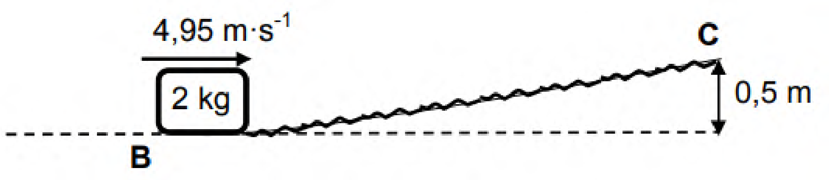
6.1 Calculate the:

6.1.1 Kinetic energy of the block immediately after the collision (3)

6.1.2 Height h (4)

The block moves from point B at a velocity of 4, 95 $m \cdot s^{-1}$ up a rough inclined plane to point C. The speed of the block at point C is 2 $m \cdot s^{-1}$. Point C is 0,5 m above the horizontal, as shown in the diagram below.

During its motion from B to C a uniform frictional force acts on the block.



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

6.3 Use energy principles to calculate the work done by the frictional force when the 2 kg block moves from point B to point C. (4)

WAVES, SOUND & LIGHT

Pre- knowledge: Grade 10 work

Teachers are strongly advised to revise with learners the following concepts

- Pulse is a single disturbance.
- Wave is a repeated disturbance.
- Period (T) is the time taken to complete a single wave.
- Frequency is the number of vibrations passing through a point in one second.
- Unit for frequency is Hertz (Hz).
  ʎ represent the wavelength in (m)
  v represents the speed of sound waves in ($m.s^{-1}$)
- Frequency can be calculated using: v= f.λ **or** $f = \frac{1}{T}$

TYPES OF WAVES

1. Electromagnetic waves
2. Mechanical waves

Types of Mechanical Waves

1. Transverse waves
   - Particles of the medium move perpendicular to the direction of propagation of a wave.
2. Longitudinal waves

• Particles of the medium move parallel to the direction of propagation of a wave.

DOPPLER EFFECT

CHAPTER SUMMARY: DOPPER EFFECT

- Use the general Doppler equation $f_L = \frac{V \pm V_L}{V \pm V_s} f_s$ for any calculation (i.e. when EITHER the source or the listener is moving).

Note: *Only the general Doppler equation, as shown above, or the equation for the specific situation are accepted as correct formulae for a calculation.*

- Teachers need to explain the Doppler equation to learners so that they can understand when and why to add or subtract the velocities of the source or listener to that of sound. For example, if the source moves towards a stationary observer, only $f_L = \frac{V}{V + V_s} f_s$ is accepted as correct formula.
- This equation is a combination of FOUR scenarios:

1. A moving source approaching a stationary listener,
2. A moving source moving away from a stationary listener,
3. A moving listener approaching a stationary source and

4. A moving listener moving away from a stationary source.

- When using the general Doppler equation the following approach can be helpful:

○ If a source of sound waves moves towards a stationary listener, f_L will be higher than fs, thus V_L = 0 and a *negative sign* is used for v_s in the *denominator* in order to obtain a higher observed frequency value.

$$f_L = \frac{V}{V - V_s} f_s$$

○ If a source of sound waves moves away from a stationary listener, f_L will be lower than f_s, thus V_L = 0 and a *positive sign* is used for v_s in the *denominator* in order to obtain a lower observed frequency value.

$$f_L = \frac{V}{V + V_s} f_s$$

○ If a listener moves towards a stationary source of sound waves, f_L will be higher than f_s, thus v_s = 0 and a *positive sign* is used for V_L in the *numerator* in order to obtain a higher observed frequency value.

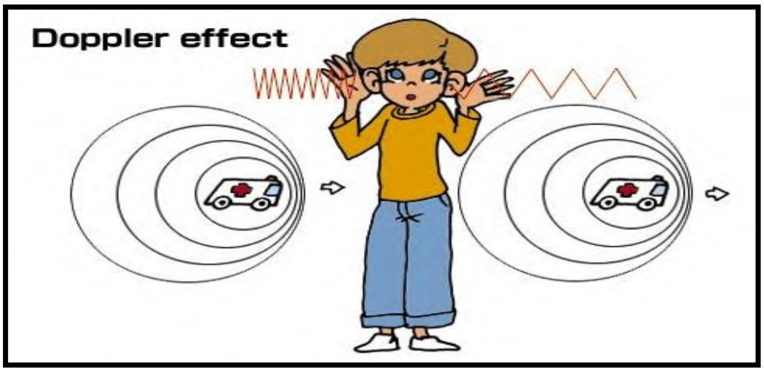
$$f_L = \frac{V + V_L}{V} f_s$$

○ If a listener moves away from a stationary source of sound waves, f_L will be lower than f_s, thus v_s = 0 and a negative sign is used for V_L in the numerator in order to obtain a lower observed frequency value.

$$f_L = \frac{V - V_L}{V} f_s$$

- Describe applications of the Doppler Effect with ultrasound waves in medicine, e.g. to measure the rate of blood flow or the heart of a foetus in the womb.

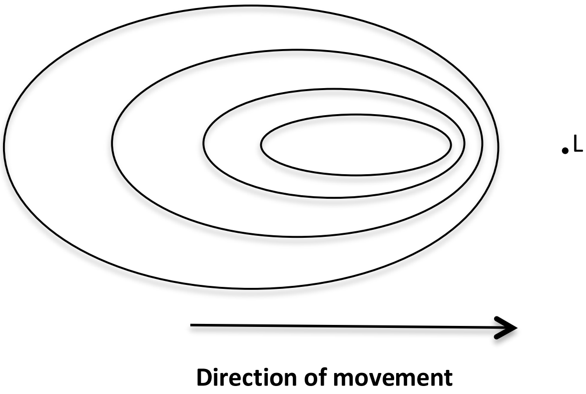
It is the change in frequency (or pitch) of the sound detected by a listener, because the sound source and the listener have different velocities relative to the medium of sound propagation.
When the source of a sound is moving towards the listener, the pitch sounds higher than that of the source. When the source moves away from the listener the pitch sounds lower. This is known as the DOPPLER EFFECT



Sketches of wave fronts

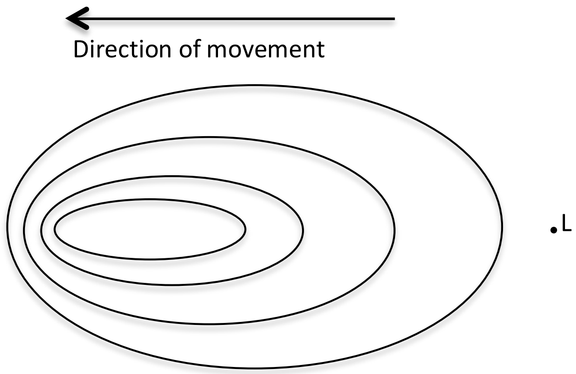
Source moving towards a stationary listener

- Wavelength decreases/ waves are compressed
- Frequency increases
- Velocity constant
- Pitch of sound increases



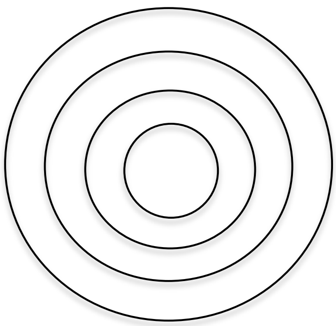
Source moving away from a stationary listener

- Wavelength increases/ waves are stretched
- Frequency decreases
- Velocity constant
- Pitch of sound decreases



Stationary source & listener / Listener inside a moving source

- The frequency is equal to (the same) / wavelength is the same at all points
- No relative motion between the source and the observer
- True pitch of sound



Equation of Doppler Effect

$$f_L = \frac{V \pm V_L}{V \pm V_s} f_s$$

Applications of Doppler Effect

- Used by traffic department as speed traps.
- Blood flow rate can be measured.
- Speed of the planets and stars can be determined.
- Used to measure heartbeat of the unborn foetus in the womb. Used in weather stations to detect precipitation.

Red Shift

- Is the shift in the spectra of distant galaxies towards longer wavelength, towards the red end of the spectra?
- The Doppler Effect is characteristic of all waves, including light.
- All stars emit white light, and stars moving away from the Earth will display light with longer wavelengths – the red colours of the spectrum, due to the Doppler Effect.
- Astronomers have found that all stars exhibit a red shift – are moving away from the earth and from each other. This suggest that the universe is expanding.

Worked Examples

1 In which direction will an absorption spectrum shift during a red shift?

A) towards the blue end of the spectrum.
B) to light of a shorter wavelength.
C) to light of a lower frequency.
D) to light of a higher energy.

(2)

SOLUTION

1. C ✓✓ (2)

2. A police car moves away from an accident scene at a constant speed with its siren on. A paramedic at the accident observes a 7% drop in the frequency of the sound of the siren in comparison to when the car was standing still. Speed of sound in air on that day is 335 m·s^{-1}.

2.1 State in words, the Doppler Effect. (2)

2.2 Calculate the speed of the car. (4)

2.3 An astronomer on Earth observes the missing frequencies in a line from a distant galaxy. The frequencies associated with specific elements are all lower than expected.

2.3.1 With what kind of line spectrum is the astronomer working?
Answer only **ABSORPTION or EMISSION** (1)

2.3.2 Identify the type of shift seen by the astronomer (2)

2.3.3 Is the distant galaxy moving towards or away from our Solar system (2)

SOLUTIONS

2.1 The apparent change in frequency in sound heard due to the relative motion between listener and/or source. ✓✓ (2)

2.2

$$f_L = \frac{V \pm V_L}{V \pm V_s} f_s$$

$$0,93fs = \frac{335 - 0}{335 + V_s} f_s$$

v_S = 25,22 m.s^{-1} (4)

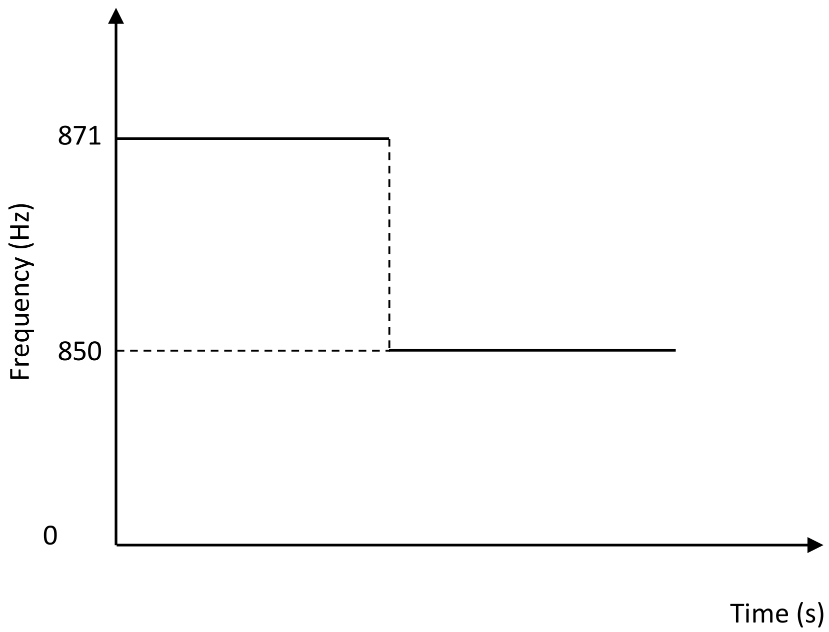
2.3.1 Absorption (line spectrum) ✓✓ (2)

2.3.2 Red-shift ✓✓ (2)

2.3.3 Away from ✓✓ (2)

3. A group of learners conducted an experiment to determine the speed of sound on a particular day. At a particular point they place a sound source emitting at a certain frequency. One learner walks away from the sound source at a constant velocity with a detector which registers the frequency of the sound detected. The graph below shows the detected frequencies versus time.

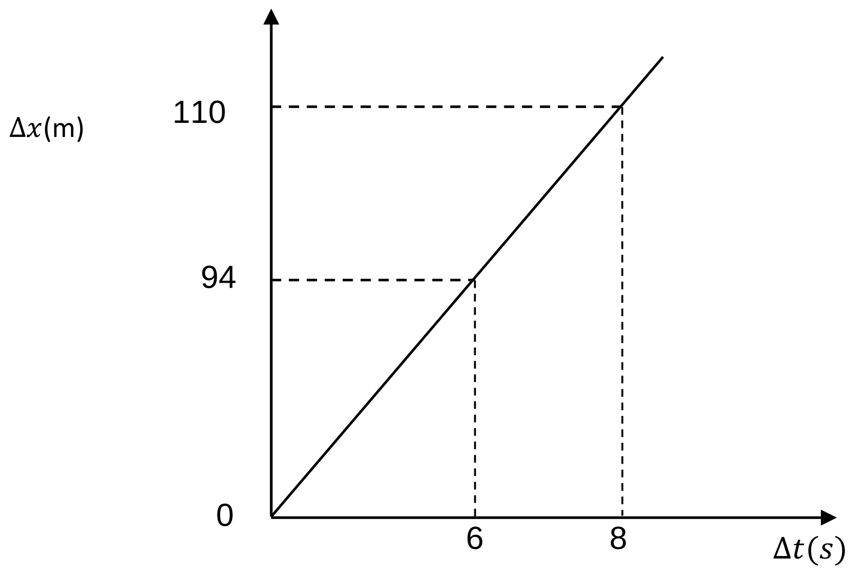
NB: THE GRAPH IS NOT DRAWN ACCORDING TO SCALE



3.1 Write down the frequency of the source (1)

3.2 Explain in terms of the wave motion why the detector registers different frequencies (2)

Another learner records the time taken for the first learners to move from the point of sound source to a particular point.
The graph below shows a position – time graph of the motion
NB: THE GRAPH IS NOT DRAWN ACCORDING TO SCALE



3.3 Calculate the velocity of sound on that particular day (7)

3.4 Name the TWO applications of Doppler effect in the medicinal field (2)

SOLUTIONS

3.1 871 Hz ✓ (1)

3.2. As the learners stands next to the sound source, the detector registers a frequency of the source because there is no relative motion.✓ As the learner moves away from the source the waves becomes stretched out, ✓ the wavelength becomes longer and the frequency becomes lower ✓

(3)

3.3 **v =** $\frac{\Delta x}{\Delta t}$ ✓

$= \frac{110-94}{8-6}$ ✓

= 8 m.s^{-1}

$f = \frac{v \pm v_L}{v \pm v_s} \cdot f_s$ ✓

850 ✓ $= \frac{v-8}{v}$ ✓ $\times 871$ ✓

v = 331,81 m.s^{-1} ✓ (7)

3.4 Used to measure the direction and the speed of blood flow in arteries and vein✓

Used to monitor the heartbeat of a newly formed foetus ✓ (2)

ACTIVITIES

QUESTION 1

The siren of a stationary police car emits sound waves of wavelength 0,55 m.With its siren on, the police car now approaches a stationary listener at constant velocity on a straight road. Assume that the speed of sound in air is 345 $m\cdot s^{-1}$.

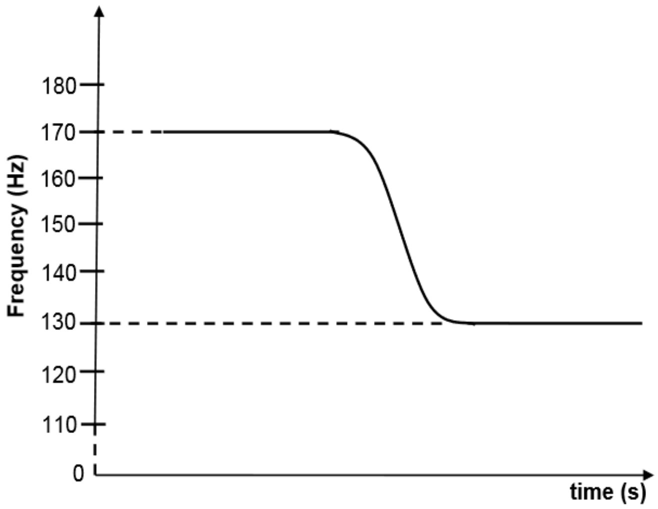
1.1. Will the wavelength of the sound waves observed by the listener be GREATER THAN, SMALLER THAN or EQUAL TO 0,55 m? (1)

1.2 Name the phenomenon observed in QUESTION 3.1. (1)

1.3 Calculate the frequency of the sound waves observed by the listener if the car approaches him at a speed of 120 $km\cdot h^{-1}$ (7)

QUESTION 2

A police car moving at a constant velocity with its siren on, passes a stationary listener. The graph below shows the changes in the frequency of the sound of the siren detected by the listener. Take the speed of sound in air to be 340 $m\cdot s^{-1}$.



2.1 Write down the frequency of the sound detected by the listener as the police car:

2.1.1 Approaches the listener (1)

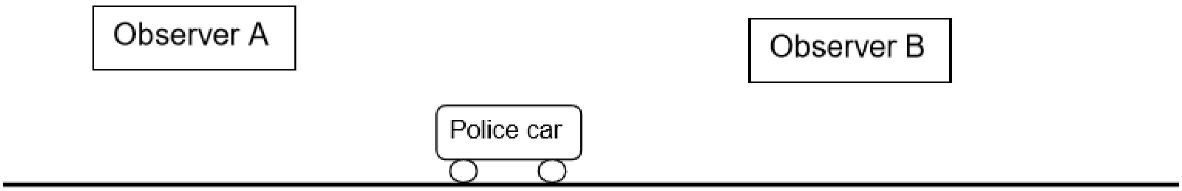
2.1.2 Moves away from the listener (1)

2.2 Calculate the speed of the police car. (6)

QUESTION 3

A police car is moving at a constant speed on a straight horizontal road. The siren of the car emits sound of constant frequency. EACH of two observers, A and B, standing some distance apart on the same side of the road, records the frequency of the detected sound.

Observer A records a frequency of 690 Hz and observer B records a frequency of 610 Hz.



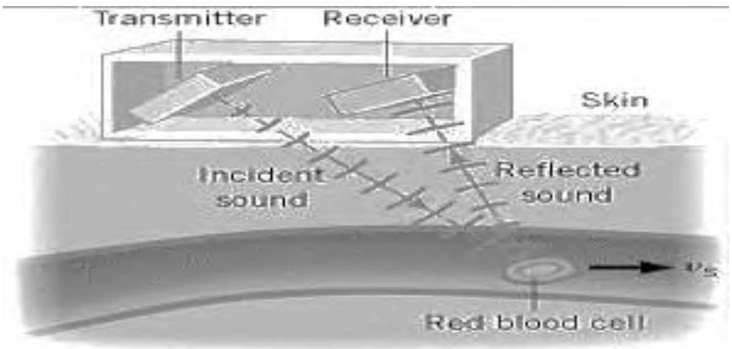
3.1 In which direction is the car moving? Choose from TOWARDS A or AWAY FROM A. Give a reason for the answer. (2)

3.2 Determine the speed of the police car. Take the speed of sound in air as 340 $m.s^{-1}$ (6)

3.3 Name ONE application of the Doppler effect. (1)

QUESTION 4

Use the diagram below to answer the following questions.



4.1 Identify the medical device shown in the diagram. (1)

4.2 Explain briefly how the device functions and what it may be used for. (2)

QUESTION 5

5.1 An ambulance is moving towards a stationary listener at a constant speed of 30 m·s^{-1}. The siren of the ambulance emits sound waves having a wavelength of 0,28 m. Take the speed of sound in air as 340 m·s^{-1}.

5.1.1 Calculate the frequency of the sound waves emitted by the siren as heard by the ambulance driver. (3)

5.1.2 Calculate the frequency of the sound waves emitted by the siren as heard by the listener. (5)

5.1.3 How would the answer to QUESTION 7.1.2 change if the speed of the ambulance were LESS THAN 30 m·s^{-1}? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

5.2 An observation of the spectrum of a distant star shows that it is moving away from the Earth. Explain, in terms of the frequencies of the spectral lines, how it is possible to conclude that the star is moving away from the Earth. (2)

6. A stationary bat sends out a sound signal and receives the same signal reflected from a moving moth at a frequency of 230,3 kHz.

6.1 Calculate the speed of this sound wave through the air (3)

6.2.1 Is the moth moving TOWARDS or AWAY FROM the bat? (1)

6.2.2 Calculate the magnitude of the velocity of the moth, assuming that the velocity is constant. (6)

QUESTION 7

The data below was obtained during an investigation into the relationship between the different velocities of a moving sound source and the frequencies detected by a stationary listener for **each** velocity. The effect of wind was ignored in this investigation.

EXPERIMENT	**1**	**2**	**3**	**4**
VELOCITY OF SOUND SOURCE	**0**	**10**	**20**	**30**
FREQUENCY OF SOUND DETECTED BY THE STATIONARY LISTENER	**900**	**874**	**850**	**827**

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

7.1.2 State the Doppler effect in words. (2)

7.1.3 Was the sound source moving TOWARDS or AWAY FROM the listener? Give a reason for the answer. (2)

7.1.4 Use the information in the table to calculate the speed of sound during the investigation. (5)

7.2 The spectral lines of a distant star are shifted towards the longer wavelengths of light. Is the star moving TOWARDS or AWAY FROM the Earth? (1)

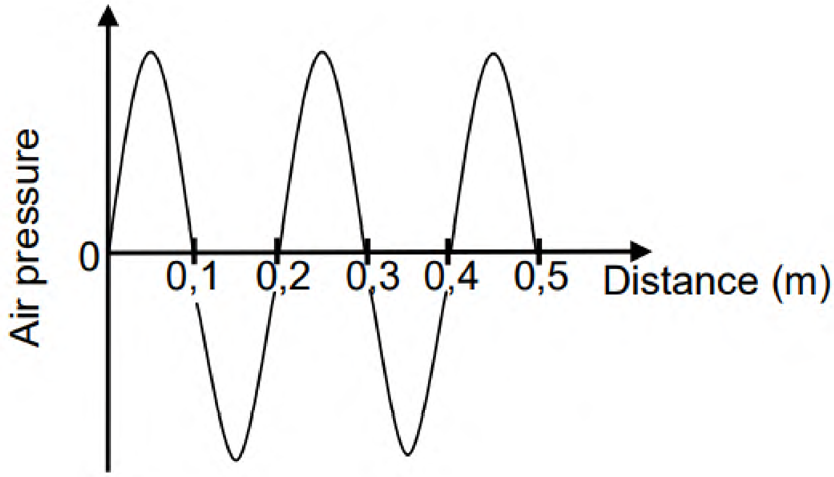
QUESTION 8

A bird flies directly towards a stationary birdwatcher at constant velocity. The bird constantly emits sound waves at a frequency of 1 650 Hz. The birdwatcher hears a change in pitch as the bird comes closer to him.

8.1 Write down the property of sound that is related to pitch. (1)

8.2 Give a reason why the birdwatcher observes a change in pitch as the bird approaches him. (1)

The air pressure versus distance graph below represents the waves detected by the birdwatcher as the bird comes closer to him. The speed of sound in air is 340 $m \cdot s^{-1}$.



8.3 From the graph, write down the wavelength of the detected waves. (1)

8.4 Calculate the:

8.4.1 Frequency of the waves detected by the birdwatcher (3)

8.4.2 Magnitude of the velocity at which the bird flies (5)

ELECTROSTATICS (COULOMB'S LAW)

Revision grade 10 work

Two types of charges

- All materials contain **positive charges** (protons) and **negative charges** (electrons)
- **Positively charged objects** are electron deficient(shortage of electrons)
- **Negatively charged objects** have an excess of electrons
- **Neutral object** has an equal number of electrons and protons (no net charge)

Charged objects exert forces on each other:

- Like charges repel each other – **repulsion force**
- unlike charges attract each other – **attraction force**

Objects can be charged by tribo-electric charging.

- **Tribo-electric charging**: A type of contact electrification in which certain materials become electrically charged after they come into contact with different materials and are then separated (such as through rubbing).

Charge conservation

- State that the SI unit for electric charge is the coulomb (C).
- State the **principle of conservation of charge**: The net charge of an isolated system remains constant during any physical process e.g. two charges making contact and then separating.
- Apply the principle of conservation of charge. When two identical conducting objects having charges Q_1 and Q_2 on insulating stands touch, each object has the same final charge on separation.
- Final charge after separation: $Q = \frac{Q_1+Q_2}{2}$

Charge quantization

- State the principle of charge quantization: All charges in the universe consist of an integer multiple of the charge on one electron, i.e. 1,6 x 10^{-19} C.
- Apply the **principle of charge quantization**: $n = \frac{Q}{q_e}$, where q_e= 1,6 x 10^{-19} C and n is an integer (number of electrons).

Coulomb's law

- State **Coulomb's law**: The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them.
- In symbols: $F = \frac{kQ_1Q_2}{r^2}$, where

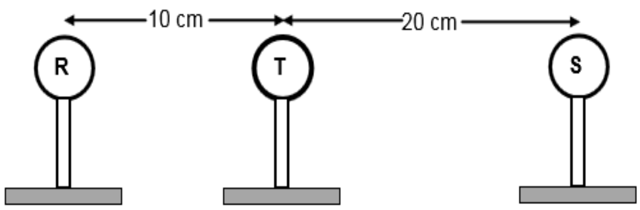
F= electrostatic force measured in Newtons (N)

Q_1 and Q_2 = charges measured in Coulombs (C)

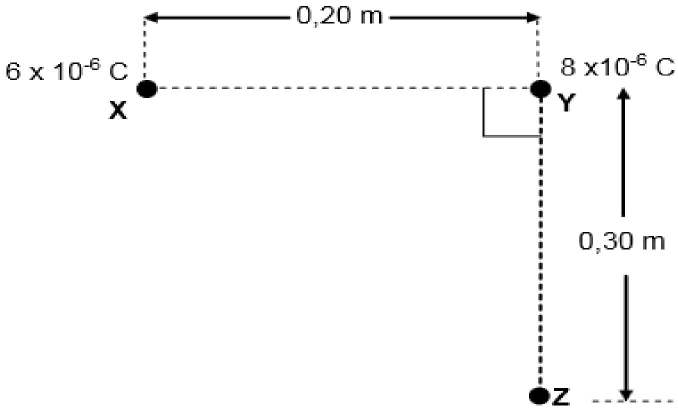
r = distance measured in metres (m)

k = Coulombs Law constant ($9 \times 10^9 N \cdot m^2 \cdot C^{-2}$)

- Solve problems for charges in one dimension 1- D (restrict to three charges in a straight line).Eg

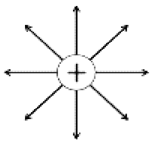


- Solve problems using the equation for charges in two dimensions (2D) – for three charges in a right-angled formation (limit to charges at the 'vertices of a right-angled triangle'). E.g

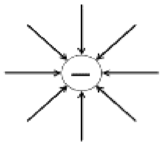


ELECTRIC FIELD

- Describe an **electric field** as a region of space in which an electric charge experiences a force.
- The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.
  - A single point charge

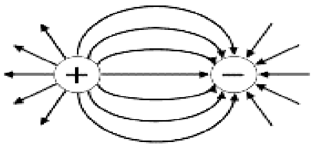


Positive

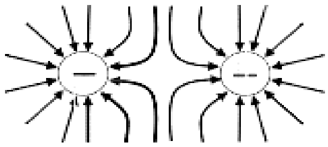


Negative

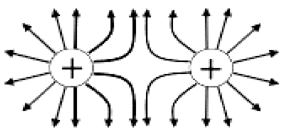
  - Two point charges (one positive , one negative)



  - Both negative



  - both positive



NOTE: Restrict to situations in which the charges are identical in magnitude.

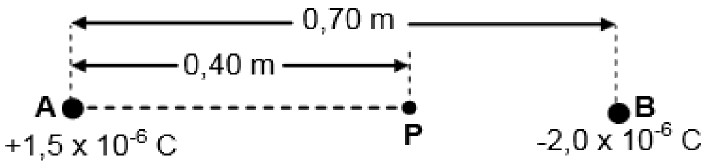
- Define **electric field at a point**: The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point.
- In symbols: $E = \frac{F}{q}$, where

E = electric field measured in Newton per Coulomb ($N.C^{-1}$)

F = electrostatic force measured in Newton (N)

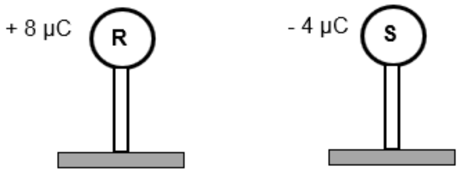
q = charge measured in Coulombs (C) (a charge that will experience a force)

- Calculate the electric field at a point due to a number of point charges, using the equation $E = \frac{kQ}{r^2}$ to determine the contribution to the field due to each charge. (Restrict to three charges in a straight line). E.g



WORKED EXAMPLE 1:

The diagram below shows two small identical metal spheres, **R** and **S**, each placed on a wooden stand. Spheres **R** and **S** carry charges of + 8 μC and - 4 μC respectively. Ignore the effects of air.

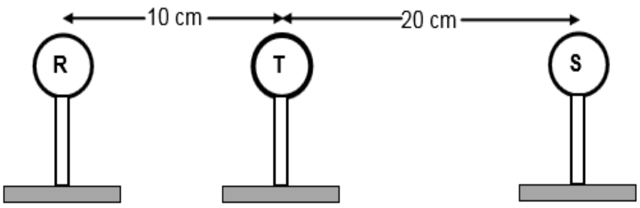


Spheres **R** and **S** are brought into contact for a while and then separated by a small distance.

1. Calculate the final charge on each of the spheres.

2. Draw the electric field pattern due to the two spheres **R** and **S**.

After **R** and **S** have been in contact and separated, a third sphere, **T**, of charge +1 μC is now placed between them as shown in the diagram below.



3. Draw a free-body diagram showing the electrostatic forces experienced by sphere **T** due to spheres **R** and **S**.

4. Calculate the net electrostatic force experienced by **T** due to **R** and **S**.

5. Define the *electric field at a point*.

6. Calculate the magnitude of the net electric field at the location of **T** due to **R** and **S**. (Treat the spheres as if they were point charges.)

Solutions

Data : $Q_R = +8\ \mu C$

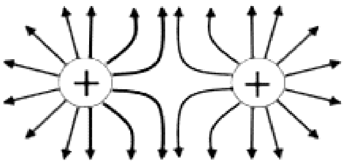
$Q_S = -4\ \mu C$

1. $$Q = \frac{Q_1 + Q_2}{2}$$

$$Q = \frac{+8 + (-4)}{2}$$

$Q = \ = 2\mu C$

2.



3. DATA:

$Q_R = +2X10^{-6}$ C

$Q_S = +\ 2X10^{-6}$ C

$Q_T = +1X10^{-6}$ C

$r_{RT} = 10cm \div 100 = 0.1m$

$r_{TS} = 20cm \div 100 = 0.2m$

$k = 9x10^9\ N.m^2C^{-2}$

$$F_{RT} = \frac{k\,Q_1Q_2}{r^2}$$

$$F_{RT} = \frac{9\times10^9\times2\times10^{-6}\times1\times10^{-6}}{(0{,}1)^2}$$

= 1.8N to the right

$$F_{ST} = \frac{k\,Q_1Q_2}{r^2}$$

$$F_{RT} = \frac{(9\times10^9)(2\times10^{-6})(1\times10^{-6})}{(0{,}2)^2}$$

= 0.45N to the left

$F_{net} = F_{RT} + F_{ST}$

= 1.8+(-0.45)

= 1.35 N to the right

5. The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point.

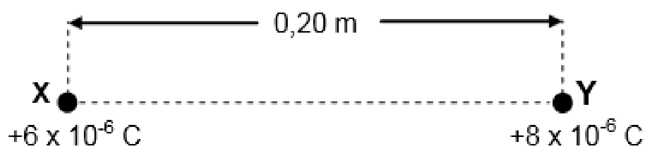
6. $E = \frac{F}{q}$

$E = \frac{1{,}35}{1 \times 10^{-6}}$

$= 1{,}35 \times 10^{6}\ N.C^{-1}$

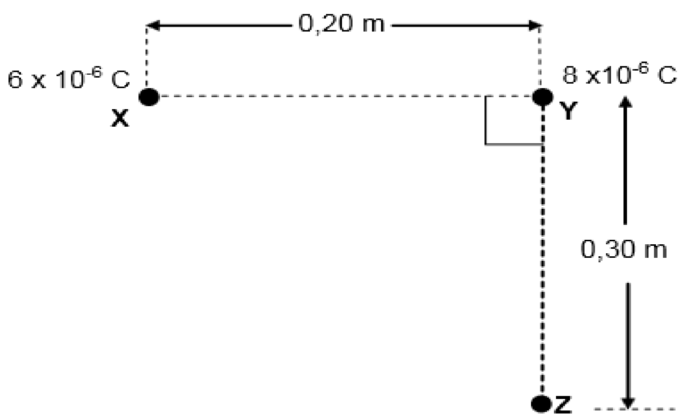
WORKED EXAMPLE 2:

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



1. State Coulomb's law in words.
2. Calculate the magnitude of the electrostatic force experienced by charged sphere **X**.

A third sphere, **Z**, of unknown **negative** charge, is now placed at a distance of 0,30 m below sphere **Y**, in such a way that the line joining the charged spheres **X** and **Y** is perpendicular to the line joining the charged spheres **Y** and **Z**, as shown in the diagram below.



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

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

Solutions

DATA:

$Q_X = +6 \times 10^{-6}$ C

$Q_Y = +8 \times 10^{-6}$ C

$R_{XY} = 0{,}20$m

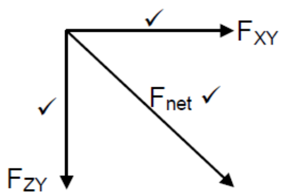
1. The magnitude of the electrostatic force exerted by one point charge on another point charge is directly proportional to the product of the (magnitudes of the) charges and inversely proportional to the square of the distance (r) between them.

2.
$$F_{XY} = \frac{kQ_1Q_2}{r^2}$$

$$F_{XY} = \frac{(9\times10^9)(6\times10^{-6})(8\times10^{-6})}{(0{,}2)^2}$$

$$= 10.8 \text{ N}$$

3.



4. DATA:

$Q_Z = ?$

$r_{YZ} = 0{,}30$m

$F_{net} = 15{,}20$ N

$(F_{net})^2 = (F_{XY})^2 + (F_{ZY})^2$

$(15.20)^2 = (10.8)^2 + (F_{XY})^2$

$F_{ZY} = 10.696$ N

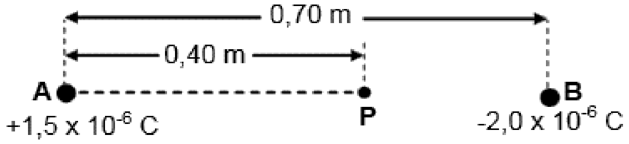
$$F_{ZY} = \frac{kQ_1Q_2}{r^2}$$

$$10{,}696 = \frac{(9\times10^9)(8\times10^{-6})(Q)}{(0{,}30)^2}$$

$Q_Z = 1.34 \times 10^{-5}$ C

WORKED EXAMPLE 3:

A and **B** are two small spheres separated by a distance of 0,70 m. Sphere **A** carries a charge of +1,5 x 10^{-6} C and sphere **B** carries a charge of -2,0 x 10^{-6} C.



P is a point between spheres **A** and **B** and is 0,40 m from sphere **A**, as shown in the diagram above.

1. Define the term *electric field at a point*.
2. Calculate the magnitude of the net electric field at point **P**.
3. A point charge of magnitude 3,0 x 10^{-9} C is now placed at point **P**.

   Calculate the magnitude of the electrostatic force experienced by this charge.

SOLUTIONS

DATA:

$Q_A = +1.5X10^{-6}C$

$Q_B = -2X10^{-6}C$

$r_{AB} = 0.70m$

$r_{AP} = 0.40m$

1. Electric field at a point is the force per unit positive charge placed at that point.

2. $E_{net} = E_A + E_B$

$$E_{net} = \frac{kQ}{r^2} + \frac{kQ}{r^2}$$

$$E_{net} = \frac{(9\times10^9)(6\times10^{-6})}{(0,4)^2} + \frac{(9\times10^9)(2,0\times10^{-6})}{(0,3)^2}$$

$E_{net} = 2.84 \times 10^5$ N.C^{-1}

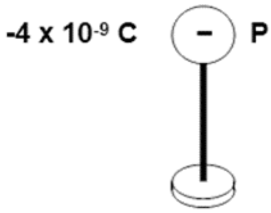
3.
$$E = \frac{F}{q}$$

$$2,84\times10^5 = \frac{F}{3\times10^{-9}}$$

F = 8,52 x 10^{-4} N

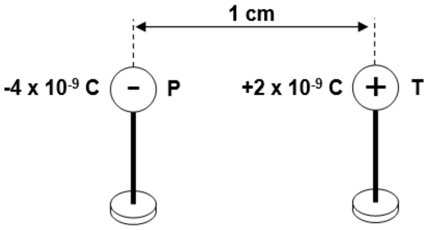
WORKED EXAMPLE 4:

The diagram below shows a small metal sphere **P** on an insulated stand. The sphere carries a charge of -4 x 10^{-9} C, as shown in the diagram.



1. Draw the electric field pattern around sphere **P**
2. Calculate the number of electrons in excess on sphere **P**.

A second metal sphere **T** carrying a charge of +2 x 10^{-9} C is placed 1 cm from sphere **P**, as shown in the diagram below



3. Calculate the magnitude of the electrostatic force that sphere **P** exerts on sphere **T**.

The spheres are now brought into contact with each other and returned to their original positions.

4. Calculate the final charge after they are separated and returned to their original positions.

5. Calculate the magnitude of the electrostatic force that sphere **P** exerts on sphere **T** after they are separated and returned to their original positions.

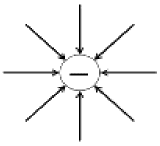
Solutions
DATA:

Q_P = -4 x 10^{-9} C

Q_T = +2 x 10^{-9} C

r_{AB} = 1cm ÷ 100 = 0.01m

1.



2.
$$n = \frac{Q}{q_e}$$

$$n = \frac{-4 \times 10^{-9}}{-1{,}6 \times 10^{-19}}$$

n = 2.5×10^{10} electrons

3.
$$F_{PT} = \frac{k\,Q_1 Q_2}{r^2}$$

$$F_{XY} = \frac{(9 \times 10^{9})(4 \times 10^{-9})(2 \times 10^{-9})}{(0{,}01)^2}$$

= 7.2×10^{-4} N

4.
$$Q = \frac{Q_1 + Q_2}{2}$$

$$Q = \frac{(-4 \times 10^{-9}) + (2 \times 10^{-9})}{2}$$

Q = $-1 \mathrm{X} 10^{-9}$C

5.
$$F_{PT} = \frac{k\,Q_1 Q_2}{r^2}$$

$$F_{PT} = \frac{(9 \times 10^{9})(1 \times 10^{-9})(1 \times 10^{-9})}{(0{,}01)^2} \mathrm{A}$$

F_{PT} = $9 \mathrm{X} 10^{-5}$ N

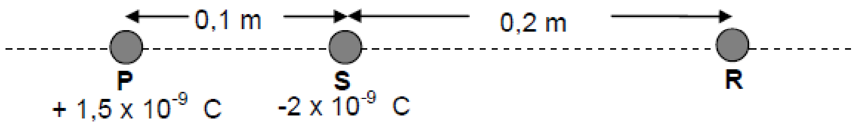
ACTIVITIES

Question 1

Two point charges, P and S, are placed a distance 0,1 m apart. The charge on

P is +1,5 x 10^{-9} C and that on S is -2 x 10^{-9} C.

A third point charge, R, with an unknown positive charge, is placed 0,2 m to the right of point charge S, as shown in the diagram below.



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

1.2 Draw a labelled force diagram showing the electrostatic forces acting on **R** due to **P** and **S**. (2)

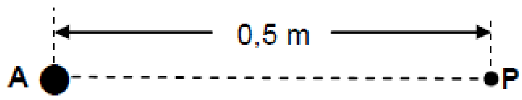
1.3 Calculate the magnitude of the charge on **R**, if it experiences a net electrostatic force of 1,27 x 10^{-6} N to the left.

Take forces directed to the right as positive. (7)

[11]

Question 2

P is a point 0,5 m from charged sphere **A**. The electric field at **P** is 3 x 10^{7} N·C^{-1} directed towards **A**. Refer to the diagram below.



2.1 Draw the electric field pattern due to charged sphere **A**. Indicate the sign of the charge on the sphere in your diagram. (2)

2.2 Calculate the magnitude of the charge on sphere **A**. (3)

Another charged sphere, **B**, having an excess of 10^{5} electrons, is now placed at point **P**.

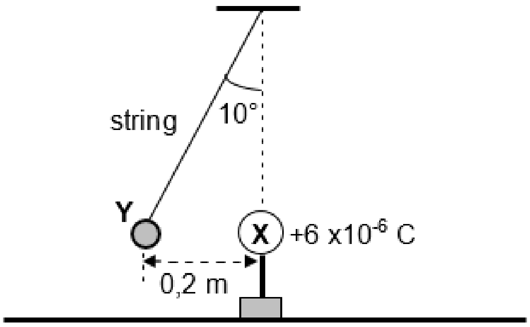
2.3 Calculate the electrostatic force experienced by sphere **B**. (7)

[12]

Question 3

3.1 A small sphere, **Y**, carrying an unknown charge, is suspended at the end of a light inextensible string which is attached to a fixed point. Another sphere, **X**, carrying a charge of +6 x10^{-6} C, on an insulated stand is brought close to sphere **Y**.

Sphere **Y** experiences an electrostatic force and comes to rest 0,2 m away from sphere **X**, with the string at an angle of 10° with the vertical, as shown in the diagram below.



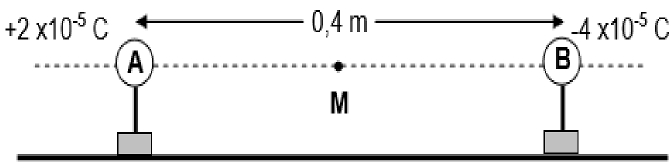
3.1.1 What is the nature of the charge on sphere **Y**? Choose from POSITIVE or NEGATIVE. (1)

3.1.2 Calculate the magnitude of the charge on sphere **Y** if the magnitude of the electrostatic force acting on it is 3,05 N. (3)

3.1.3 Draw a labelled free-body diagram for sphere **Y**. (3)

3.1.4 Calculate the magnitude of the tension in the string. (3)

3.2 Two small charged spheres, **A** and **B**, on insulated stands, with charges +2 x10^{-5} C and -4 x10^{-5} C respectively, are placed 0,4 m apart, as shown in the diagram below. **M** is the midpoint between spheres **A** and **B**.



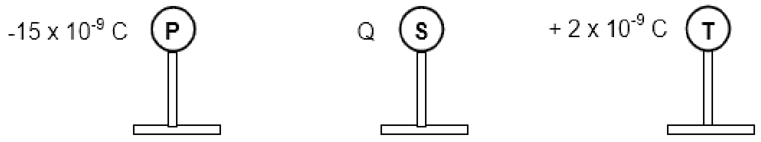
3.2.1 Define the term *electric field at a point*. (2)

3.2.2 Calculate the net electric field at point **M**. (6)

[18]

Question 4

Three small identical metal spheres, **P**, **S** and **T**, on insulated stands, are **initially neutral**. They are then charged to carry charges of -15×10^{-9} C, Q and $+2 \times 10^{-9}$ C respectively, as shown below.

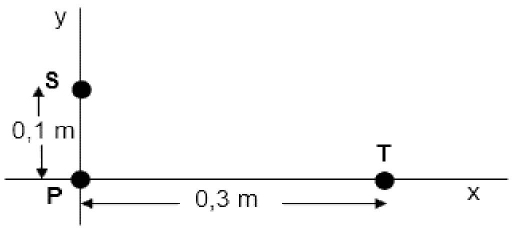


The charged spheres are brought together so that all three spheres touch each other at the same time, and are then separated. The charge on each sphere, after separation, is -3×10^{-9} C.

4.1 Determine the value of charge Q. (2)

4.2 Draw the electric field pattern associated with the charged spheres, **S** and **T**, **after they are separated** and returned to their original positions. (3)

The spheres, each with the **new charge** of -3×10^{-9} C, are now placed at points on the *x*-axis and the *y*-axis, as shown in the diagram below, with sphere **P** at the origin.



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

Calculate the magnitude of the:

4.4 Net electrostatic force acting on sphere **P** (5)

4.5 Net electric field at the origin due to charges **S** and **T** (3)

4.6 ONE of the charged spheres, **P** and **T**, experienced a very small increase in mass **after it was charged initially**.

4.6.1 Which sphere, **P** or **T**, experienced this very small increase in mass? (1)

4.6.2 Calculate the increase in mass by the sphere in QUESTION 4.6.1. (3)

[19]

ELECTRIC CIRCUITS

Current is the rate of flow of charge. In symbols:

$$I = \frac{\Delta Q}{\Delta t}$$

The amount of **energy transferred per coulomb of charge** is called the **potential difference**. In symbols:

$$V = \frac{W}{Q}$$

The same equation can be used to define the following:
EMF as the **maximum or total energy transferred per unit charge by the battery**
''Lost volts'' as the **energy transferred per unit charge inside the battery.**

Ohm's Law: potential difference (V) **across** it, is directly proportional to the the current (I) **through** a conductor provided the temperature remains constant. In symbols:

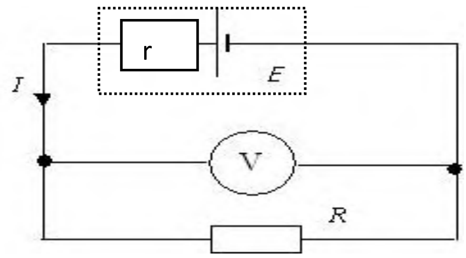
$$R = \frac{V}{I}$$

An Ampere is 1 coulomb of charge that passes a point per second
A Volt is 1 joule of energy transferred per unit coulomb.
A watt is 1 joule of energy that passes a point per second.

INTERNAL RESISTANCE

Internal resistance is defined as **the opposition of flow of charge within the battey**A battery is said to produce an **emf** (electromotive force). EMF is equivalent to the reading on the voltmeter across the terminals of the battery when there is no current flowing.

Suppose we now add a load (component with resistance) as shown in the circuit diagram below. We will assume the wires have **negligible** resistance.



This time we find that the terminal potential difference (voltage) drops from Ɛ to *V*. Since V is **less** than the EMF, it tells us that not all of the potential difference (voltage) is transferred to the external circuit. Some voltage is "lost" due to the internal resistance of the battery causing the battery to become hot.

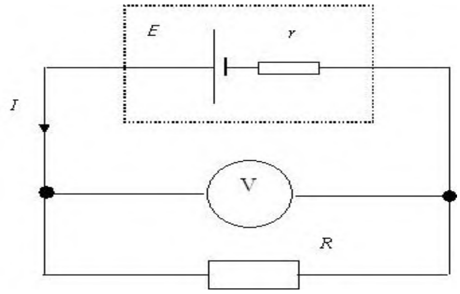
EMF = terminal voltage + lost voltage

In symbols: $\varepsilon = V_{terminal} + V_{lost}$

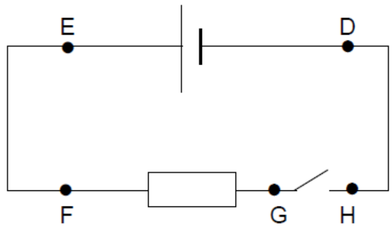
$= I(R + r)$

$= IR + Ir$

We can thus represent the circuit as in the accompanying circuit diagram.

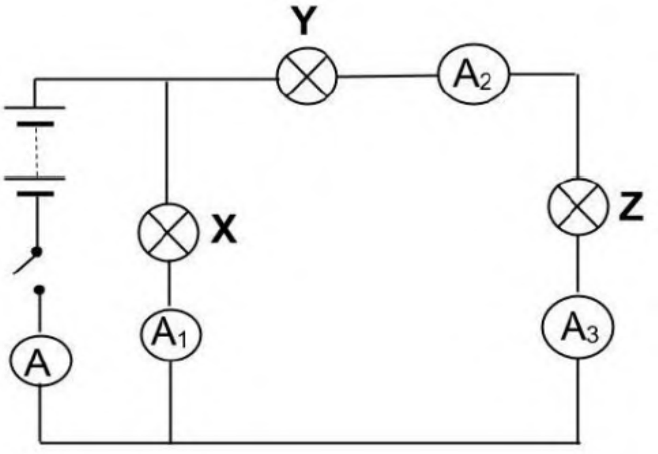


We can now treat this as a simple series circuit and we know that the current, I, will be the same throughout the circuit. We also know the potential difference (voltage) in a series circuit add up to the battery potential difference (voltage).

EXAMPLE 1			
1.1	A cell is connected to a resistor and an open switch. Five points in the circuit are labelled D, E, F, G and H respectively.		
			
	A voltmeter will have a zero reading if it is connected across points…		
	A.	ED	
	B.	FH	
	C.	FG	
	D.	GH	
		Answer : C	(2)

1.2 Three light bulbs, **X**, **Y** and **Z**, are connected in a circuit as shown below. **X** and **Y** are identical and both has a resistance **R**, while the resistance of **Z** is **2R**. The battery has negligible internal resistance.

When switch S is closed, all the bulbs glow. The reading on ammeter A is 2,0 A.

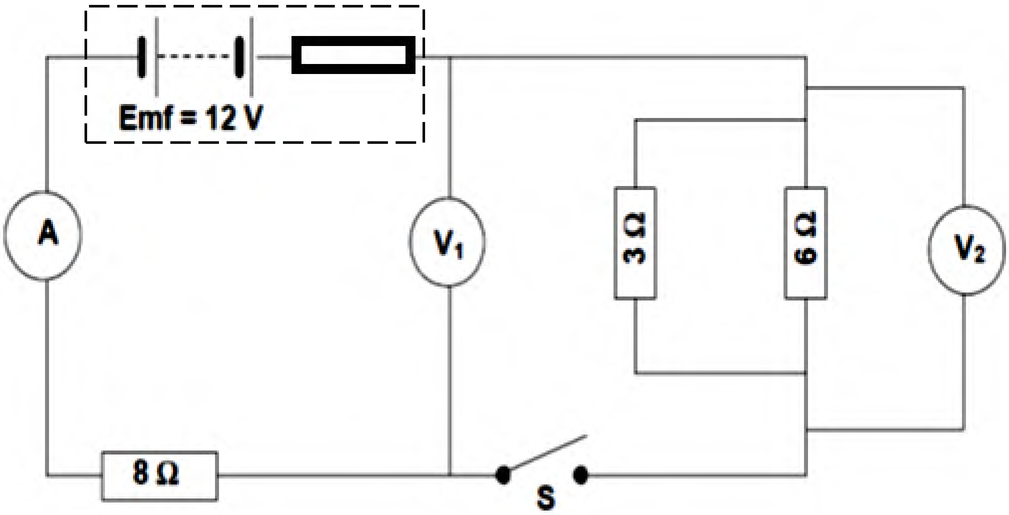


Which ONE of the following correctly describes the readings on the ammeters (in amperes) when bulb Z burns out?

	A_1	A_2	A_3	A
A	2	0	0	2
B	1.5	0	0	1.5
C	0.5	0.5	0	1
D	0.2	0.2	0.2	0.6

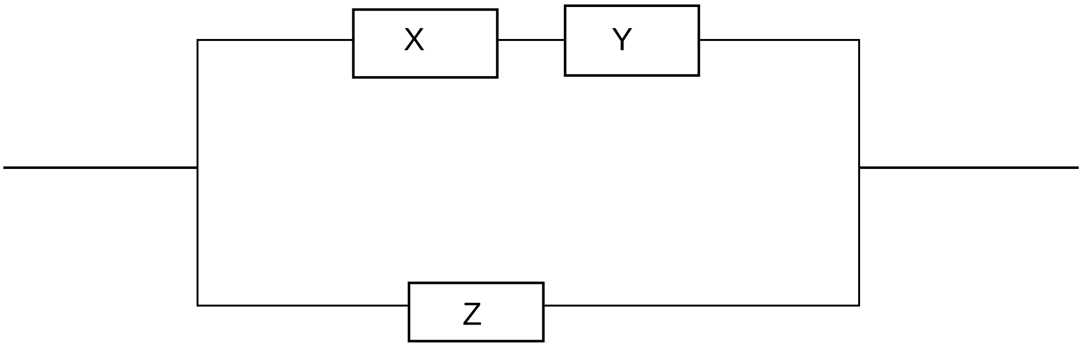
Answer : B **(2)**

1.3	In the circuit represented below, the battery has an emf of 12 V. The resistance of the connecting wires and ammeter can be ignored. The battery has an internal resistance of 1 Ω.	



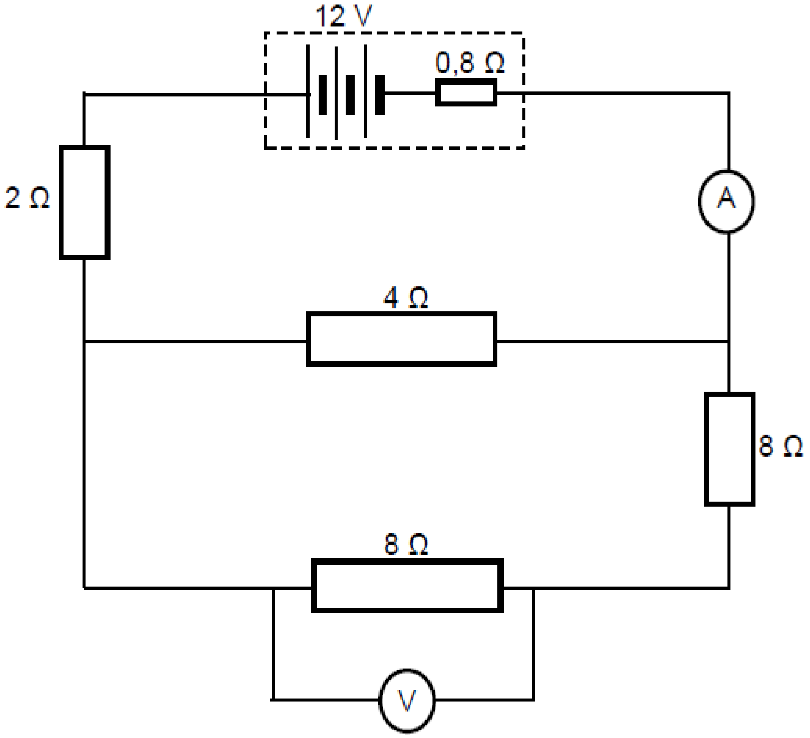
	1.3.1	State, in words, Ohm's Law.	(2)
		Switch S is open.	
	1.3.2	What is the reading on V1?	(1)
	1.3.3	What is the reading on V2?	(1)
		Switch S is then closed.	
	1.3.4	Calculate the effective resistance of the entire circuit.	(5)
	1.3.5	Calculate the charge moving past a cross section of the 8 Ω in one minute.	(5)
			[18]
	1.3.1	*The potential difference across the conductor is directly proportional to the current at constant temperature*√√	
	1.3.2	12 v✓	
	1.3.3	0v ✓	
	1.3.4	$\frac{1}{Rp} = \frac{1}{R1} + \frac{1}{R2}$✓ $= \frac{1}{3} + \frac{1}{6}$✓ $Rp = 2\ \Omega$ $Rext = 2 + 8$✓$= 10\ \Omega$	

		$Reff = 10 + 1 ✓ = 11\ \Omega ✓$	
	1.3.5	$Emf = I(R + r) ✓$ 12 = I(11) ✓ I = 1.09 A $I = \frac{\Delta Q}{\Delta t} ✓$ 1.09 ✓ = $\frac{\Delta Q}{60}$ $\Delta Q = 65.40\ C ✓$	
EXAMPLE 2			
2.1	The three resistors shown in the section of an electric circuit below are identical.		



		How do the potential differences across the individual resistors compare?	
	A.	$V_X = V_Y \neq V_Z$	
	B.	$V_X = V_Y = V_Z$	
	C.	$V_X = 2V_X$	
	D.	$V_X = \frac{1}{4} V_Z$	
		Answer = A	**(2)**

2.2	In the circuit diagram below, the battery has an emf of 12 V and an internal resistance of 0,8 Ω. The resistance of the ammeter and connecting wires may be ignored.	



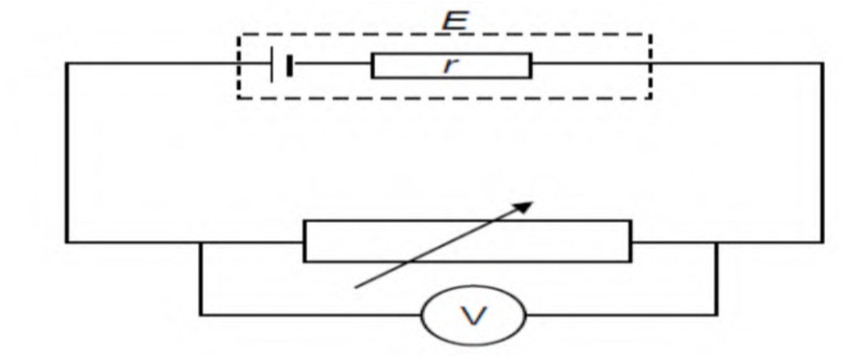
	Calculate the:		
	2.2.1	Effective resistance of the circuit	(4)
	2.2.2	Reading on the ammeter	(3)
	2.2.3	Reading on the voltmeter	(4)
			[13]
	2.2.1	$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ ✓ $= \frac{1}{4} + \frac{1}{16}$ ✓ $\therefore R = 3{,}2\ \Omega$ $R_{effective/effektief} = 3{,}2\ \Omega + 2\ \Omega + 0{,}8\ \Omega$ ✓ $= 6\ \Omega$ ✓	
	2.2.2	emf = I(R + r) ✓ 12 = I(5,2 + 0,8) ✓ I = 2 A ✓	

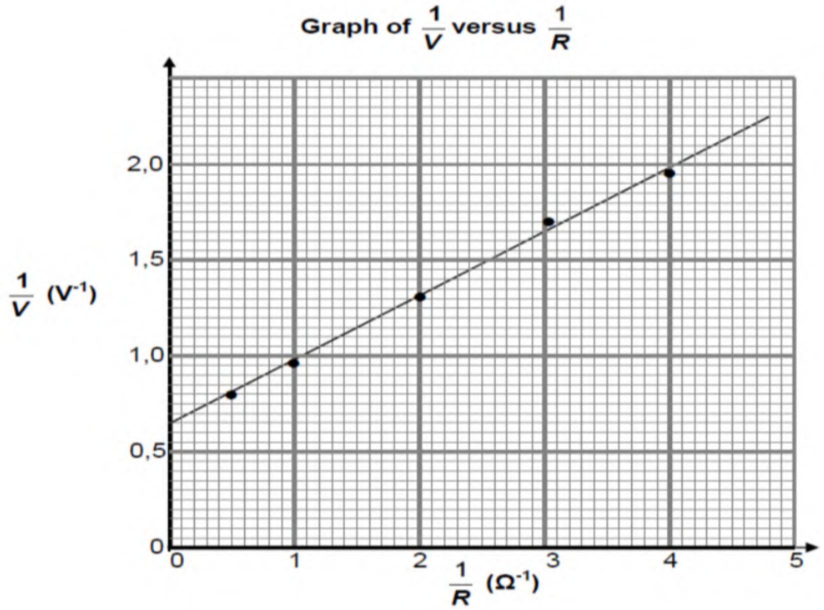
2.2.3

Option 1/*Opsie 1*:	**Option 2/*Opsie 2*:**
$V_{parallel} = IR$ ✓ $=(2)(3,2)$ ✓ $= 6,4\ V$ $V_{8\Omega} = \frac{6,4}{2}$ ✓ $= 3,2\ V$ ✓	$Vp = \frac{R_p}{R} \times V$ ✓ $= \frac{3,2}{6}$ ✓ $\times 12$ ✓ $= 6,4\ V$ $\therefore V_{8\Omega} = 3,2\ V$ ✓
Option 3/*Opsie 3*:	**Option 4/*Opsie 4*:**
$I_{8\Omega} = \frac{4}{20}(2)$ ✓ $= 0,4\ A$ $V_{8\Omega} = IR$ ✓ $= (0,4)(8)$ ✓ $= 3,2\ V$ ✓	emf $= I(R + r)$ ✓ $12 = IR_{2\,\Omega} + V_p + Ir$ $12 = (2)(2) + V_p + (2)(0,8)$ ✓ $Vp = 6,4\ V$ $V_{8\Omega} = \frac{6,4}{2}$ ✓ $= 3,2\ V$ ✓

EXAMPLE 3

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



	The circuit consists of a cell of emf E and internal resistance r. A voltmeter is placed across a variable resistor which can be set to known values R. They obtain the graph below.		
			
		Use the graph to determine the following:	
	3.1.1	The equation of the graph in the form of y=mx+c	(1)
	3.1.2	The mathematical relationship for the slope of the graph	(1)
	3.1.3	Emf of the cell	(2)
	3.1.4	The internal resistance of the cell	(3)
			[7]
	3.1.1	$\frac{1}{V} = \frac{r}{RE} + \frac{1}{E}$	
	3.1.2	$gradient = \frac{r}{E}$ ✓	
	3.1.3	$y\ intercept = \frac{1}{v} = \frac{1}{E} = \frac{0.65}{1}$ ✓ $E = 15.38\ v$ ✓	
	3.1.4	$gradient = \frac{r}{E} = \frac{1.3 - 0.65 ✓}{2 - 0 ✓}$ $\frac{r}{15.38} = 0.325$ $r = 5.00\Omega$ ✓	

ELECTRIC CIRCUITS ACTIVITIES

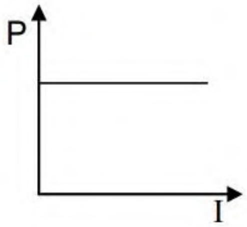
QUESTION 1

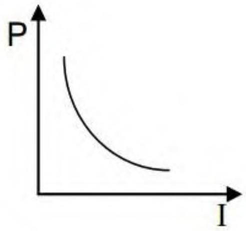
Four possible options are provided as answers to the following questions. Each question has only ONE correct answer. Choose the correct answer

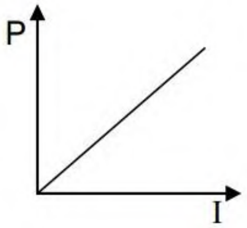
1.1 The unit of measurement for the energy transferred PER UNIT TIME is a…

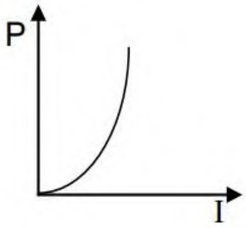
A. Volt
B. Ampere
C. Watt
D. Joule (2)

1.2 Which ONE of the following graphs best represents the relationship between the electrical power and the current in a given ohmic conductor?

A


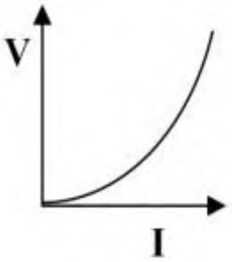
B


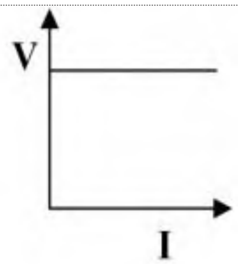
C


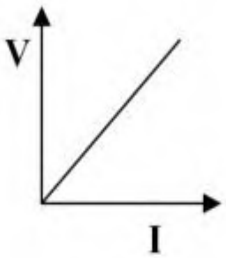
D


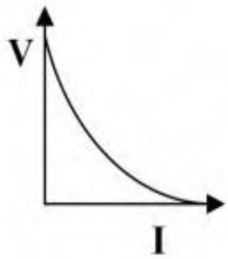
(2)

1.3 Which one of the following graphs best represents the relationship between the potential difference (V) across an ohmic conductor and the current (I) in the conductor at constant temperature?

A


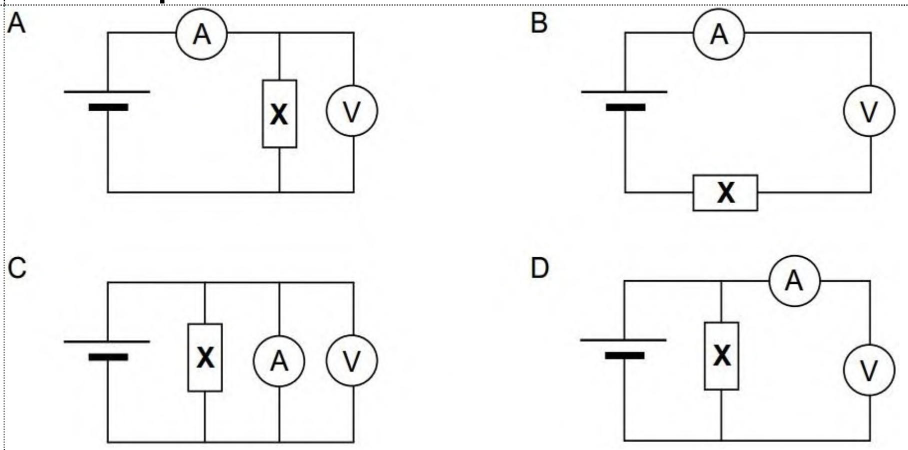
B


C


D


(2)

1.4 Which ONE of the circuits below can be used to measure the current in a conductor X **and the potential difference across its ends?**



(2)

1.5 The table below shows the current in two different electrical appliances when connected to a 240 V AC (alternating current) supply.

Appliance	Current
Toaster	3,5 A
Kettle	7,8 A

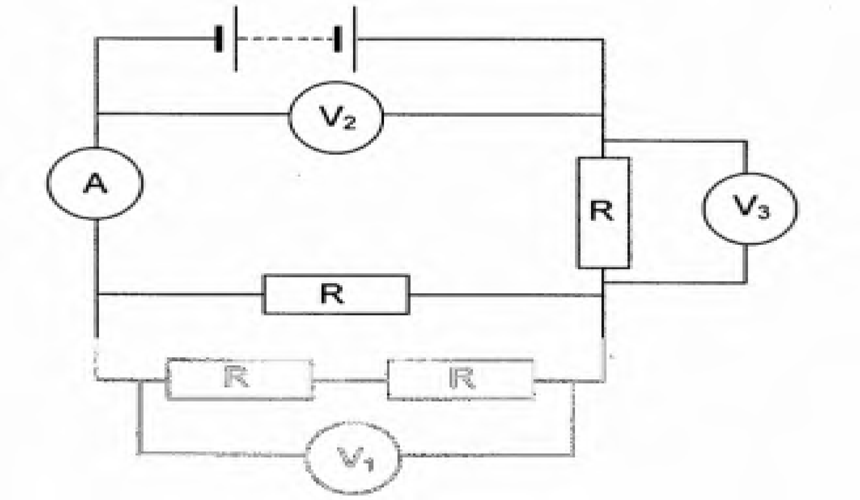
Which ONE of the following combinations is correct for the power dissipated by the appliances and the resistance when the appliances operate at 240 v

	Power dissipated	Resistance
A	$P_{toaster} > P_{kettle}$	$R_{toaster} < R_{kettle}$
B	$P_{toaster} = P_{kettle}$	$R_{toaster} < R_{kettle}$
C	$P_{toaster} < P_{kettle}$	$R_{toaster} > R_{kettle}$
D	$P_{toaster} = P_{kettle}$	$R_{toaster} > R_{kettle}$

(2)

Thabo has two light bulbs, X and Y, marked 100 W and 60 W respectively. He first connects them in parallel (circuit 1) and then in series (circuit 2) in order to compare their brightness in each circuit.

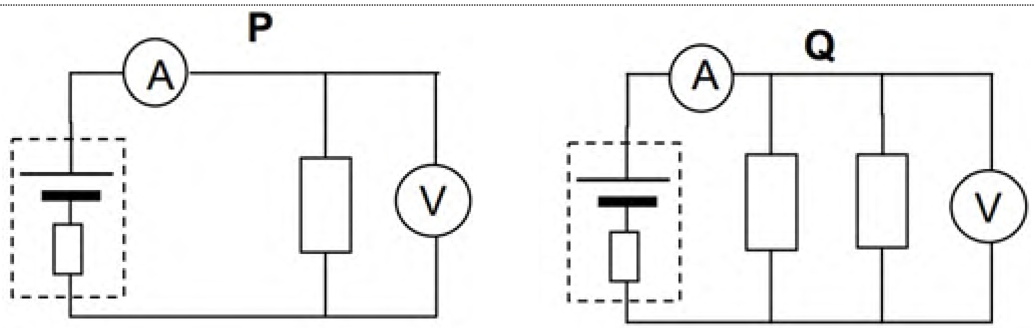
1.6 In the circuit below the battery has internal resistance and all the resistors are identical



Which one of the following statements regarding voltmeter reading is true ? (2)

A. Emf = $V_1 + V_2 + V_3$
B. $V_1 = V_2$ and $V_1 < V_3$
C. $V_2 = V_1 + V_3$
D. Emf = V_2

1.7 In the circuits shown below all resistors and cells are identical.

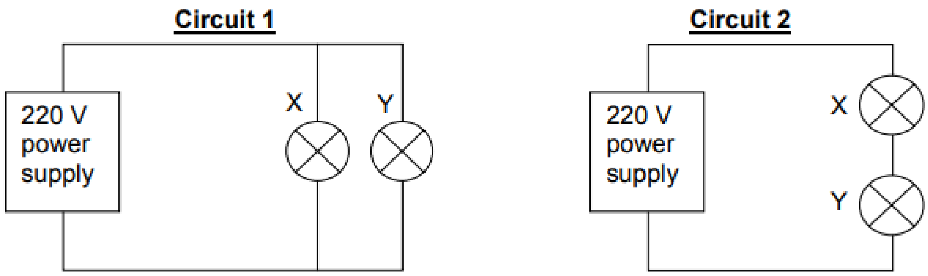


Which ONE of the following gives the correct comparison between the voltmeter and ammeter readings in circuit **P** and **Q**.

	VOLTMETER READING	AMMETER READING
A.	$V_P > V_Q$	$A_P > A_Q$
B.	$V_P > V_Q$	$A_P < A_Q$
C.	$V_P < V_Q$	$A_P = A_Q$
D.	$V_P = V_Q$	$A_P < A_Q$

(2)

1.8 A learner has two light bulbs, X and Y, marked 100 W and 60 W respectively. He first connects them in parallel (circuit 1) and then in series (circuit 2) in order to compare their brightness in each circuit.



Which light bulb, X or Y, glows brighter in each circuit?

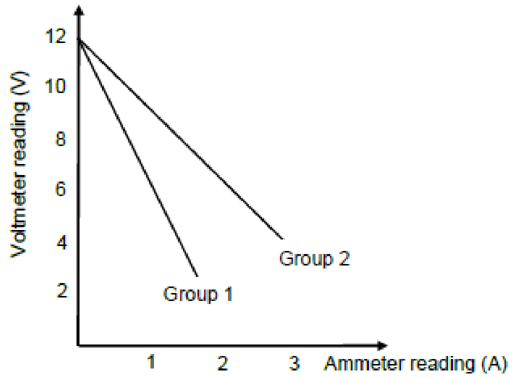
	Bulb that glows brighter in circuit 1	Bulb that glows brighter in circuit 2
A	X	X
B	Y	X
C	X	Y
D	Y	Y

(2)

1.9 Grade 12 learners conduct an experiment to determine the INTERNAL RESISTANCE of a battery. The learners are divided into two groups.

Group 1 uses battery 1 with an internal resistance r1.
Group 2 uses battery 2 with an internal resistance r2.

The results of each group are shown in the graph below.



(2)

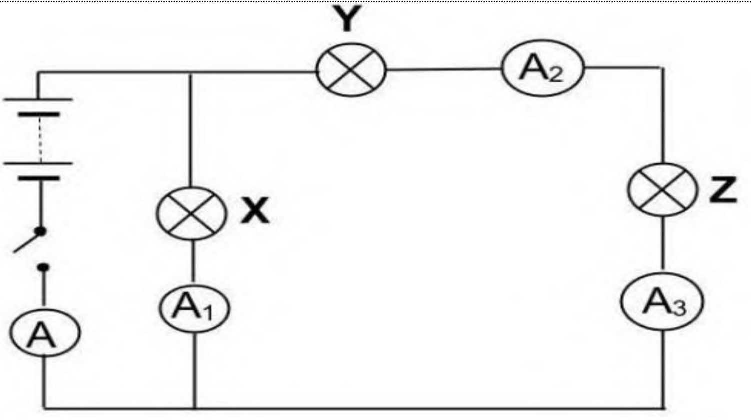
Use the information on the graph and state which option is CORRECT

A	Emf1= Emf2	r1 = r2
B	Emf1>Emf2	r1 < r2
C	Emf1= Emf2	r1 > r2
D	Emf1<Emf2	r1 < r2

1.10 Three light bulbs, **X**, **Y** and **Z**, are connected in a circuit as Shown below. **X** and **Y** are identical and both has a Resistance **R**, while the resistance of **Z** is **2R**.

The battery has negligible internal resistance.

When switch **S** is closed, all the bulbs glow. The reading on ammeter **A** is 2,0 A.



Which ONE of the following correctly describes the readings on the ammeters (in amperes) when bulb **Z** burns out?

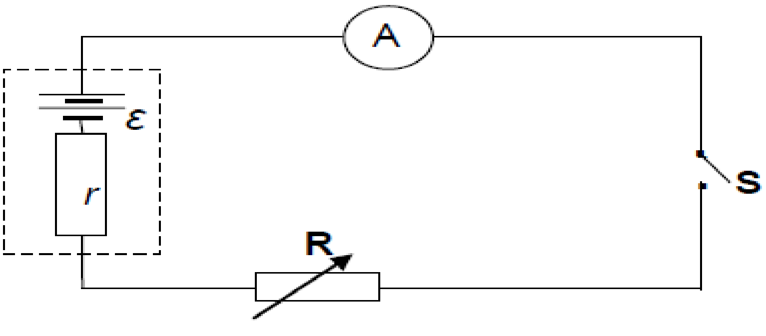
	A_1	A_2	A_3	A
A	2	0	0	2
B	1.5	0	0	1.5
C	0.5	0.5	0	1
D	0.2	0.2	0.2	0.6

(2)

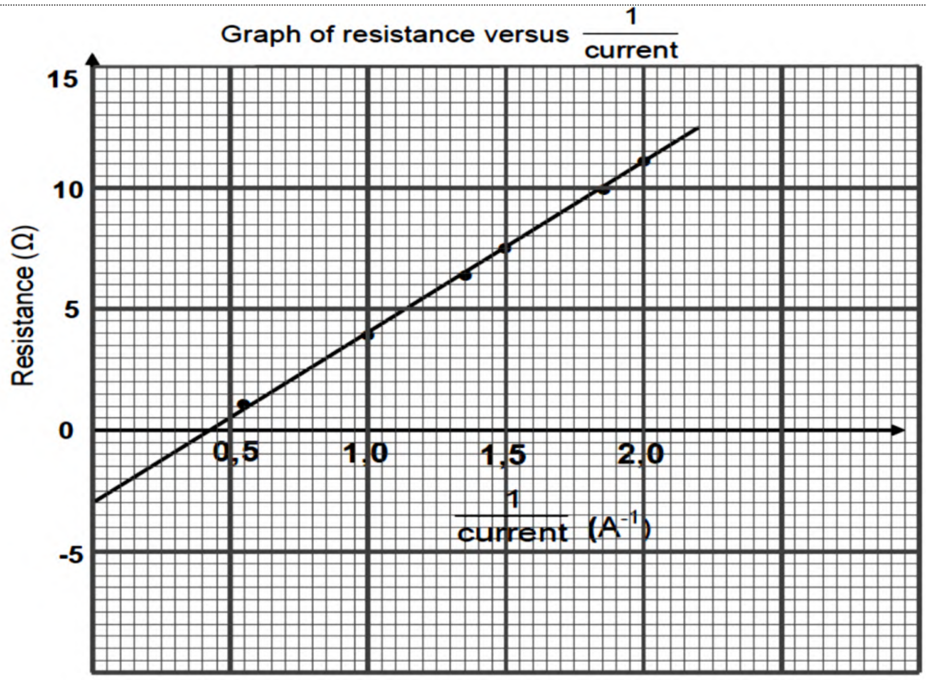
[20]

QUESTION 2

Learners conduct an investigation to determine the emf and the internal resistance of the battery using the circuit below.



The results obtained are shown in the graph below.

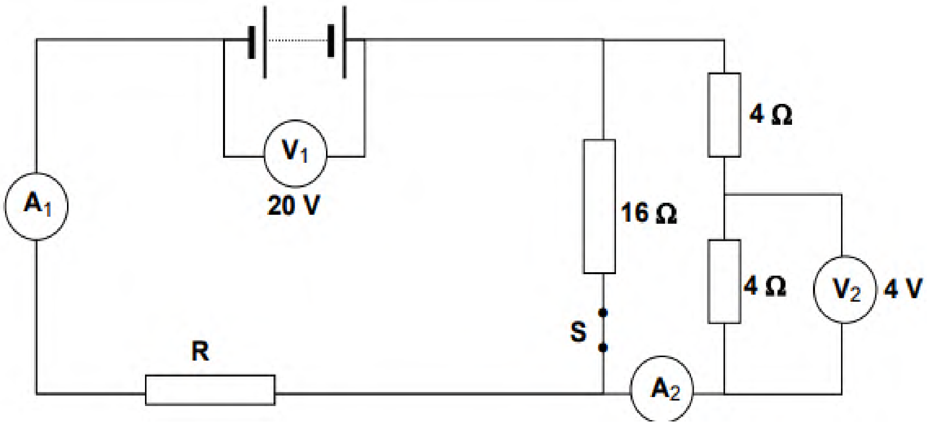


Use the graph to determine the following:

2.1	The equation of the graph in the form of y=mx+c.	(1)
2.2	The value of the internal resistance of the cell*.	(2)
2.3	The emf of the battery.	(3)
		[6]

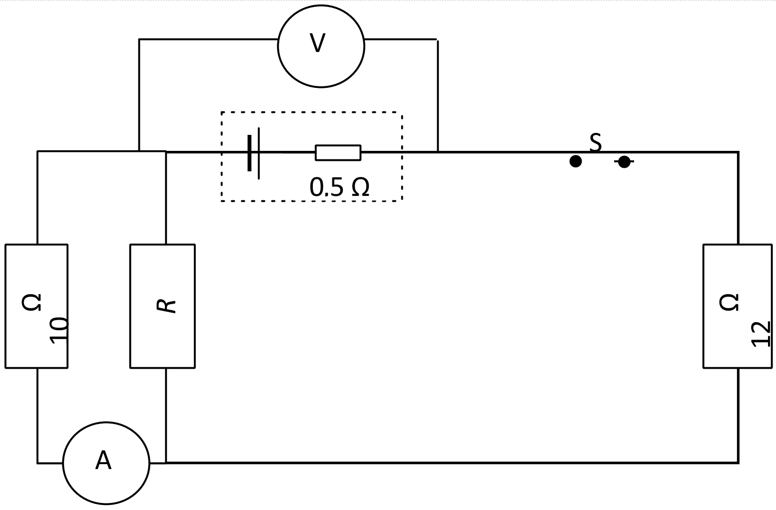
QUESTION 3

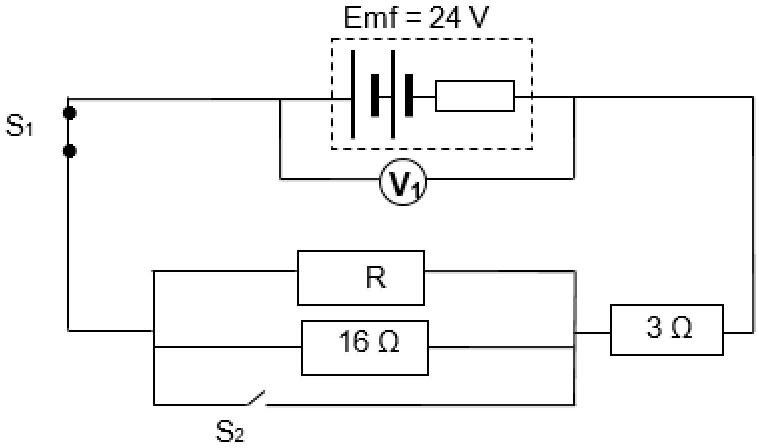
In the circuit represented below, the battery has an **emf of 24 V**. The ammeter and the connecting wires have negligible resistance.



When switch ***S* is closed,** *voltmeter V_1 registers 20 V and V_2 registers 4 V*

3.1	Calculate the :		
	3.1.1	Reading on ammeter A_2	(4)
	3.1.2	Reading on ammeter A_1.	(4)
	3.1.3	Resistance of resistor R	(3)
	3.1.4	Internal resistance of the battery	(3)
	3.1.5	Energy transferred in resistor R in 10 minutes.	(4)

3.2	A hairdryer operates at a potential difference of 240V and a current of 9,5A. It takes a learner 12 minutes to completely dye her hair. Eskom charges energy usage at R1, 47 per unit. Calculate the cost of operating the hairdryer for the 12 minutes (1 unit =1 kW.h)	
3.3	Switch **S is now opened**. State whether the reading on V_1 will **INCREASE, DECREASE OR REMAIN THE SAME.** ***Briefly explain your answer.***	(4)
		[22]
QUESTION 4		
A circuit is connected as shown below. The resistance of *R*, which is connected in parallel with the 10 Ω resistor, is unknown. With switch S closed, the reading on voltmeter V decreases from 45 V to 43,5 V. The internal resistance of the battery is 0,5 Ω.		
		
4.1	Calculate the reading on ammeter A. Show ALL your calculations.	(8)
4.2	Determine the resistance of resistor *R*.	(3)
	Resistor R burns out how will each of the following be affected? Write **INCREASE, DECREASE OR REMAIN THE SAME**	
4.3	The reading on the ammeter	(1)
4.3	The reading on voltmeter V ***Give a reason for your answer.***	(4)
		[16]

QUESTION 5		
A circuit is connected as shown below. When switch S_1 is closed, $V_{external}$ is equal to 22,5. The internal resistance of the battery is 0.8 Ω		
		
5.1	State ***Ohm's law*** in words	(2)
5.2	Calculate the power dissipated by the 16 Ω resistor	(7)
5.3	Calculate the resistance of R	(3)
5.4	Switch S_2 is now closed. How will voltmeter reading V_1 be influenced? (Write down only **INCREASE, DECREASE or STAYS THE SAME.**) Give an explanation to your answer.	(4)
		[16]

ELECTRODYNAMICS

The learner must understand the following:

Electrical machines (generators, motors)

- Electrical machines (generators, motors)
- State the energy conversion in generators.
- Use the principle of electromagnetic induction to explain how a generator works.
- Explain the functions of the components of an AC and a DC generator.
- State examples of the uses of AC and DC generators.
- State the energy conversion in motors.
- Use the motor effect to explain how a motor works.
- Explain the functions of the components of a motor.
- State examples of the use of motors.

Alternating current

- State the advantages of alternating current over direct current.
- Sketch graphs of voltage versus time and current versus time for an AC circuit.
- Define the term rms for an alternating voltage/current.
- The rms potential difference is the AC potential difference which dissipates/produces the same amount of energy as an equivalent DC potential difference.
- The rms current is the alternating current which dissipates/produces the same amount of energy as an equivalent direct current (DC).

Generators

Generators convert mechanical energy to electrical energy.

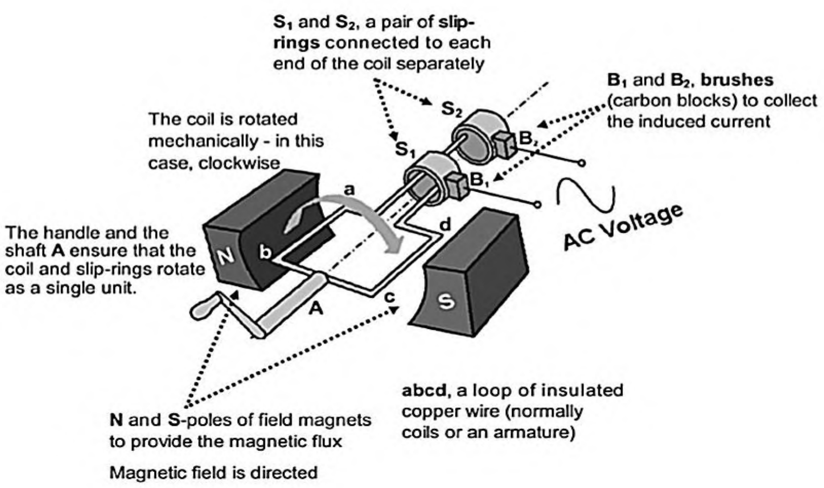
The principle on which generators operate is called electromagnetic induction.

Electromagnetic induction: is a process where the relative motion between the magnetic field and the conductor induces current in the conductor

The law on which generators operate is called Faradays law.

It states that the induced emf is equal to the rate of change of magnetic flux.

AC GENERATOR



The above diagram shows the components of an AC generator

Functions of the components of an AC generator

Slip rings

- Connect the coil to the brushes (external circuit) –contact
- Allows electrical contact between coil and conducting wires
- Ensures that AC current is produced in the external circuit.

Carbon Brushes

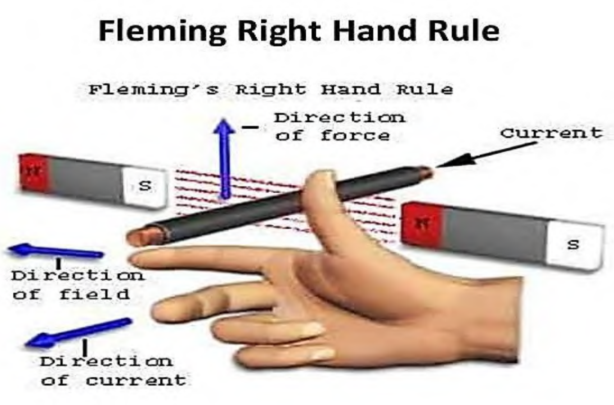
- Makes electrical contact with the slip rings.

Magnets

Provide magnetic flux.

Uses of AC generators:

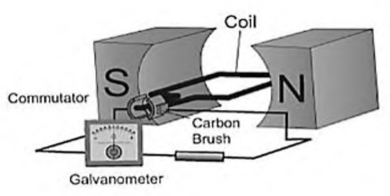
Used in electric power plants i.e. Eskom power stations



The Right Hand Rule is used to determine the direction of the force on the charges (F) in the conductor of the **generator** – the conventional current direction (I) of the induced current. The magnetic field (B) is in the North to South direction.

- **F**irst **F**inger is **F**ield;
- Se**C**ond finger is **C**urrent;
- **T**hu**M**b is **M**ovement or **T**hrust

DC GENERATOR



Function of the commutator (split ring)

Ensures that the produced current flows in one direction in the external circuit.

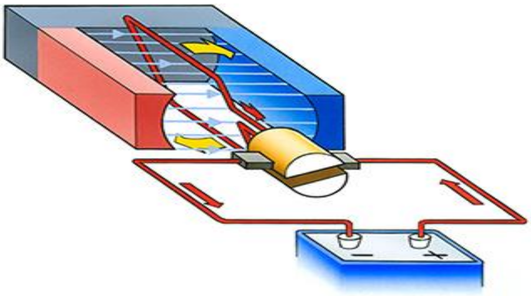
Uses of DC generators

Used as alternators to recharge batteries.

MOTORS

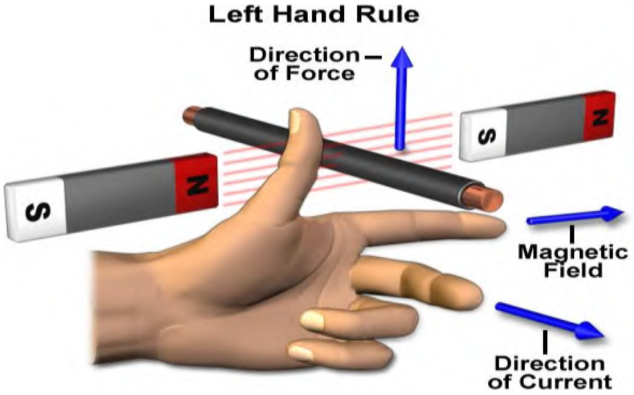
Converts electrical energy to mechanical energy

Principle in which a motor operates is called **motor effect**



The Left Hand Rule is used to determine the direction of the force on the charges (F) in the conductor of the **motor**.

- **F**irst **F**inger is **F**ield;
- Se**C**ond finger is **C**urrent;
- **T**hu**M**b is **M**ovement or **T**hrust



ALTERNATING CURRENT

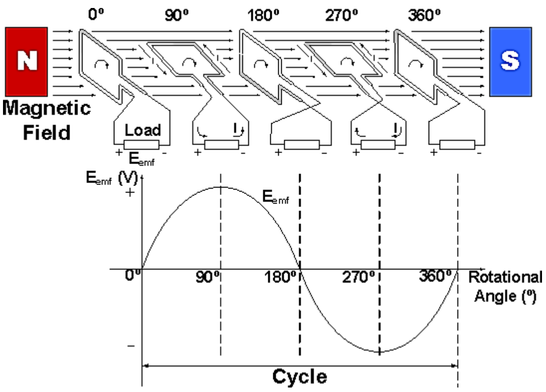
- Current that changes direction over time.

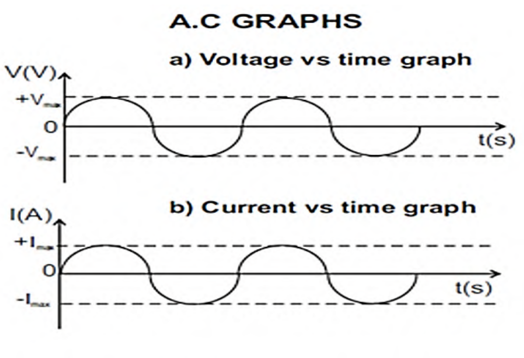
Advantages of alternating current

- AC can be stepped up or stepped down by using transformers.
- Allows electrical energy to be transmitted in electric cables over long distances without energy loss.

Graphs

In AC (alternating current), the current changes voltage (and direction) every cycle; that is, every time the generator or dynamo turns over through one revolution (full cycle).





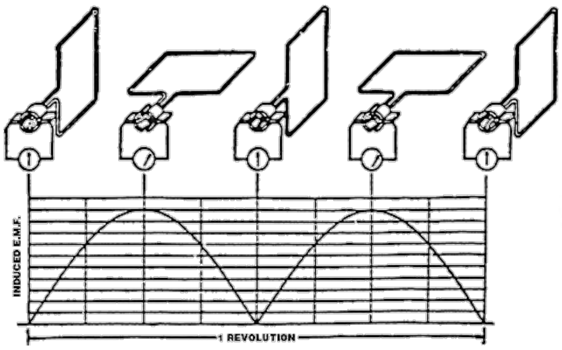
When the coil is vertical:

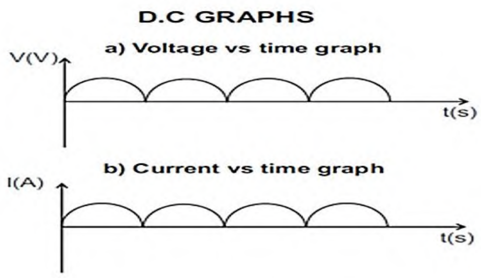
- there is no changing magnetic flux
- no emf or current is induced in the coil
- V = 0 V and I = 0 A

When the coil is horizontal

- there is a changing magnetic flux
- emf and current are induced in the coil
- V = Vmax and I = Imax
- emf and current change direction.

In DC (direct current), the current is in one direction.





When the coil is vertical

- there is no changing magnetic flux
- no emf or current is induced in the coil
- V = 0 V and I = 0 A

When the coil is horizontal

- there is a changing magnetic flux
- emf and current are induced in the coil
- V = Vmax and I = Imax
- emf and current is always positive.

Root mean square (rms)

- The rms potential difference is the AC potential difference which dissipates/produces the same amount of energy as an equivalent DC potential difference.
- The rms current is the alternating current which dissipates/produces the same amount of energy as an equivalent direct current (DC).

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

$$P_{ave} = V_{rms} I_{rms}$$

$$P_{ave} = I_{rms}^2 R$$

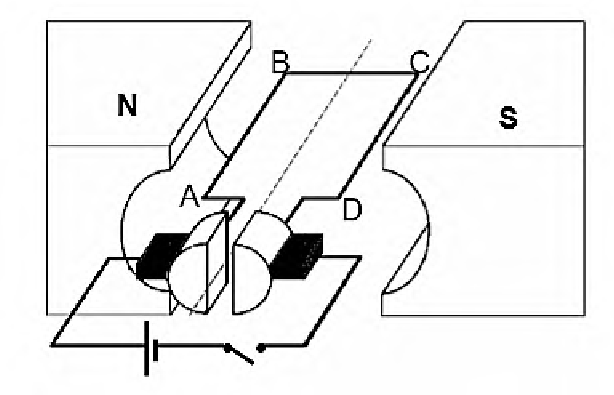
$$P_{ave} = \frac{V_{rms}^2}{R}$$

WORKED EXAMPLES

Multiple choice questions

Example 1

The simplified diagram of an electric motor is shown below.



Which ONE of the following statements is TRUE?

A Coil ABCD will rotate clockwise and mechanical energy will be converted into electrical energy

B Coil ABCD will rotate anti-clockwise and electrical energy will be converted into mechanical energy.

C Coil ABCD will rotate clockwise and electrical energy will be converted into mechanical energy.

D Coil ABCD will rotate anti-clockwise and mechanical energy will be converted into electrical energy. (2)

ANSWER: B

Example 2

Graph P represents the output emf of an AC generator. Graph Q is the output emf after a change has been made using the SAME generator

Which ONE of the following changes has been made to the generator to produce graph Q?

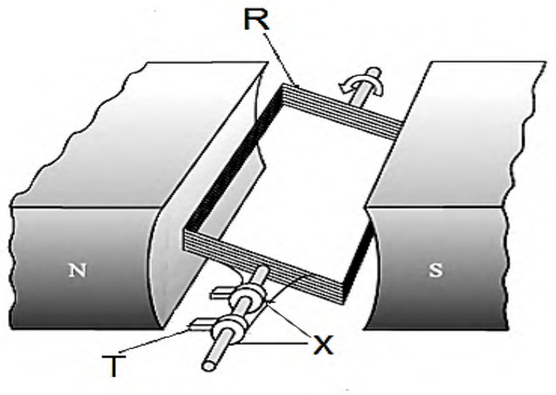
A The number of turns of the coil has been doubled.
B The surface area of the coil has been doubled.
C The speed of rotation has been doubled.
D The strength of the magnetic field has been doubled. (2)

ANSWER: C

ACTIVITIES

Activity 1

1.1 The diagram below shows a simplified version of a generator.



1.1.1 Write down the name of EACH part, R, T and X. (3)

1.1.2 Give the NAME of the law upon which the operation of the generator is based. (1)

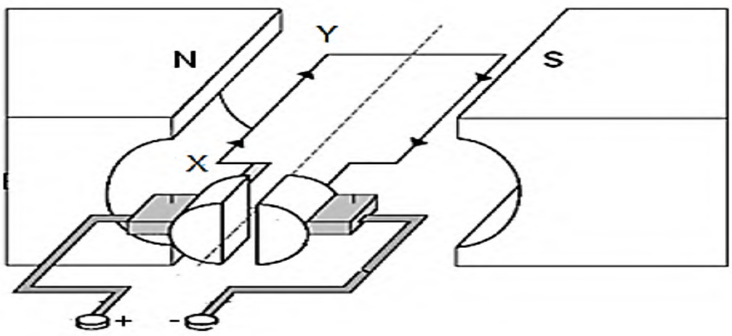
1.2 An AC supply is connected to a light bulb. The light bulb lights up with the same brightness as it does when connected to a 15 V battery.

1.2.1 Write down the rms value of the potential difference of the AC supply. (1)

1.2.2 If the resistance of the light bulb is 45 Ω, calculate the maximum current delivered to the light bulb. (4)

Activity 2

2.1 The diagram below is a simplified representation of a DC motor. The current in the coil is in the direction XY.



2.1.1 Name the component that ensures that the coil rotates continuously in ONE DIRECTION. (1)

2.1.2 In which direction will the coil rotate? Write down only CLOCKWISE or ANTICLOCKWISE. (2)

2.1.3 Write down the energy conversion which takes place while the motor is working (2)

2.2 An AC generator, producing a maximum voltage of 320 V, is connected to a heater of resistance 35 Ω.

2.2.1 Write down the structural difference between an AC generator and a DC generator. (1)

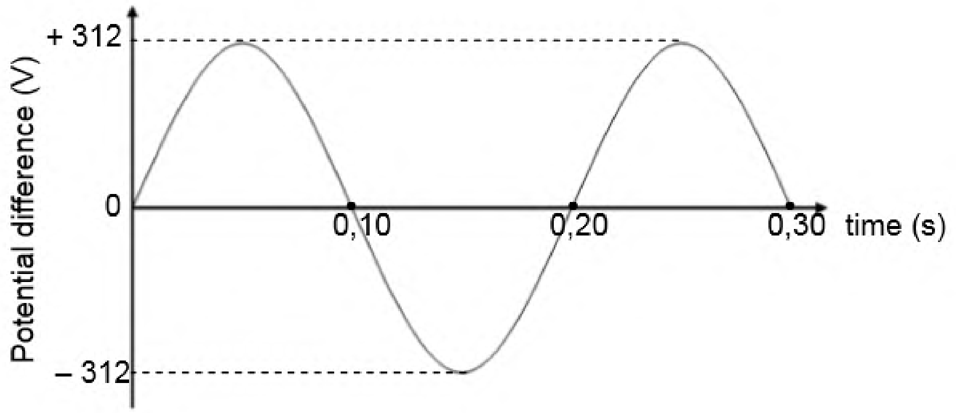
Calculate the:

2.2.2 Root mean square (rms) value of the voltage (3)

2.2.3 Root mean square (rms) value of the current in the heater (4)

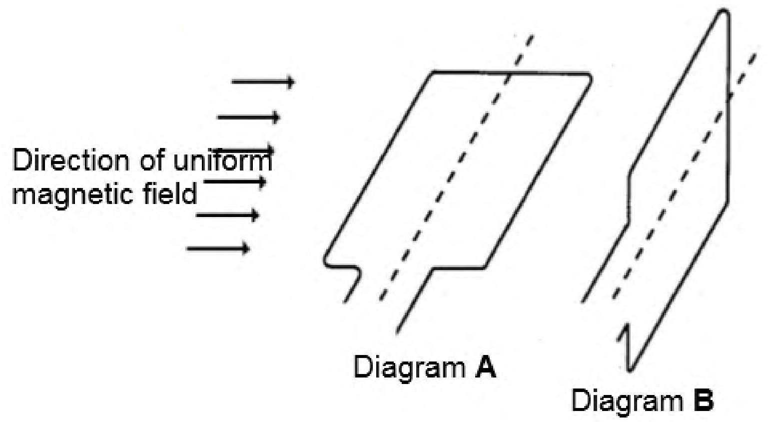
Activity 3

The diagram below shows the voltage output of a generator.



3.1 Does this generator have split rings or slip rings? (1)

3.2 Which ONE of the diagrams below, A or B, shows the position of the generator's coil at time = 0,10 s? (1)



3.3 Calculate the root mean square (rms) voltage for this generator. (3)

3.4 A device with a resistance of 40 Ω is connected to this generator.

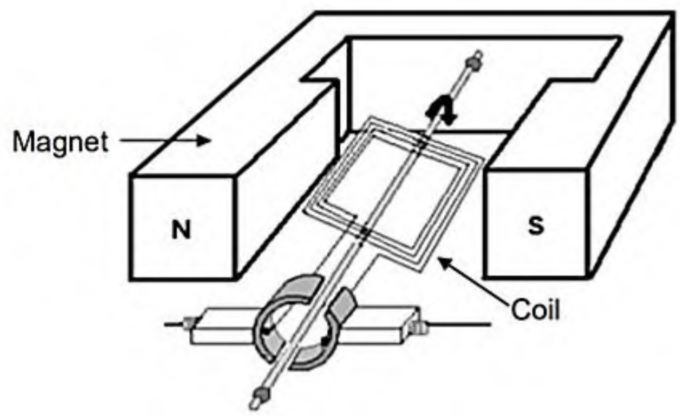
Calculate the:

3.4.1 Average power delivered by the generator to the device (3)

3.4.2 Maximum current delivered by the generator to the device (4)

Activity 4

4.1 A simplified diagram of an electric generator is shown below. When the coil is rotated with a constant speed, an emf is induced in the coil.



4.1.1 Is this an AC generator or a DC generator? (1)

4.1.2 Briefly explain how an emf is generated in the coil when the coil is rotated by referring to the principle of electromagnetic induction. (2)

4.1.3 Draw a sketch graph of the output voltage versus time for this generator. Show ONE complete cycle. (2)

4.2 A 200 Ω resistor is connected to a DC voltage supply, as shown in diagram A. The energy dissipated in the resistor in 10 s is 500 J.

The same resistor is now connected to an AC source (diagram B) and 500J of energy is also dissipated in the resistor in 10 s.

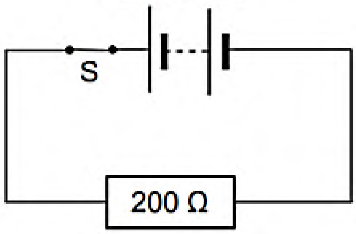


Diagram **A**

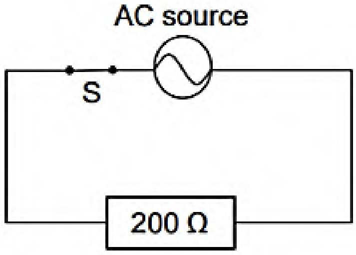


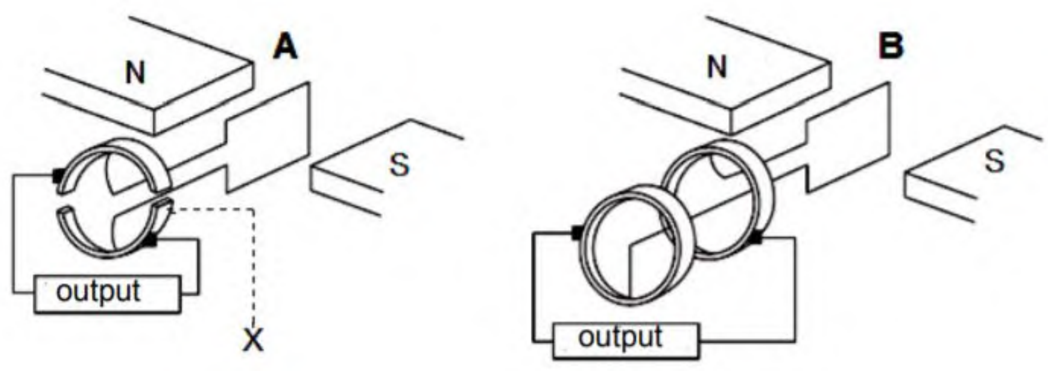
Diagram **B**

4.2.1 Define the term rms voltage of an AC source. (2)

4.2.2 Calculate the maximum (peak) voltage of the AC source. (5)

ACTIVITY 5

5.1 Refer to the two devices below. The output of the devices can be measured using a galvanometer.



5.1.1 Write down the name of the principle on which the above devices operate. (1)

5.1.2 Write down the name of part X in device A. (1)

5.2 A 220 V, AC voltage is supplied from a wall socket to an electric kettle of resistance 40,33 Ω. Wall sockets provide rms voltages and currents.

Calculate the:

5.2.1 Electrical energy consumed by the kettle per second (4)

5.2.2 Maximum (peak) current through the kettle (3)

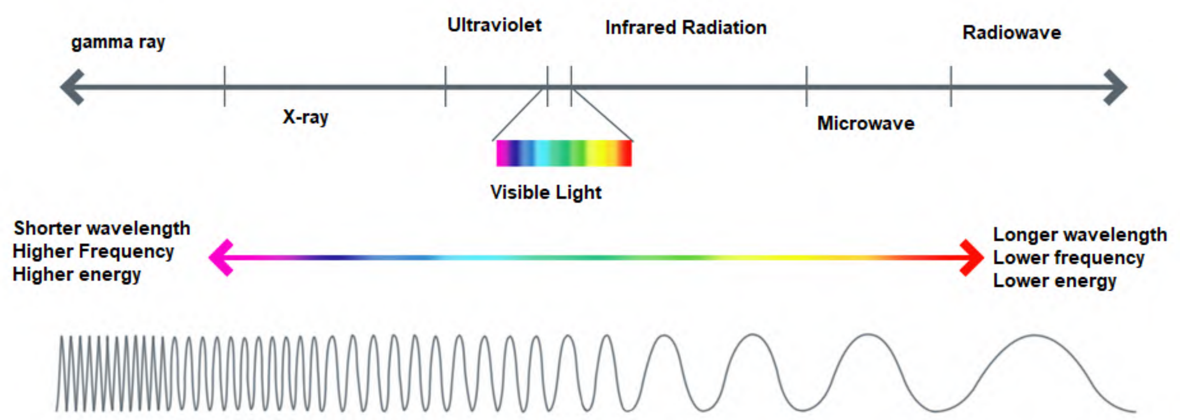
OPTICAL PHENOMENA AND PROPERTIES OF MATERIALS

Revision Grade 11/10

Transverse Waves

- Frequency (f): The number of complete waves that pass a point per second. Measured in Hertz (Hz).
- Wavelength (λ): The distance between two consecutive points on a wave that are in phase. Measures in meters (m).
- Wave speed (v): The product of the frequency and wavelength of a wave. $V = f\lambda$ Measured in $m.s^{-1}$

Electromagnetic Spectrum

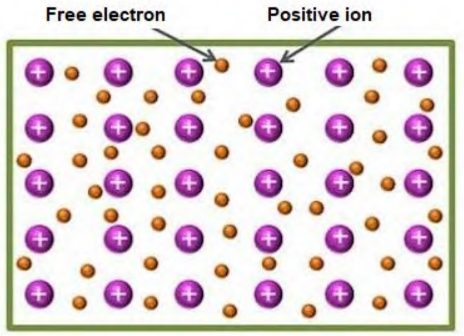


All electromagnetic waves travel at a speed (c) of $3 \times 10^8\ m.s^{-1}$ through a vacuum.

Light undergoes diffraction and interference – Light displays properties of a wave.

PHOTO-ELECTRIC EFFECT

The PHOTOELECTRIC EFFECT is the process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.



Delocalized electrons in a metal are free to move around it.

- Found in the outermost energy levels of the metal atoms.

If an electron is to be removed from the surface of the metal, it must be given sufficient energy to escape.

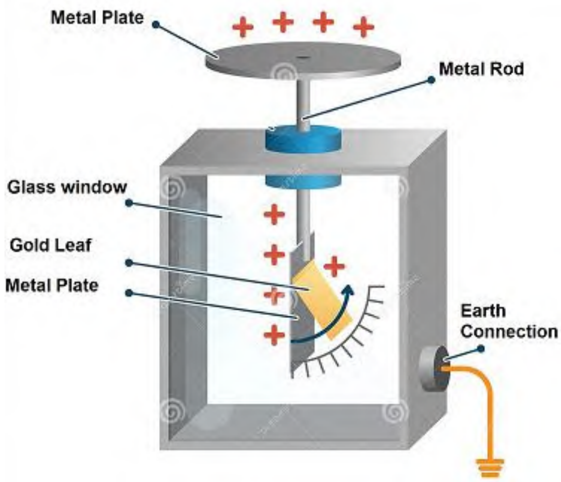
- This is known as the PHOTOELECTRIC EMISSION.

PHOTOELECTRIC EMISSION is the release of electrons from the surface of a metal when electromagnetic radiation is incident onto its surface.

- These ejected electrons are called PHOTOELECTRONS.

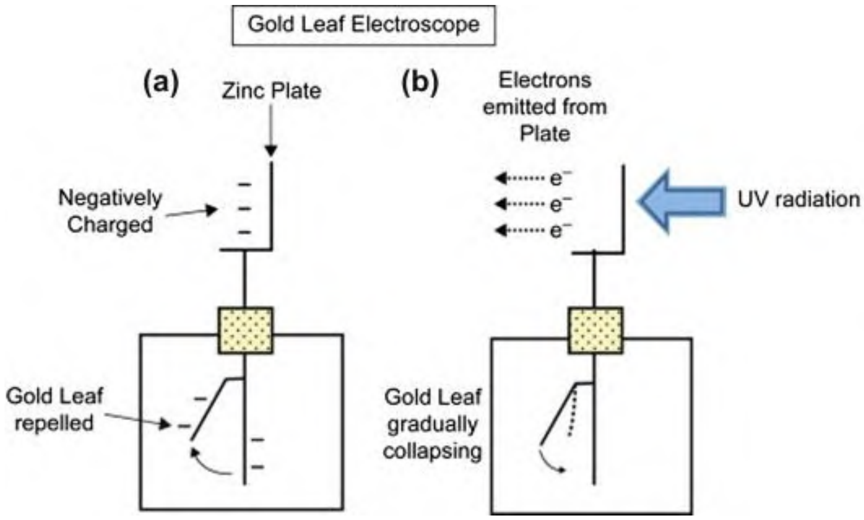
The Gold Leaf Electroscope

- A device that is used to detect charge.
  - In a neutral electroscope, the leaf hangs vertically.
  - In a negatively charged electroscope the leaf is repelled or rises.



A clean zinc plate is placed on the metal disc and the electroscope is negatively charged.

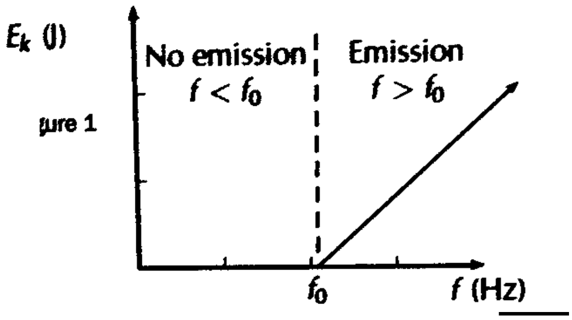
- If visible light of any color is shone on the zinc plate, the leaf does not move.
- If the intensity *(brightness)* of the visible light is increased, the leaf still does not move.
- The visible light is replaced with ultra-violet radiation (*light with higher frequency*) onto the zinc plate, the leaf falls, showing that the zinc plate is losing electrons.
  - Electrons are being ejected from the zinc plate.
- If the intensity of the ultra-violet radiation is increased, the leaf falls more quickly.
  - The rate, at which electrons being ejected, has increased.



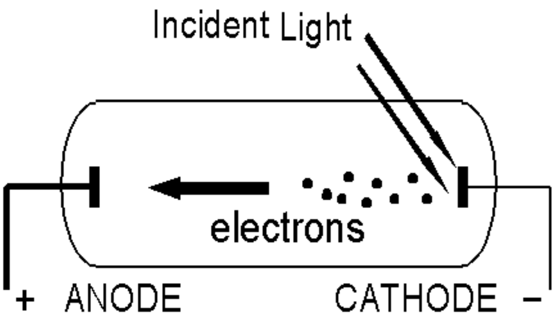
- Visible light could not eject electrons from the zinc plate but ultra-violet could.
- Ultra-violet light has a higher frequency than visible light.
- Electromagnetic radiation only causes the photoelectric emission if it has a frequency higher than a certain value.

Threshold frequency, f_0, is the minimum frequency of light needed to emit electrons from a certain metal surface.

- The threshold frequency depends on the type of metal used.



The photoelectric effect is also demonstrated by making use of photosensitive vacuum tube (photocell).



Incident light is shone on the cathode, electrons are ejected and attracted to the anode, the micro-ammeter register a current.

The Wave Theory of Light

Light is a wave since it undergoes *interference* and *diffraction.*

The following are the assumptions of the Wave Theory of Light which WAS NOT observed in a Photoelectric effect:

- If light is shone on a metal, the electron will absorb energy from it. If the light is shone long enough, eventually electrons will be ejected from the surface of the metal.
- Electrons should be ejected at any frequency of radiation.
- Increasing the intensity of the light would increase the energy of the wave. Light of greater intensity should cause electrons to be ejected.

The energy carried by electromagnetic radiation exists as “packets of energy” called *quanta*. The energy carried by each quantum is given by:

$\boldsymbol{E = hf}$ **or** $E = \frac{\mathbf{hc}}{\boldsymbol{\lambda}}$

Where, E = the amount of energy in one quantum of that particular radiation measured in joules (J)

f = the radiation’s frequency, measured in Hertz (Hz)

h = the Planck constant = 6.63×10^{-34} J.s

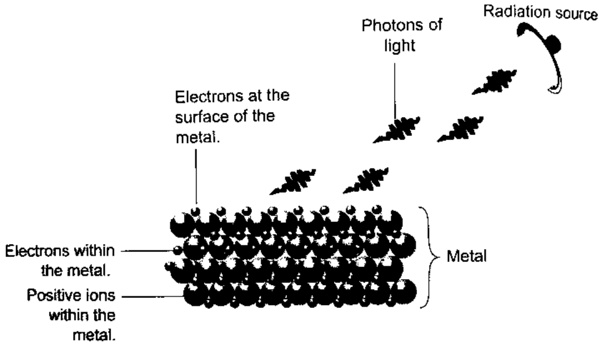
c = speed of electromagnetic radiation in a vacuum = 3×10^{8} m.s^{-1}

λ = wavelength of light measure in meters (m)

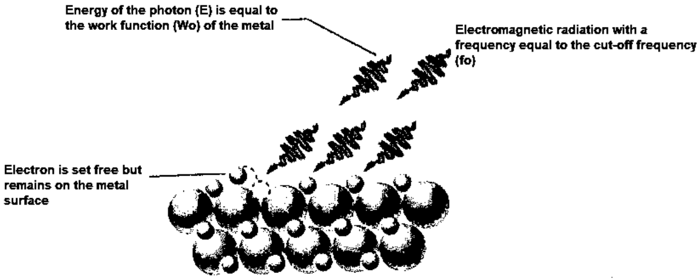
The Particle Theory of Light

PHOTON: A quantum (package) of energy of electromagnetic radiation.

- The energy of the photon can be calculated using Planck's equation $E = hf$.
- $E_{photon} \propto f$



- If the frequency of the photon is LESS THAN the threshold frequency (f_0) of the metal, electrons will not be ejected - The photoelectric effect DOES NOT occur.
- If the frequency of the photon is EQUAL to the threshold frequency (f_o) of the metal, the energy of the photon is equal to the work function (W_0).
  - The photoelectric effect will occur.
  - The photon has SUFFICIENT ENERGY to overcome the work function of the metal.



WORK FUNCTION (W_O): The minimum energy that an electron in the metal needs to be emitted from the metal surface.

$\boldsymbol{W_o = hf_o}$

Where, W_o = work function of the metal, measured in joules (J)

f_o = cut-off frequency of the metal, measured in Hertz (Hz)

h = the Planck constant = 6.63×10^{-34} J.s

If the energy of the photon is GREATER than the work function of the metal, then the electron still has extra energy after overcoming the work function.

- This energy is hence known as the maximum kinetic energy of the photoelectron.

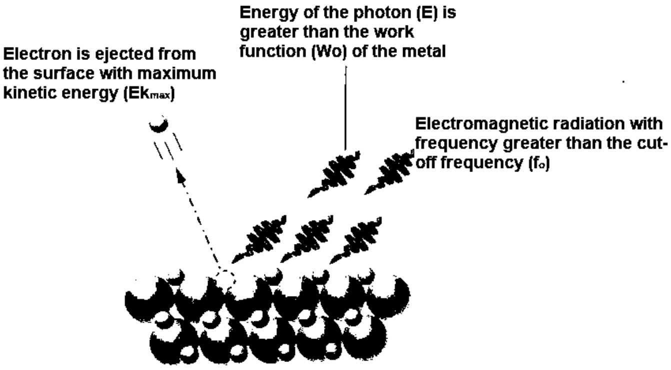
This phenomenon leads to the PHOTOELECTRIC EQUATION where:

Energy of the photon = Work function + Maximum kinetic energy of the electron

$$\boldsymbol{E = W_o + Ek_{max}}$$

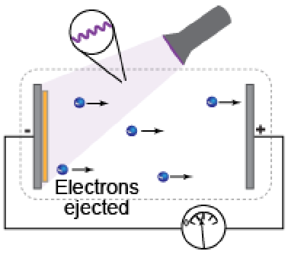
$$\boldsymbol{hf = hf_o + \frac{1}{2}mv^2{}_{max}}$$

Where m is the mass of the electron in kg ($m_e = 9.11 \times 10^{-31}$ kg) and v_{max} is the maximum speed of the ejected electrons (in $m.s^{-1}$)

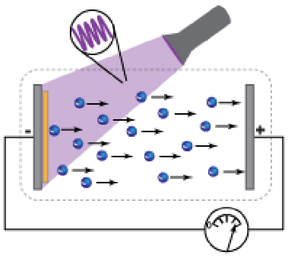


Intensity of the Electromagnetic Radiation

Increasing the intensity (brightness) of the radiation means that more photons are arriving on the metal surface per second.

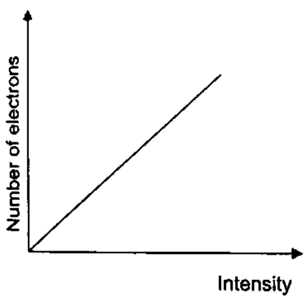


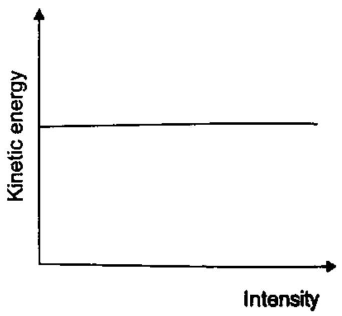
Low intensity light above threshold frequency, some elctrons ejected from metal; small current



High intensity light above threshold frequency, many ejected electrons; high current

- Increasing the intensity of electromagnetic radiation does not affect whether or not the photoelectric effect takes place.
  - If the frequency of the photon is less than the threshold frequency of the metal, then the photoelectric effect will not take place, regardless of increasing intensity.
  - Increasing the intensity does not affect the maximum kinetic energy of the ejected photoelectrons.
- If the frequency of the electromagnetic radiation is equal to or greater than the threshold frequency of the metal, then an increase in the intensity will result in **more electrons being ejected per second.**
  - This implies that the current that an ammeter reads will increase.





The effect of frequency on the photoelectric effect

- If the frequency of the incident radiation is increased, the maximum kinetic energy of the photoelectrons also increases.
- If the frequency of the incident radiation is constant, then the maximum kinetic energy of the photoelectrons is NOT affected by intensity of this radiation.
- In a photo-cell experimental set-up, the stopping voltage is the measure of the maximum kinetic energy of the ejected electrons.
  - Electromagnetic radiation with a higher frequency/energy will have a greater stopping voltage.

NOTE: 1eV = 1.6×10^{-19} J

Significance of the Photoelectric Effect

The photoelectric effect is important because it led to the discovery of the Quantum (Particle) Theory of Light.

- The photoelectric effect indicates that light has a DUAL NATURE.
  - Light behaves as both a wave and a particle.

ATOMIC EMISSION AND ABSORPTION SPECTRA

A CONTINUOUS EMISSION SPECTRUM is produced when WHITE light is shone through a prism forming a band of colors with different frequencies and wavelengths.

A GAS DISCHARGE TUBE is a transparent tube containing gas at low pressure.

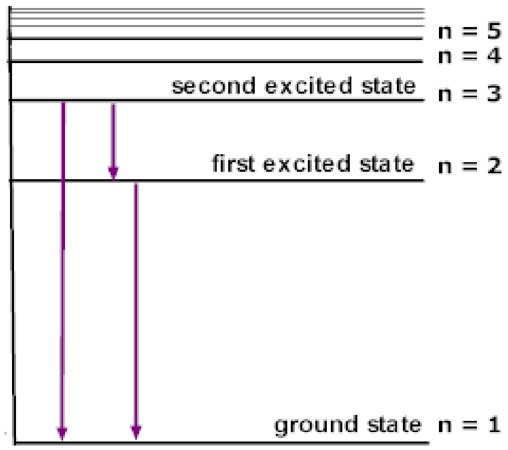
- When a high voltage is applied across its two electrodes, light is emitted from the gas inside the tube.
  - Some electrons are stripped from the atoms of the gas (and move towards the anode) and the gas ionizes, becoming positive ions (and move towards the cathode).
  - When the positive and negative charges collide and recombine, energy in the form of a photon of light is released. (Recall bond formation = energy released)

ATOMIC LINE EMISSION SPECTRUM is dark with spectral lines of color at different frequencies.

- Each element emits its own unique line emission spectrum.

Electron Energy Levels

Electrons in an atom can only have certain specific energies called the electron energy levels of the atom.



Electrons in energy level 1 (n =1) are closest to the nucleus of the atom.

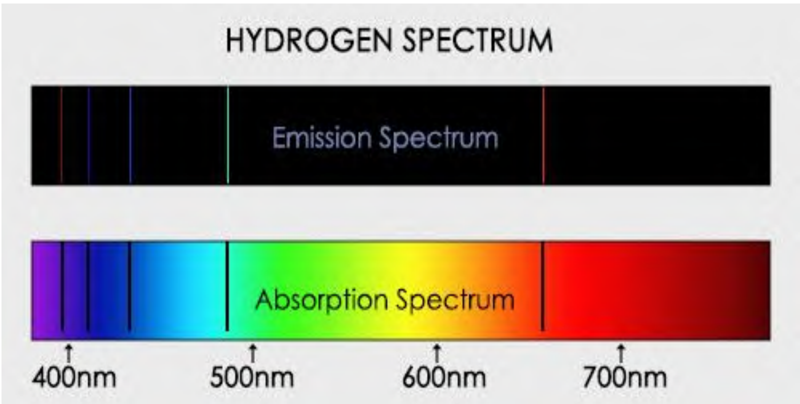
- When electrons absorb energy, they move to a higher energy level, known as an excited energy state which is unstable.
- The movement of electrons between energy levels is known as an ELECTRON TRANSITION.
- A transition from a lower energy level to a higher energy level, results in a line absorption spectrum.
- LINE ABSORPTION SPECTRUM is formed when certain frequencies of electromagnetic radiation passing through a substance is absorbed.
    - When light passes through a COLD GAS, atoms in the gas absorb certain frequencies of the light and the spectrum absorbed is a continuous spectrum with dark lines where certain frequencies were removed.
- A transition from a higher energy level to a lower energy level results in a line emission spectrum. (Photons of light are emitted)
- LINE EMISSION SPECTRUM is formed when certain frequencies of electromagnetic radiation are emitted due to an atom making a transition from a higher energy state to a lower energy state.
    - Atoms in a HOT gas emit light at certain frequencies. The spectrum observed is a line spectrum with only a few colored lines of frequencies unique to the type of atom that is producing the emission lines.
- Energy of emitted photon (E) = hf = $E_2 - E_1$

Significance of the Line Emission Spectrum

- Gives evidence of the existence of energy levels within atoms.
- Every element has a different set of electron energy levels. The line emission spectrum is like a finger print, no two individuals have the same.
- Astronomers are able to analyze light from distant stars and identify the different elements found in these stars.

Comparing Line Emission and Absorption Spectra

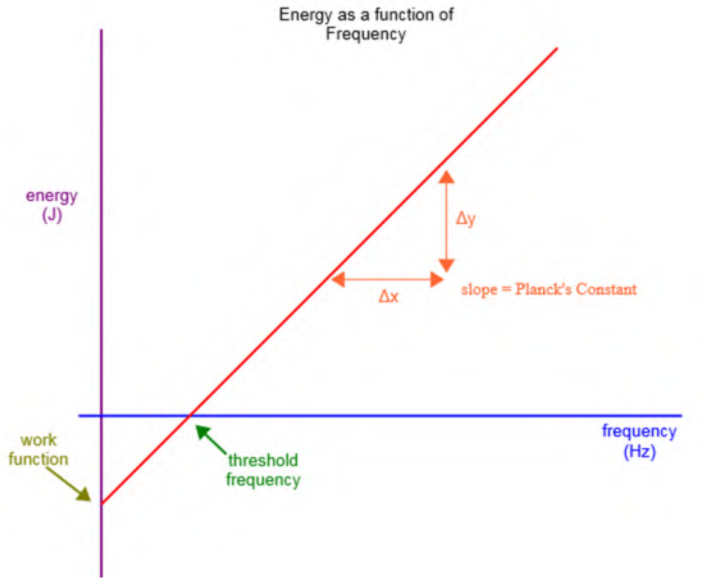
The energy of the incoming photon must be exactly equal to the energy difference between the two levels.



Notice that the wavelengths of light that are ABSORBED by COLD hydrogen gas correspond exactly to the wavelengths of light that are EMITTED by HOT hydrogen gas.

INTERPRETATION OF GRAPHS

The following graph is a typical example of how the photoelectric effect will be shown to you.



Some parts can be changed, and although this will change the graph (like flipping it around), the same essential information is there.

The vertical axis is labeled as energy.

- The positive values are showing the kinetic energy of the photoelectron.
- The y-intercept is the value of the work function of metal.

The horizontal axis is the frequency of the light striking the metal.

- The x-intercept is the value of the threshold frequency of the metal.

The slope or gradient of the line (Δx and Δy), is the change in energy over a change in frequency. Look at the formula E = hf and solve for energy over frequency.

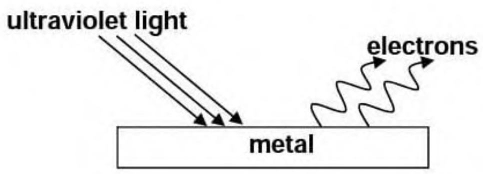
$$\text{gradient} = \frac{\Delta \text{y}}{\Delta \text{x}} = \frac{E}{f} = h$$

WORKED EXAMPLES

WORKED EXAMPLE 1.

1. A metal surface is illuminated with ultraviolet light of wavelength 330 nm. Electrons are emitted from the metal surface.

   <u>The minimum amount of energy required to emit an electron from the surface of this metal</u> is 3.5×10^{-19} J.



1.1. Name the phenomenon illustrated above. (1)

Photoelectric effect

1.2. Give one word for the underlined sentence in the above paragraph. (1)

Work function

1.3. Calculate the frequency of ultraviolet light. (4)

$c = f\lambda$

$3 \times 10^{8} = f\,(330 \times 10^{-9})$

$f = 9.09 \times 10^{14}\ Hz$

OR

$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^{8})}{330 \times 10^{-9}} = 6.03 \times 10^{-19}\ J$

$E = hf$

$6.03 \times 10^{-19} = (6.63 \times 10^{-34})f$

$f = 9.09 \times 10^{14}\ Hz$

1.4. Calculate the kinetic energy of a photoelectric emitted from the surface of the metal when the ultraviolet light shines on it. (4)

$E = W_o + Ek_{max}$

$\frac{hc}{\lambda} = W_o + Ek_{max}$

$\frac{(6.63 \times 10^{-34})(3 \times 10^{8})}{330 \times 10^{-9}} = 3.5 \times 10^{-19} + Ek_{max}$

$Ek_{max} = 2.53 \times 10^{-19} J$

OR

$E = W_o + Ek_{max}$

$hf = W_o + Ek_{max}$

$(6.63 \times 10^{-34})(9.09 \times 10^{14}) = 3.5 \times 10^{-19} + Ek_{max}$

$Ek_{max} = 2.53 \times 10^{-19} J$

1.5. The intensity of the ultraviolet light illuminating the metal is not increased. What effect will this change have on the following:

1.5.1. Kinetic energy of the emitted photoelectrons (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1)

Remains the same

1.5.2. Number of photoelectrons emitted per second (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1)

Increases

1.6. Over exposure to sunlight causes damage to skin cells.

1.6.1. Which type of radiation in sunlight is said to be primarily responsible for this damage? (1)

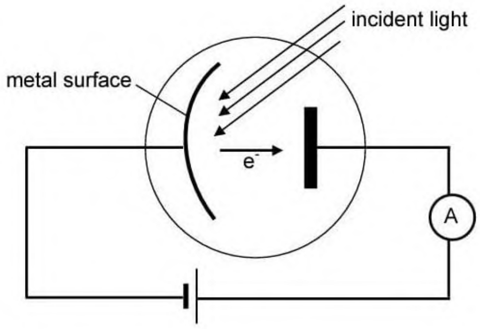
Ultraviolet radiation

1.6.2. Name the property of this radiation responsible for the damage. (1)

High energy

WORKED EXAMPLE 2.

2. In the diagram shown below electrons are released from a metal plate when light of a certain frequency is shone on its surface.



2.1. Name the phenomenon described above. (1)

Photoelectric effect

2.2. The frequency of the incident light on a metal is 6.16 x 10^{14} Hz an electron released with kinetic energy of 5.6 x 10^{-20} J.

Calculate the:

2.2.1. The energy the incident photons. (3)

$E = hf$

$E = (6.63 \text{ x } 10^{-34})(6.16 \text{ x } 10^{14})$

$E = 4.08 \text{ x } 10^{-19} \, J$

2.2.2. Threshold of the metal plate. (5)

$E \; = W_o + Ek_{max}$

$4.08 \text{ x } 10^{-19} = (6.63 \text{ x } 10^{-34})f_o + 5.6 \text{ x } 10^{-20}$

$f_o = 5.31 \text{ x } 10^{14} \, Hz$

2.3. The brightness of the incident light is now increased. What effect will this change have on the following: (Write down only INCREASE, DECREASE or REMAIN THE SAME)

2.3.1. Reading on the ammeter. Explain your answer. (2)

Increases, more photoelectrons emitted per second.

2.3.2. The kinetic energy of the released photoelectrons. Explain your answer. (2)

Remains the same, intensity does not affect energy/ frequency of light remains the same.

WORKED EXAMPLE 3.

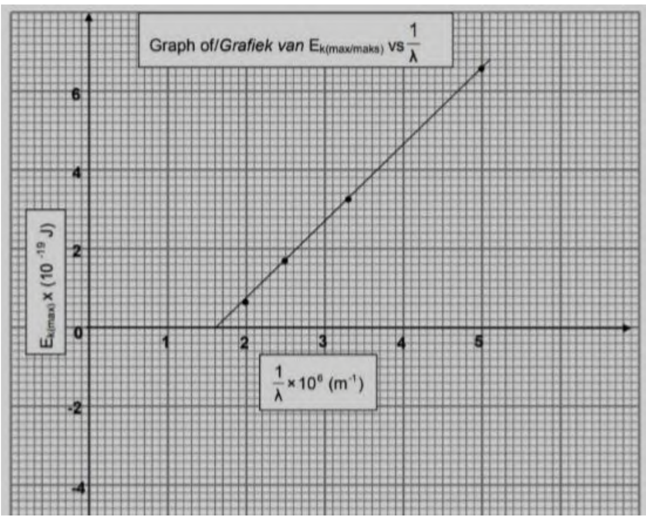
3. In an experiment to demonstrate the photoelectric effect, light of different wavelengths was shone onto a metal surface of a photoelectric cell. The maximum kinetic energy of the emitted electrons was determined for the various wavelengths and recorded in the table below.

INVERSE OF WAVELENGTH $\frac{1}{\lambda}$ (× 10^6 m^{-1})	MAXIMUM KINETIC ENERGY $E_{k(max)}$ (× 10^{-19} J)
5,00	6,60
3,30	3,30
2,50	1,70
2,00	0,70

3.1. What is meant by the term photoelectric effect? (2)

The process whereby electrons are ejected from a metal surface.

3.2. Draw a graph of $E_{k(max)}$ (y-axis) versus $\frac{1}{\lambda}$ (x- axis). (3)



3.3. USE THE GRAPH to determine:

3.3.1. The threshold frequency of the metal in the photoelectric cell. (4)

$$\frac{1}{\lambda} = 1.6 \text{ x } 10^6 m^{-1}$$

$$f_o = c\frac{1}{\lambda}$$

$$f_o = (3 \text{ x } 10^8)(\ 1.6 \text{ x } 10^6)$$

$$f_o = 4.8 \text{ x } 10^{14} Hz$$

OR

$$W_o = hf_o$$

$$3.2 \text{ x } 10^{-19} = (6.63 \text{ x } 10^{-34})f_o$$

$$f_o = 4.8 \text{ x } 10^{14} Hz$$

3.3.2. Planck's constant (4)

$$hc = gradient = \frac{\Delta y}{\Delta x}$$

$$\frac{6.6 \text{ x } 10^{-19} - 0}{(5 - 1.6)\text{x } 10^{6}} = 1.941 \text{ x } 10^{-25}$$

$$h = \frac{1.941 \text{ x } 10^{-25}}{3 \text{ x } 10^{8}} = 6.47 \text{ x } 10^{-34} J.s$$

OR

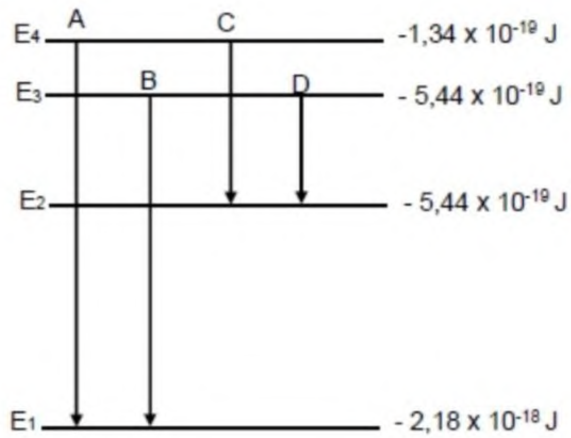
$$W_o = hf_o$$

$$3.2 \text{ x } 10^{-19} = h\,(4.8 \text{ x } 10^{14})$$

$$h = 6.47 \text{ x } 10^{-34} J.s$$

WORKED EXAMPLE 4.

4. The diagram below shows electron transitions between energy levels of an atom.



4.1. A photon of light is released when an electron moves from E_3 state to the E_1 state. Calculate the frequency of this photon. (5)

$$\Delta E = E_3 - E_1 = -5.44 \text{ x } 10^{-19} - (-2.18 \text{ x } 10^{-18}) = 1.68 \text{ x } 10^{-18} J$$

$$E = hf$$

$$1.68 \text{ x } 10^{-18} = (6.63 \text{ x } 10^{-34})\, f$$

$$f = 2.47 \text{ x } 10^{15} Hz$$

4.2. How many different photons can be produced when excited electrons from the E_3 state to the E_1? (1)

3

4.3.1. Define the work function of a metal. (2)

The minimum energy that an electron in a metal needs to be emitted from a certain metal surface.

4.3.2. The photon in QUESTION 4.1. is incident to the metal surface. The work function of a metal is 2 x 10^{-19} J. Calculate the maximum velocity. (4)

$$E = W_o + Ek_{max}$$

$$hf = hf_o + \frac{1}{2}mv^2{}_{max}$$

$$(6.63 \text{ x } 10^{-34})(2.47 \text{ x } 10^{15}) = 2 \text{ x } 10^{-19} + \frac{1}{2}(9.11 \text{ x } 10^{-31})(v)^2$$
$$v = 1.78 \text{ x } 10^6 m.s^{-1}$$

MULTIPLE CHOICE QUESTIONS

1. Light of a certain frequency is shone onto a metal M and electrons are ejected from the surface. The same source of light is shone onto another metal N. (2)
The electrons ejected from the surface of metal N have a much higher kinetic energy than that from metal M
This means that …

A metal N has the same work function as mental M
B metal N has a larger work function than metal M
C the threshold frequency of metal N is higher than that of metal M
D the threshold frequency of metal N is lower than that of metal M

2. In an experiment on the photoelectric effect, a scientist shines red light on a metal surface and observes that electrons are ejected from the metal surface. Later the scientist shines blue light, with the same intensity as the red light on the same metal surface. (2)
Which ONE of the statements below will be the CORRECT observations as a result of this change?
A The number of ejected electrons per second will increases
B The number of ejected electrons per second will decrease
C The speed of the ejected electrons will decrease
D The maximum kinetic energy of the ejected electrons will increase

3. When light of a certain wavelength is incident on a metal surface, no electrons are ejected. Which ONE of the following changes may result in electrons being ejected from the metal surface? (2)

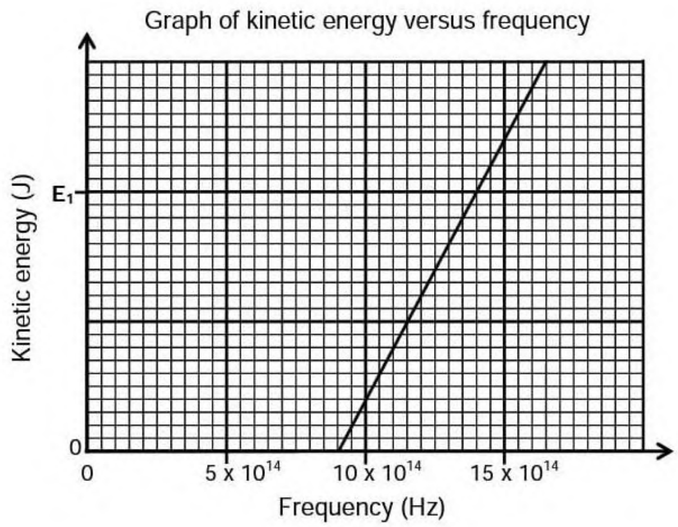
A Increase the intensity of the light
B Use light with a much shorter wavelength
C Use metal with a larger work function
D Increase the surface area of the metal

4. In an experiment on the photoelectric effect, the frequency of the incident light is high enough to cause the removal of electrons from the surface of the metal. (2)
The number of electrons ejected from the metal surface is proportional to the …
A Kinetic energy of the electrons
B number of incident photons
C work function of the metal
D frequency of the incident light

ACTIVITIES

ACTIVITY 1

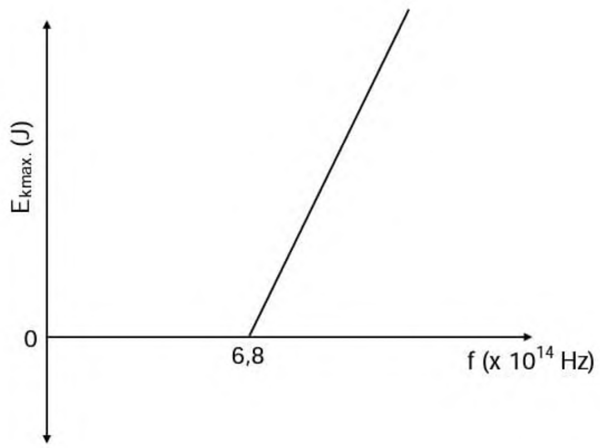
1. During an investigation, light of different frequencies is shone onto the metal cathode of a photocell. The kinetic energy of the emitted electrons is measured. The graph below shows the results obtained.



1.1.	For the investigation write down the following:	
1.1.1.	Dependent variable	(1)
1.1.2.	Independent variable	(1)
1.1.3.	Controlled variable	(1)
1.2.	Define the term threshold frequency.	(2)
1.3.	Use the graph to obtain the threshold frequency of the metal used as a cathode in the photocell.	(1)
1.4.	Calculate the kinetic energy at E_1 shown on the graph.	(4)
1.5.	How will the kinetic energy calculated in question 3.4. be affected if the light of higher intensity is used? Write down only INCREASE, DECREASE or REMAIN THE SAME.	(1)

ACTIVITY 2

2. The graph below is obtained for an experiment on the photoelectric effect using different frequencies of light and a given metal plate.



2.1. What is the threshold frequency of the metal? (1)

2.2. Define the term threshold frequency. (2)

In the experiment the brightness of the light incident on the metal surface is increased.

2.3. State how this change will influence the speed of the photoelectrons emitted. (1)

Choose form INCREASES, DECREASES or REMAINS THE SAME.

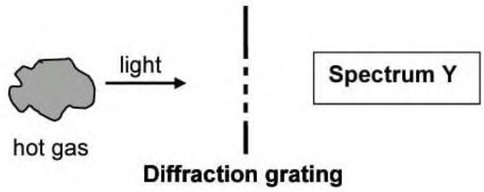
2.4. Show by means of calculation whether the photoelectric effect will be OBSERVED or NOT OBSERVED, if monochromatic light with a wavelength of 6×10^{-7} m is used in this experiment. (5)

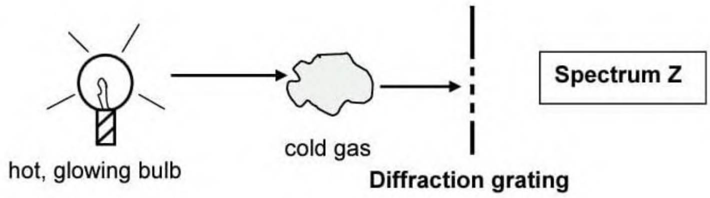
One of the radiations used in this experiment has a frequency of 7.8×10^{14} Hz.

2.5. Calculate the maximum speed of an ejected photoelectron. (5)

ACTIVITY 3

3. A teacher in a science class explains how different types of spectra are obtained. The teacher uses the simplified diagrams shown below for the explanation.





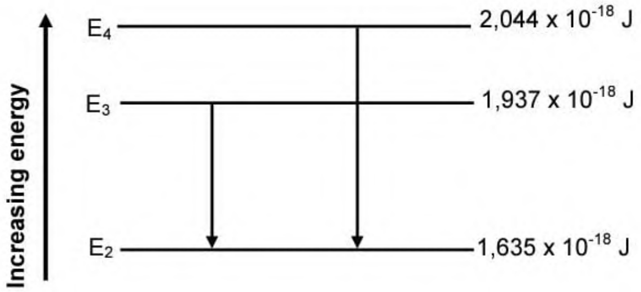
3.1. Name the type of spectrum formed in:

3.1.1. Y (1)

3.1.2. Z (1)

3.2. In an excited atom, electrons can "jump" from lower energy levels to higher energy levels. They can also drop from higher energy levels to lower energy levels.

The diagram below (not drawn to scale) shows some of the transitions for an electron in an excited atom.



3.2.1. Do the transitions indicated in the diagram lead to ABSORPTION or EMISSION spectra? (1)

3.2.2. Calculate the frequency of the photon produced when an electron in an excited atom makes a transition from E_4 to E_2, as shown in the diagram. (4)

The threshold frequency of a metal, Q, is 4.4×10^{14} Hz.

3.2.3. Calculate the kinetic energy of the most energetic electron ejected when the photon produced in QUESTION 3.2.2. is incident on the surface of metal Q. (4)

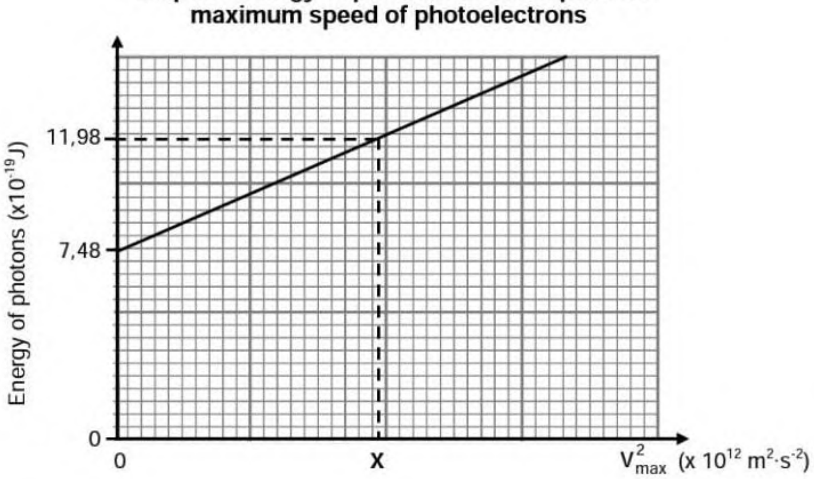
Another metal, R, has a threshold frequency of 7.5×10^{14} Hz.

3.2.4. Will the photon produced in QUESTION 3.2.2. be able to eject electrons from the surface of metal R? Write down only YES or NO. Give a reason for the answer. (2)

ACTIVITY 4

4. During an experiment, light of different frequencies is radiated onto a silver cathode of a photocell and the corresponding maximum speed of the ejected photoelectrons are measured.

A graph of the energy of the incident photons versus the square of the maximum speed of the ejected photoelectrons is shown below.



4.1. Define the term photoelectric effect. (2)

Use the graph to answer the following questions:

4.2. Write down the value of the work function of silver. Use a relevant equation to justify the answer. (3)

4.3. What physical quantity can be measured from the gradient of the graph? (1)

4.4. Calculate the value of X as shown on the graph. (5)

The experiment above is now repeated using light of higher intensity.

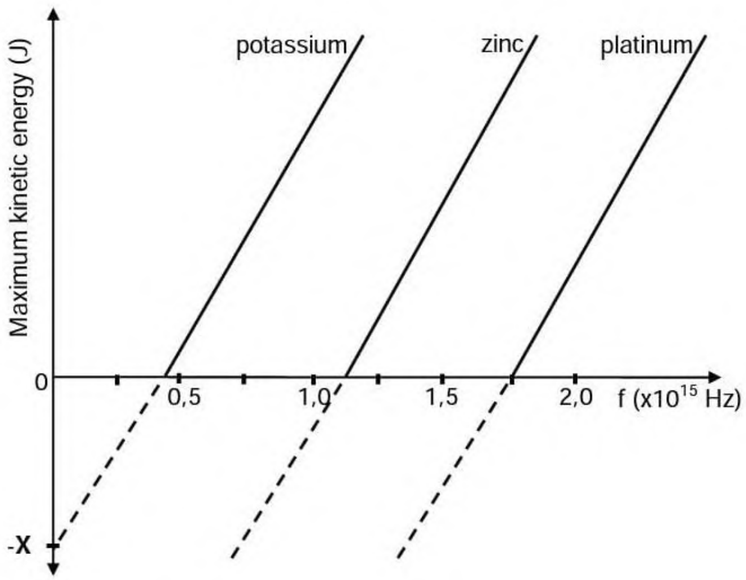
4.5. How will EACH of the following be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

4.5.1. The gradient of the graph. (1)

4.5.2. The number of photoelectrons emitted per unit time. (1)

ACTIVITY 5

5. An experiment is conducted to investigate the relationship between frequency of light incident on a metal and the maximum kinetic energy of the emitted electrons from the surface of the metal. This experiment is conducted for three different metals. The graph below represents the results obtained.



5.1. Name the phenomenon of which this experiment is based. (1)

5.2. Name the physical quantity represented by X on the graph. (1)

5.3. Which ONE of the three metals needs incident light with the largest wavelength for the emission of electrons? Give a reason for the answer. (2)

5.4. Define the term work function. (2)

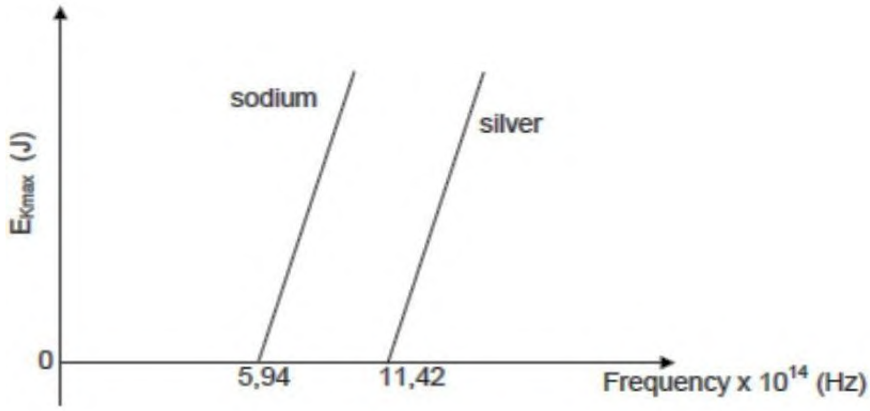
5.5. Calculate the:

5.5.1. Work function of platinum. (3)

5.5.2. Frequency of the incident light that will emit electrons from the surface of the platinum with a maximum velocity of 5.60×10^5 m.s^{-1}. (4)

ACTIVITY 6

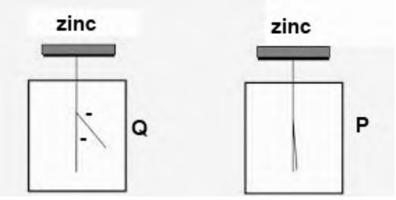
6. A learner is investigating the photoelectric effect for two different metals, silver and sodium, using light of different frequencies. The maximum kinetic energy of the emitted photoelectrons is plotted against the frequency of the light for each of the metals, as shown in the graphs below.



6.1.	Define the term threshold frequency.	(2)
6.2.	Which metal, sodium or silver, has the larger work function? Explain the answer	(3)
6.3.	Name the physical constant represented by the slopes of the graphs.	(1)
6.4.	If light of the same frequency is shone on each of the metals, in which metal will the ejected photoelectrons have a larger maximum kinetic energy?	(1)
6.5.	In a different photoelectric experiment blue light obtained from a light bulb is shone onto a metal plate and electrons are released. The wavelength of the blue light has 470 x10^{-9} m and the bulb is rated at 60 mW. The bulb is only 5% efficient.	
6.5.1.	Calculate the number of photons that will be incident on the metal plate per second, assuming all the light from the bulb is incident on the metal plate.	(5)
6.5.2.	Without any further calculation, write down the number of electrons emitted per second from the metal.	(1)

ACTIVITY 7

7. You are investigating the photoelectric effect in your classroom. Two clean pieces of zinc metal are placed on the discs of the electroscopes P and Q. Electroscope P is neutral (leaves are not open), while electroscope Q is negatively charged (leaves are open).



White light is shone on the zinc metal of each electroscope, but **no change is observed** in either of them. However, if the white light replaced by the ultraviolet light and is then shone onto the zinc metal of each electroscope, the leaves of electroscopes Q close.

7.1. Give a reason for the behavior of the leaves of electroscope Q when ultraviolet light is shone onto the zinc. (2)

7.2. Describe what happens to the leaves of electroscope P when ultraviolet light is shone onto the zinc. (1)

7.3. Give a reason for your observation in QUESTION 7.2. (2)

7.4. Compare white light and ultraviolet light by referring to the electromagnetic spectrum and the frequency and energy of their photons. (3)

ORGANIC CHEMISTRY

Representing Chemical Change

Balanced chemical equations

- Write and balance chemical equations.
- Interpret balanced reaction equations in terms of:
  - Conservation of atoms
  - Conservation of mass (use relative atomic masses)

Quantitative Aspects of Chemical Change

Molar volume of gases

- 1 mole of any gas occupies 22,4 dm^3at 0 °C (273 K) and 1 atmosphere (101,3 kPa).

Volume relationships in gaseous reactions

- Interpret balanced equations in terms of volume relationships for gases, i.e. under the same conditions of temperature and pressure, equal number of moles of all gases occupy the same volume.

Concentration of solutions

- Calculate the molar concentration of a solution.

More complex stoichiometric calculations

- Determine the empirical formula and molecular formula of compounds.
- Determine the percentage yield of a chemical reaction.
- Determine percentage purity or percentage composition, e.g. the percentage $CaCO_3$ in an impure sample of seashells.
- Perform stoichiometric calculations based on balanced equations.
- Perform stoichiometric calculations based on balanced equations that may include limiting reagents.

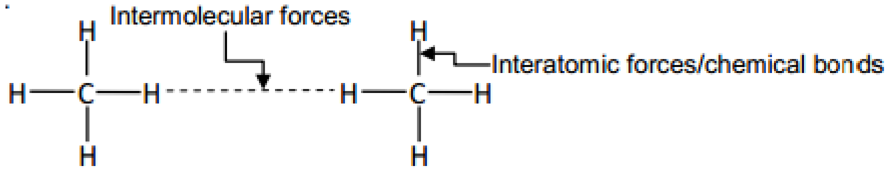
Intermolecular Forces

Intermolecular forces and interatomic forces (chemical bonds)

- Name and explain the different intermolecular forces (Van der Waal's forces):
  i. Dipole-dipole forces:
     Forces between two polar molecules
  ii. Induced dipole forces or London forces:
     Forces between non-polar molecules
  iii. Hydrogen bonding:
     Forces between molecules in which hydrogen is covalently bonded to nitrogen, oxygen or fluorine – a special case of dipole-dipole forces

- Describe the difference between intermolecular forces and interatomic forces (intramolecular forces) using a diagram of a group of small molecules; and in words.

Example:



- State the relationship between intermolecular forces and molecular size. For non-polar molecules, the strength of induced dipole forces increases with molecular size.
- Explain the effect of intermolecular forces on boiling point, melting point and vapour pressure.

Boiling point:
The temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the higher the boiling point.
Melting point:
The temperature at which the solid and liquid phases of a substance are at equilibrium. The stronger the intermolecular forces, the higher the melting point.

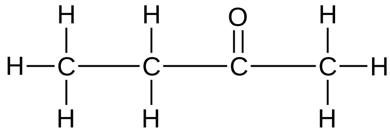
Vapour pressure:
The pressure exerted by a vapour at equilibrium with its liquid in a closed system. The stronger the intermolecular forces, the lower the vapour pressure.

Organic Molecules
- Define organic molecules as molecules containing carbon atoms.

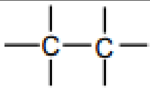
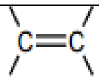
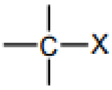
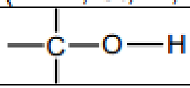
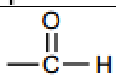
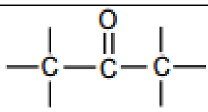
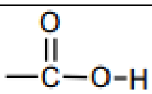
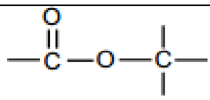
Organic molecular structures – functional groups, saturated and unsaturated structures, isomers
- Write down condensed structural formulae, structural formulae and molecular formulae (up to 8 carbon atoms, one functional group per molecule) for:
  - Alkanes (no ring structures)
  - Alkenes (no ring structures)
  - Alkynes
  - Halo-alkanes (primary, secondary and tertiary haloalkanes; no ring structures)
  - Alcohols (primary, secondary and tertiary alcohols)
  - Carboxylic acids
  - Esters
  - Aldehydes
  - Ketone
- Know the following definitions/terms:

Molecular formula: A chemical formula that indicates the type of atoms and the correct number of each in a molecule.
Example: C_4H_8O

Structural formula: A structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together. Example:



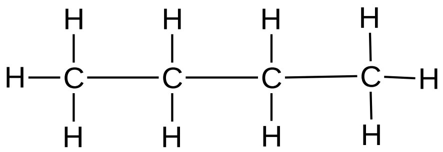
Hydrocarbon: Organic compounds that consist of hydrogen and carbon only.
Homologous series: A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH_2 group.
Saturated compounds: Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains.
Unsaturated compounds: Compounds with one or more multiple bonds between C atoms in their hydrocarbon chains.
Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

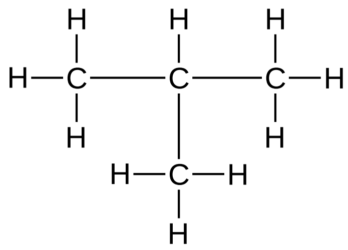
Homologous Series	**Structure of functional group**	
	Structure	**Name/Description**
Alkanes		Only C–H and C–C single bonds
Alkenes		Carbon-carbon double bond
Alkynes		Carbon-carbon triple bond
Haloalkanes	 (X = F, Cℓ, Br, I)	Halogen atom bonded to a saturated C atom.
Alcohols		Hydroxyl group bonded to a saturated C atom
Aldehydes		Formyl group
Ketones		Carbonyl group bonded to two C atoms
Carboxylic acids		Carboxyl group
Esters		-

Structural isomer: Organic molecules with the same molecular formula, but different structural formulae

- Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.

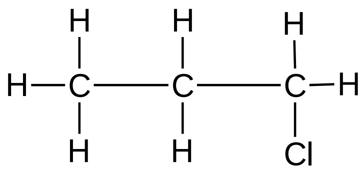
- Restrict structural isomers to chain isomers, positional isomers and functional isomers.
  - **Chain isomers**: Same molecular formula, but different types of chains, e.g. butane and 2-methylpropane.



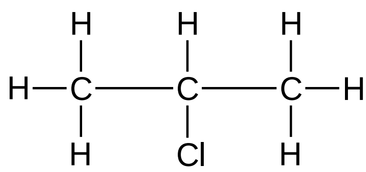


butane 2-methylpropane

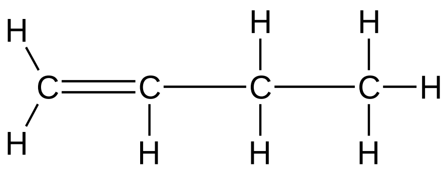
  - **Positional isomers**: Same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain, e.g. 1-choropropane and 2-chloropropane or but-2-ene and but-1-ene



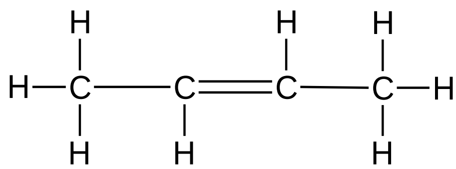
1-chromopropane



2-chromopropane

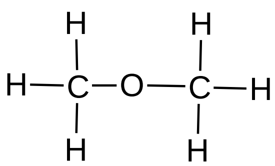


but-1-ene

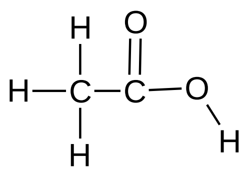


but-2-ene

  - **Functional isomers**: Same molecular formula, but different functional groups, e.g. methyl methanoate and ethanoic acid



methyl methanoate



ethanoic acid

IUPAC naming and formulae

- Write down the IUPAC name when given the structural formula or condensed structural formula for compounds from the homologous series above, restricted to one functional group per compound, except for haloalkanes. For haloalkanes, maximum two functional groups per molecule.
- Write down the structural formula when given the IUPAC name for the above homologous series.
- Identify alkyl substituents (methyl- and ethyl-) in a chain to a maximum of THREE alkyl substituents on the parent chain.
- When naming haloalkanes, the halogen atoms do not get preference over alkyl

groups – numbering should start from the end nearest to the first substituent, either the alkyl group or the halogen. In haloalkanes, where e.g. a Br and a Cℓ have the same number when numbered from different ends of chain, Br gets alphabetical preference.

- When writing IUPAC names, substituents appear as prefixes written alphabetically (bromo, chloro, ethyl, methyl), ignoring the prefixes di- and tri.

Structure and physical properties (boiling point, melting point, vapour pressure) relationships

- For a given example (from the above functional groups), explain the relationship between physical properties and:
  - Strength of intermolecular forces (Van der Waal's forces), i.e. hydrogen bonds, dipole-dipole forces, induced dipole forces
  - Type of functional groups
  - Chain length
  - Branched chains

Factors that influence the strength of IMF

1. Surface area

Length of the carbon chain and **branched molecules**.
For compounds that belong to the same homologous series, the larger the surface area the higher the Melting point, the Boiling point, the Viscosity and the lower the Vapour pressure.

- The more branched the organic molecules are, the more compact it becomes.
- The surface area is smaller and less Van der Waals forces are available.
- The IMF are weaker resulting in lower boiling points and melting points.
- The vapour pressure will increase.

2. The type of functional group

For compounds with comparable molecular mass (C-chain length) the functional group will be the determining factor regarding the strength of the IMF. The more polar the functional group the stronger the IMF.

Carboxylic acid > Alcohol > Ketone, Aldehyde & Ester > Alkyne, Alkane & Alkene

The **stronger** the intermolecular force the **higher** the **boiling point** and **melting point**, **lower vapour pressure**

London forces	**Dipole-dipole forces**	**Hydrogen Bond**
Alkanes Alkenes Alkynes	Aldehydes Ketones Halo- alkanes Esters	Alcohols (1 site) Carboxylic acids (2 sites)

ORGANIC REACTIONS

Substitution and addition reactions

- Identify reactions as elimination, substitution or addition.
- Write down, using structural formulae, equations and reaction conditions for the following addition reactions of alkenes:
  - **Hydrohalogenation**:

The addition of a hydrogen halide to an alkene

  - **Halogenation**:

The reaction of a halogen (Br_2, $C\ell_2$) with a compound

  - **Hydration**:

The addition of water to a compound

  - **Hydrogenation**:

The addition of hydrogen to an alkene

- Write down, using structural formulae, equations and reaction conditions for the following elimination reactions:
  - **Dehydrohalogenation of haloalkanes**:

The elimination of hydrogen and a halogen from a haloalkane

- Write down, using structural formulae, equations and reaction conditions for the following substitution reactions:
  - **Hydrolysis of haloalkanes**

Hydrolysis: The reaction of a compound with water

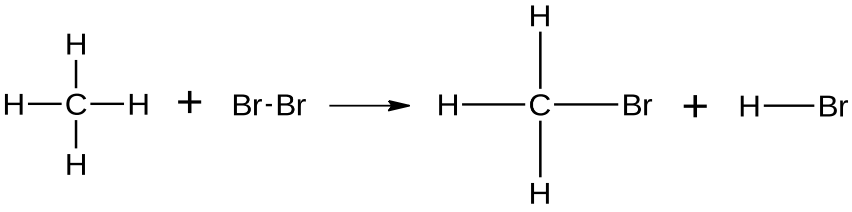
  - Reactions of HX (X = $C\ell$, Br) with alcohols to produce haloalkanes
  - **Halogenation of alkanes**

The reaction of a halogen (Br_2, $C\ell_2$) with a compound

- Distinguish between saturated and unsaturated hydrocarbons using bromine water.

REACTIONS OF ALKANES

1. **SUBSTITUTION**
   Alkane → haloalkane



Conditions: Heat **OR** sunlight(uv)

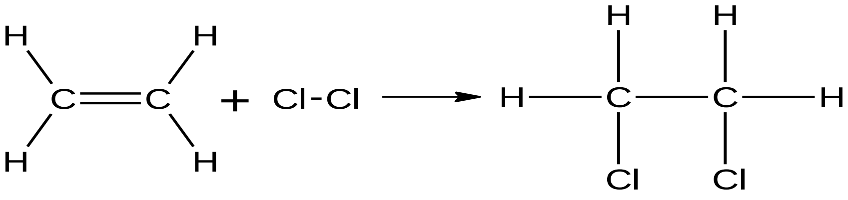
Reactants: alkane + X_2 (F, Cl, Br, I)

Type of substitution: halogenation(bromination)

Substitution reaction will only occur when the compound is saturated.

REACTIONS OF ALKENES

ADDITION REACTION 1 (Halogenation)



Conditions: Unreactive solvent

Type of addition: halogenation

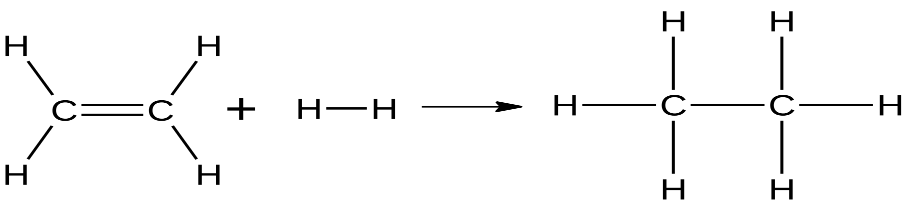
Reactants: alkene + X_2 (X = Cl, Br)

Product: haloalkane

Bromine test: to distinguish between **alkane** and **alkene**

- Add bromine water (orange-brown) to unknown substances.
- If bromine water discolours the substance is an alkene.
- $CH_2CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$

ADDITION REACTION 2 (Hydrogenation)



Conditions: Pt, Pd or Ni as catalyst

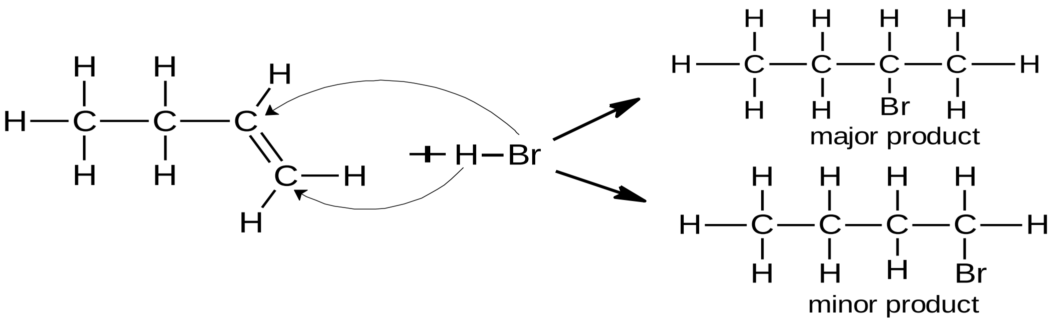
Type of addition: hydrogenation

Reactants: alkene + H_2

Product: Alkane

Application: Hydrogenation of unsaturated vegetable oils is used to manufacture margarine.

ADDITION REACTION 3 (Hydrohalogenation)



Conditions:No water; Unreactive solvent
Type of addition: hydrohalogenation
Reactants: alkene + HX (X = I, Br, Cl)
Product(s): haloalkane(s)
Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)

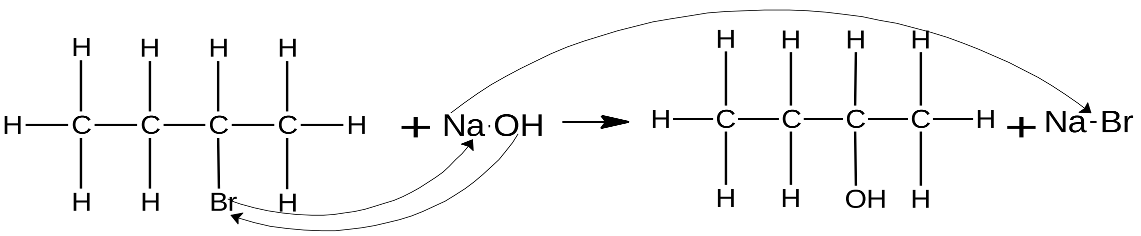
ADDITION REACTION 4 (Hydration)

Conditions: Excess H_2O; Acid (H_2SO_4 / H_3PO_4) as catalyst.
Type of addition: hydration
Reactants: alkene + H_2O **Product**: Alcohol(s)

Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)
Addition reaction will only occur when the compound is unsaturated.
REACTIONS OF HALOALKANES

1. **SUBSTITUTION :**

Haloalkane → alcohol
2.1

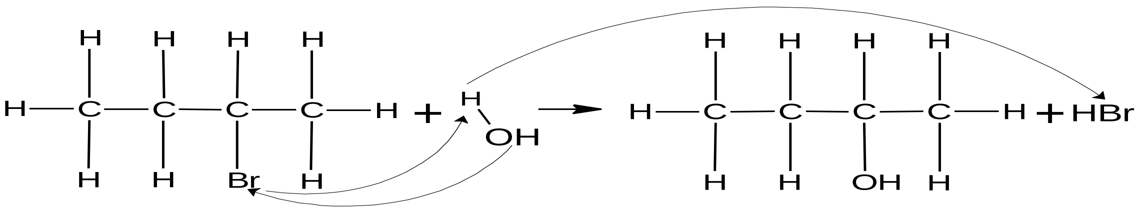


Conditions: Diluted strong base (NaOH/KOH/LiOH) + mild heat

Type of substitution: hydrolysis/ hydration

Reactants: Haloalkane in ethanol + diluted strong base

Products: Alcohol + NaBr/KBr/LiBr
2.2

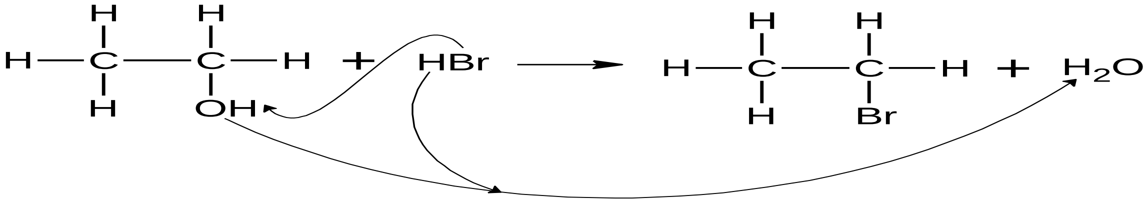


Conditions: Excess H_2O + mild heat
Type of substitution: hydrolysis
Reactants: Haloalkane + H_2O
Products: Alcohol + HBr

REACTIONS OF ALCOHOL

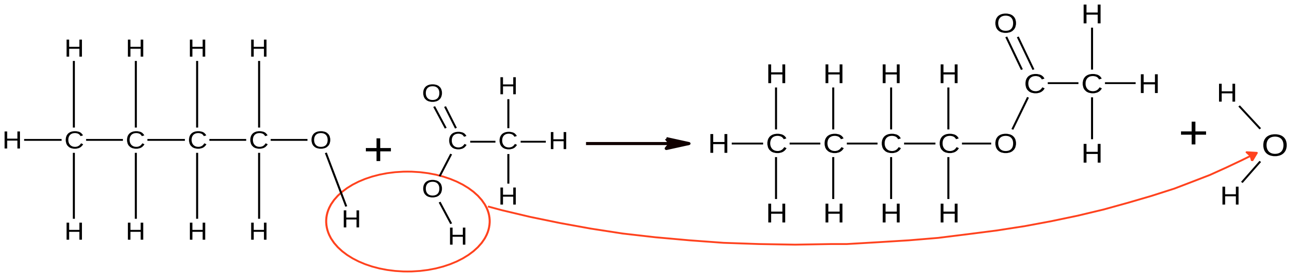
1. **SUBSTITUTION**

Alcohol → haloalkane



Conditions: Heat
Reactants needed: Alcohol + HX
For primary & secondary alcohols: NaBr + conc H_2SO_4 is used to prepare HBr in reaction flask.
For tertiary alcohols: HBr (or HCl) are directly applied.
Products: Haloalkane + H_2O

ESTERIFICATION



Conditions: Concentrated H_2SO_4 as catalyst + heat
Reactants: Alcohol + carboxylic acid + H_2SO_4
Products: Ester + water

- The process whereby esters is formed is called **esterification.**
- Esters form when an **alcohol** reacts with a **carboxylic acid** when **heated** (condensation reaction).
- The catalyst is **concentrated sulphuric acid (H_2SO_4)**, a **dehydrating agent** that **extracts** the **water.**
- The **homologous series** is an **esters** and the name, therefore, ends in "**-oate**".

The name of the example above is therefore, **butyl ethanoate.**

Plastics and polymers (ONLY BASIC POLYMERISATION as application of organic chemistry)

- Describe the following terms:
  Macromolecule: a molecule that consists of a large number of atoms
  Polymer: a large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern
  Monomer: small organic molecules that can be covalently bonded to each other in a repeating pattern
  Polymerisation: a chemical reaction in which monomer molecules join to form a polymer

Plastics: synthetic materials derived from organic compounds

- Identify monomers from given addition polymers.
- Discuss the industrial uses of polythene.

QUESTION 1
MULTIPLE-CHOICE QUESTIONS

Four options are given as possible answers to the following questions. Each question has only ONE correct answer.

1.1 Which ONE of the compounds below is an aldehyde?

A CH_3CHO

B CH_3COCH_3

C CH_3COOH

D CH_3OH (2)

1.2 The reaction represented by the equation below takes place in the presence of a catalyst.

$$C_{13}H_{28(\ell)} \longrightarrow C_2H_{4(g)} + C_3H_{6(g)} + C_8H_{18(\ell)}$$

This reaction is an example of …

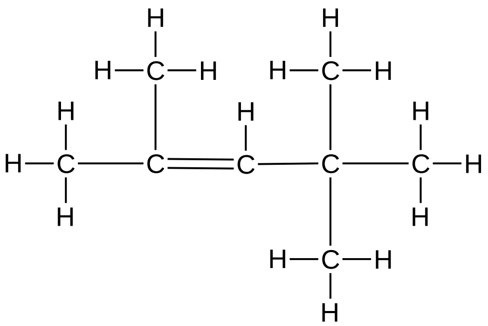
A addition.

B cracking.

C substitution.

D polymerisation. (2)

1.3 Consider the structural formula of an organic compound below.



Which ONE of the following is the correct IUPAC name of this compound?

A 2,2,4-trimethylpent-2-ene

B 2,2,4-trimethylpent-3-ene

C 2,4,4-trimethylpent-2-ene

D 2,4,4-trimethylpent-3-ene (2)

1.4 Which ONE of the following statements is CORRECT?

Alkenes …

A have the general formula C_nH_{2n+2}.

B are unsaturated hydrocarbons.

C readily undergo substitution reactions.

D have one triple bond between two carbon atoms. (2)

1.5 The following equation represents the cracking of a hydrocarbon at high temperature and pressure:

$$C_{11}H_{24} \longrightarrow 2C_2H_4 + \mathbf{Y} + C_4H_{10}$$

Which ONE of the following is the IUPAC name of product **Y**?

A Prop-1-ene.
B Propane.
C Ethene.
D Ethane. (2)

1.6 When 2-chlorobutane is strongly heated in the presence of concentrated sodium hydroxide, the major product formed is …

A but-1-ene.
B but-2-ene.
C butan-1-ol.
D butan-2-ol. (2)

1.7 Which ONE of the following compounds is an aldehyde?

A Pentanal
B Pentan-2-ol
C Pentan-2-one
D Ethyl propanoate (2)

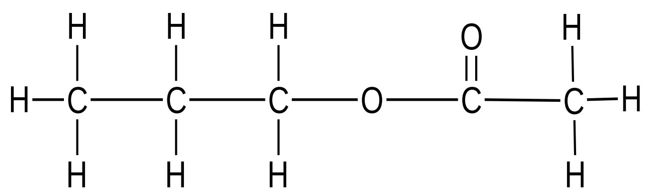
Consider the reaction represented by the equation below:

$$CH_3CHCH_2 + H_2 \longrightarrow CH_3CH_2CH_3$$

This reaction is an example of …

A hydration.
B dehydration.
C substitution.
D hydrogenation. (2)

1.8 Consider the structural formula of a compound below.



1.9 Which ONE of the following pairs of reactants can be used to prepare this compound in the laboratory?

A Propanoic acid and ethanol
B Propanoic acid and methanol
C Ethanoic acid and propan-1-ol
D Methanoic acid and propan-1-ol (2)

1.10 Which ONE of the following compounds has dipole-dipole forces between its molecules?

A Ethanal

B Ethane

C Ethene

D Ethyne (2)

1.11 Which ONE of the following is a product formed during the hydrolysis of bromoethane?

A Water

B Ethene

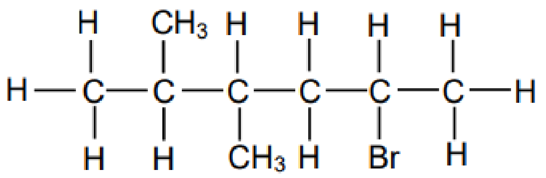
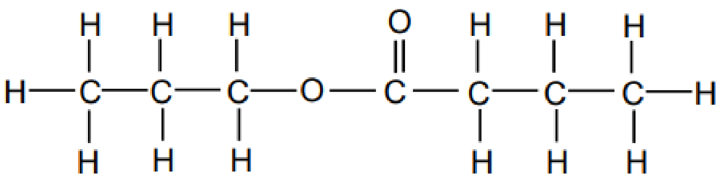
C Ethanol

D Bromine (2)

LONG QUESTIONS

QUESTION 2

The letters A to E in the table below represent five organic compounds.

A		**B**	C_3H_8O
C		**D**	Pentan-2-one
E	4-methylpent-2-yne		

Use the information in the table to answer the questions that follow.

2.1 For compound D, write down the:

2.1.1 Homologous series to which it belongs (1)

2.1.2 IUPAC name of a FUNCTIONAL ISOMER (2)

2.2 Write down the:

2.2.1 IUPAC name of compound A (3)

2.2.2 STRUCTURAL FORMULA of compound E (2)

2.3 Compound B is a primary alcohol.

2.3.1 Write down the meaning of the term primary alcohol. (2)

Compound B reacts with another organic compound X to form compound C.

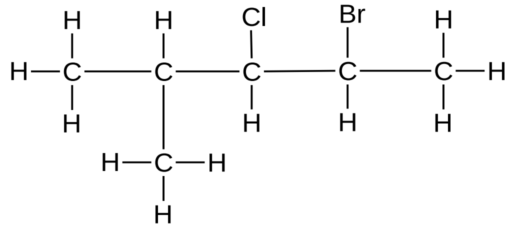
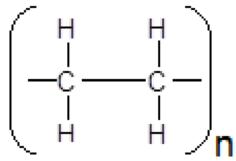
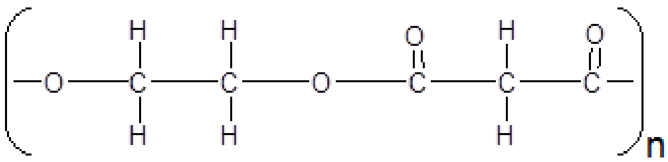
Write down the:

2.3.2 Type of reaction that takes place (1)

2.3.3 IUPAC name of compound X (1)

QUESTION 3

Consider the organic compounds represented by the letters A to F in the table below.

A	2,2,4-trimethylhexane	B	$CH_3CH_2CH_2CH_2CHO$
C		D	
E		F	Pentan-2-one

3.1 Write down the LETTER that represents the following:

3.1.1 An aldehyde. (1)

3.1.2 A condensation polymer (1)

3.1.3 A compound which has a carbonyl group bonded to two carbon atoms as its functional group. (1)

3.2 Write down the IUPAC name of:

3.2.1 Compound **C** (3)

3.2.2 The monomer of compound **D** (1)

3.3 Write down the structural formula of:

3.3.1 Compound **A** (2)

3.3.2 Compound **F** (2)

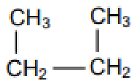
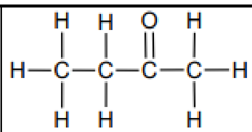
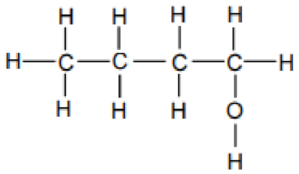
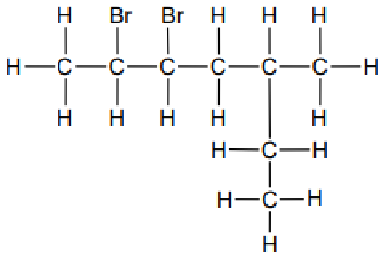
3.4 The table contains compounds which are functional isomers.

3.4.1 Define the term *functional isomer*. (2)

3.4.2 Write down the LETTERS that represent two compounds that are functional isomers. (1)

QUESTION 4

The letters A to F in the table below represent six organic compounds.

A		**B**	
C	$CH_3CCCH_2CH_3$	**D**	Butyl propanoate
E		**F**	

4.1 Is compound C SATURATED or UNSATURATED? Give a reason for the answer. (2)

4.2 Write down the LETTER that represents each of the following:

4.2.1 An ester (1)

4.2.2 A FUNCTIONAL ISOMER of butanal (1)

4.2.3 A compound with the general formula CnH2n-2 (1)

4.2.4 A compound used as reactant in the preparation of compound D (1)

4.3 Write down the STRUCTURAL FORMULA of:

4.3.1 The functional group of compound C (1)

4.3.2 Compound D (2)

4.3.3 A CHAIN ISOMER of compound A (2)

4.4 Write down the:

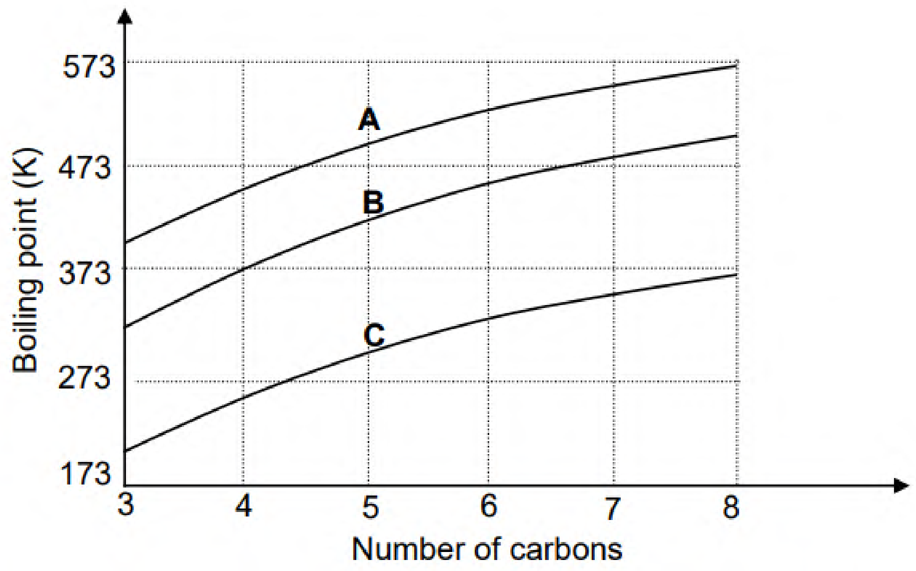
4.4.1 IUPAC name of compound F (3)

4.4.2 Balanced equation, using MOLECULAR FORMULAE, for the complete combustion of compound A (3)

Questions 5 - 7 involve Properties of Organic Compounds & Intermolecular Forces.

QUESTION 5

The relationship between boiling point and the number of carbon atoms in straight chain molecules of aldehydes, alkanes and primary alcohols is investigated. Curves A, B and C are obtained.



5.1 Define the term boiling point. (2)

5.2 Write down the STRUCTURAL FORMULA of the functional group of the aldehydes.

5.3 The graph shows that the boiling points increase as the number of carbon atoms increases. Fully explain this trend. (3)

5.4 Identify the curve (A, B or C) that represents the following:

5.4.1 Compounds with London forces only (1)

5.4.2 The aldehydes

Explain the answer. (4)

5.5 Use the information in the graph and write down the IUPAC name of the compound with a boiling point of 373 K. (2)

3.6 Write down the IUPAC name of the compound containing five carbon atoms, which has the lowest vapour pressure at a given temperature. (2)

QUESTION 6

The boiling points of five organic compounds (P, Q, R, S and T) are studied.

COMPOUND	IUPAC NAME
P	Pentanal
Q	2,2-dimethylbutane
R	3-methylpentane
S	Hexane
T	Pentan-1-ol

6.1 Define the term boiling point. (2)

The boiling points of compounds Q, R and S are compared.

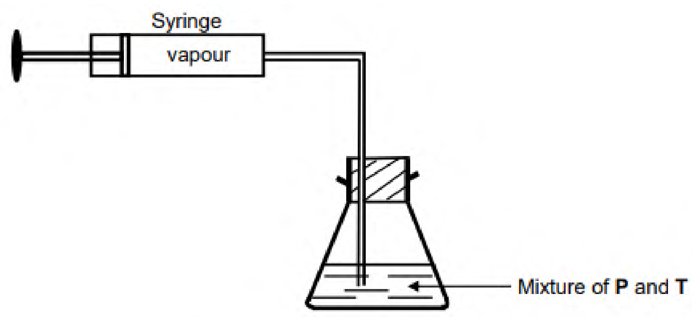
6.2 Give a reason why this is a fair comparison. (1)

The boiling points of Q, R and S are given below (NOT necessarily in the correct order).

55 °C	49,7 °C	68 °C

6.3 Which ONE of the three boiling points is most likely the boiling point of compound R? Explain the answer. (4)

6.4 A mixture of equal amounts of P and T is placed in a flask and heated to a temperature below their boiling points. Assume that no reaction or condensation takes place. The vapour produced is collected in a syringe.



6.4.1 Which compound (P or T) will be present in a greater amount in the SYRINGE? (2)

6.4.2 Explain the answer to QUESTION 6.4.1 by referring to the TYPES and STRENGTHS of intermolecular forces. (3)

QUESTION 7

The table below shows the results obtained from experiments to determine the boiling point of some alkanes and alcohols of comparable molecular masses.

Compound	Relative molecular mass	Boiling point (°C)
CH_3CH_3	30	-89
CH_3OH	32	65
$CH_3CH_2CH_3$	44	-42
CH_3CH_2OH	46	78
$CH_3CH_2CH_2CH_3$	58	0
$CH_3CH_2CH_2OH$	60	97
$CH_3CH_2CH_2CH_2CH_3$	72	36
$CH_3CH_2CH_2CH_2OH$	74	117

7.1 Define the term *boiling point.* (2)

7.2 Consider the boiling points of the four alkanes in the above table.

7.2.1 Describe the trend in their boiling points. (1)

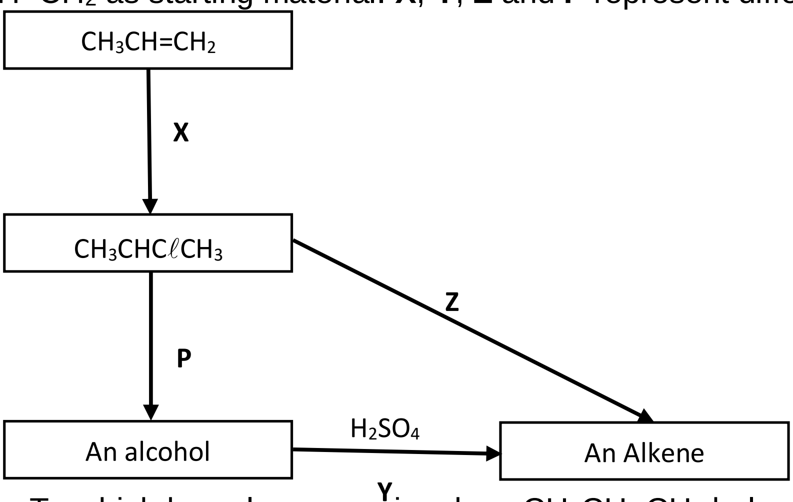
7.2.2 Fully explain the trend in QUESTION 7.2.1. (3)

7.2.3 The boiling point of each alcohol is much higher than that of the alkane of comparable relative molecular mass. Explain this observation by referring to the type and strength of the intermolecular forces in alkanes and alcohols. (2)

Questions 8 to 10 involve Types of Organic Reactions.

QUESTION 8

The flow diagram below shows the preparation of the organic compounds using $CH_3CH{=}CH_2$ as starting material. **X**, **Y**, **Z** and **P** represent different organic reactions.



8.1 To which homologous series does $CH_3CH{=}CH_2$ belong? (1)

8.2 Write down the:

8.2.1 Type of reaction of which **X** is an example. (1)

8.2.2 Structural formula and IUPAC name of the alcohol produced during reaction **P**. (3)

8.2.3 The type of reaction of which **Y** is an example. (1)

8.2.4 Function of the acid in reaction **Y**. (1)

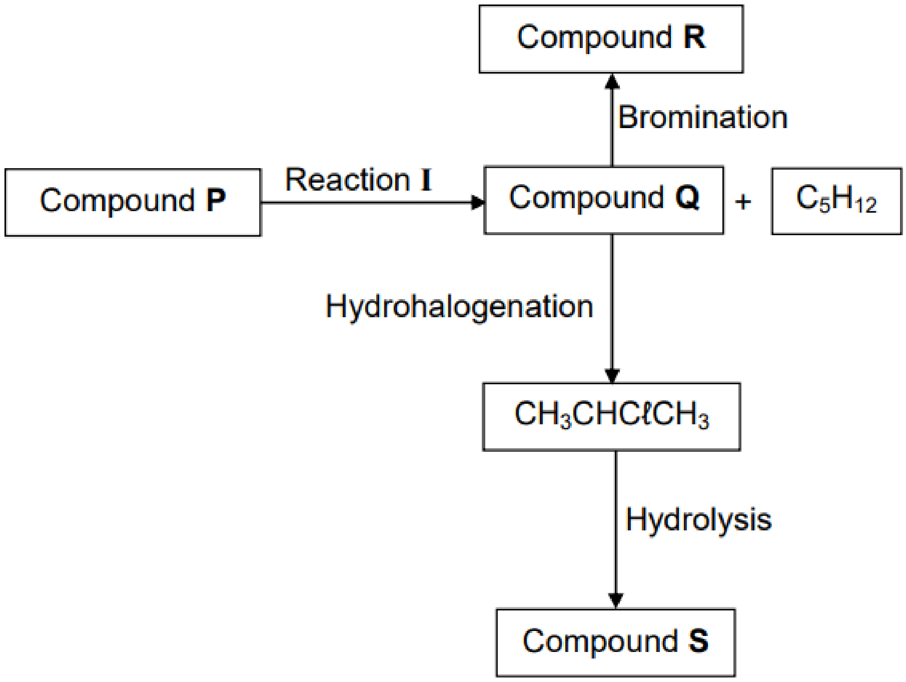
8.3 For reaction **Z**, write down:

8.3.1 The NAME of the inorganic reagent needed. (1)

8.3.2 TWO reaction conditions needed. (2)

QUESTION 9

The flow diagram below shows how various organic compounds can be prepared using compound P as starting reagent.



9.1 Write down the meaning of the term hydrohalogenation. (2)

9.2 Write down the STRUCTURAL FORMULA of compound Q. (2)

9.3 Reaction I is an elimination reaction.

Write down the:

9.3.1 TYPE of elimination reaction (1)

9.3.2 MOLECULAR FORMULA of compound P (1)

9.4 Write down the IUPAC name of compound R. (2)

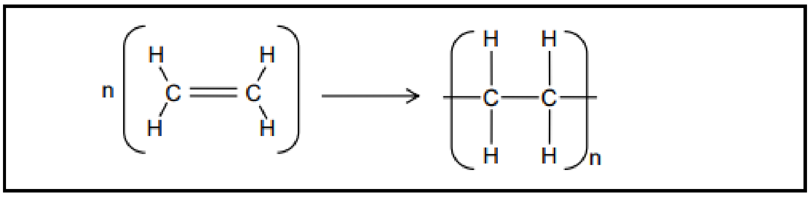
9.5 For the HYDROLYSIS REACTION, write down the:

9.5.1 Balanced equation using structural formulae (5)

9.5.2 TWO reaction conditions (2)

QUESTION 10

10.1 The balanced equation for a polymerisation reaction is shown below.



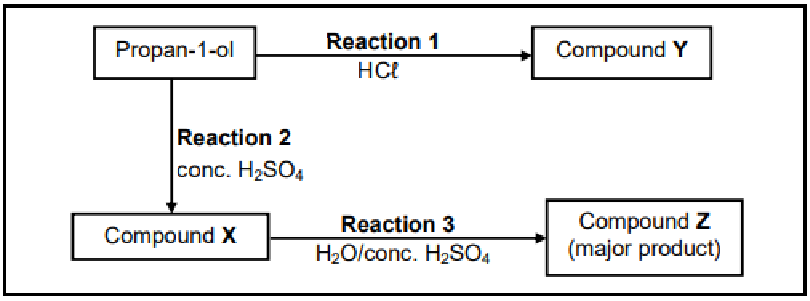
Write down the:

10.1.1 Type of polymerisation reaction represented by the equation (1)

10.1.2 IUPAC name of the monomer (1)

10.1.3 IUPAC name of the polymer (1)

10.2 Propan-1-ol undergoes two different reactions, as shown in the diagram below.



Write down the:

10.2.1 Type of reaction represented by reaction 2 (1)

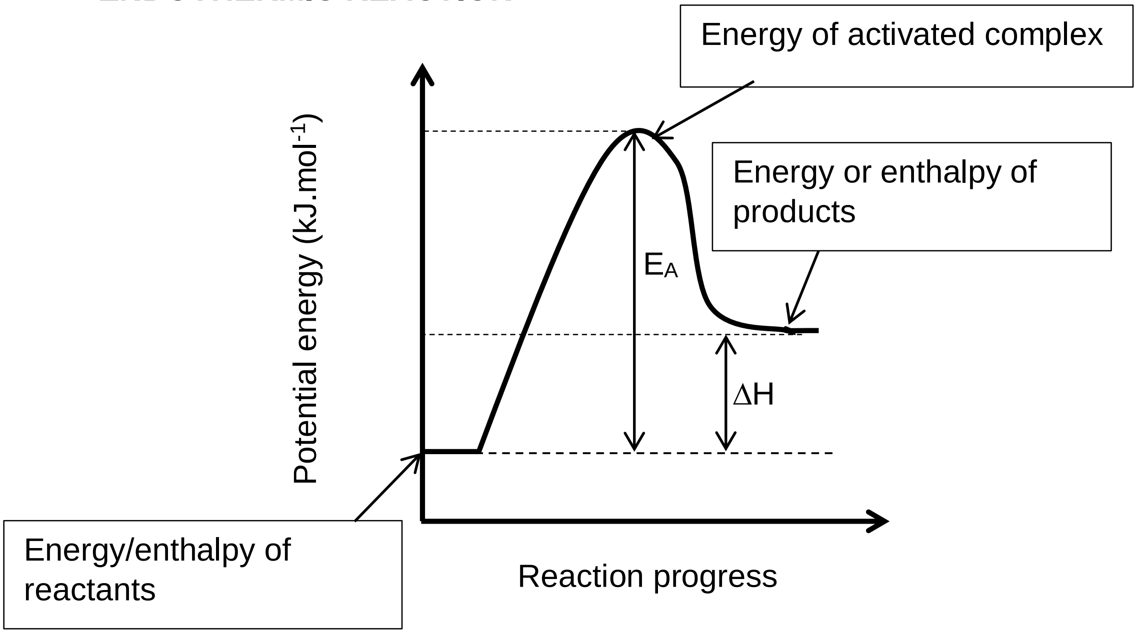
10.2.2 Function of concentrated H2SO4 in reaction 2 (1)

10.2.3 IUPAC name of compound X (2)

ENERGY CHANGES IN CHEMICAL REACTIONS

The energy profile graph shows the energy changes in a chemical reaction as the reaction progresses forward. There are two types of reactions shown by the energy profile graph; the **endothermic reaction** and the **exothermic reaction**.

ENDOTHERMIC REACTION



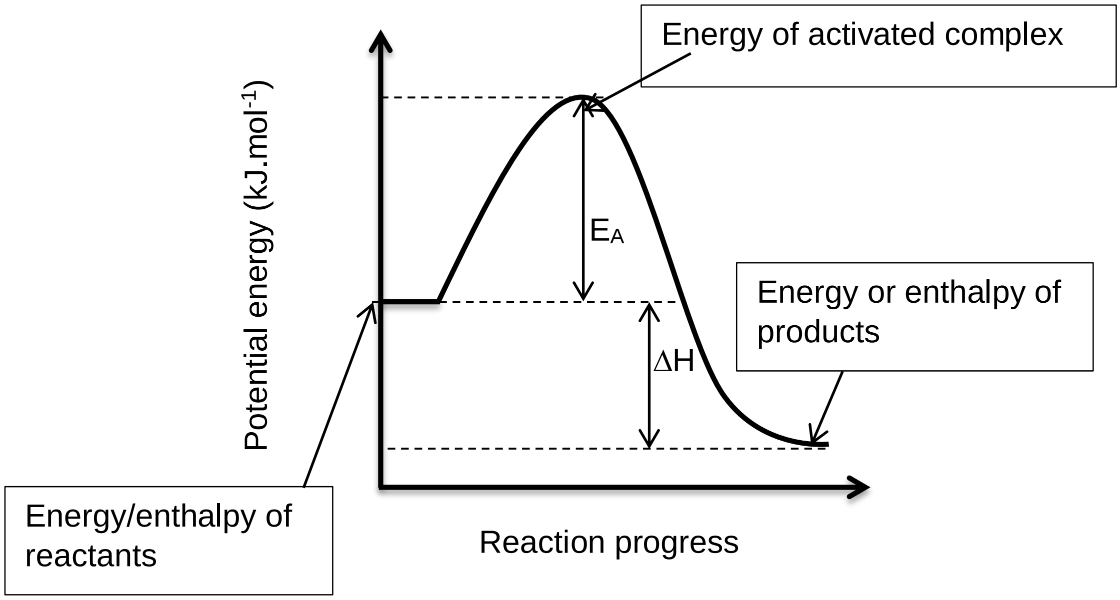
Here are the properties of the energy profile graph for the endothermic reaction:

- An **endothermic reaction** is a reaction that absorbs energy from its surroundings
- The energy of the products ($H_{PRODUCTS}$) is greater than the energy of the reactants ($H_{REACTANTS}$)
- The **Heat of reaction** or **Enthalpy change (ΔH)** is the difference between the energy of the products and the energy of the reactants

$$\Delta H = H_{PRODUCTS} - H_{REACTANTS} \qquad \mathbf{[\Delta H > 0]}$$

- The activation energy is the difference between the energy of the activated complex and the energy of the reactants.

EXOTHERMIC REACTION



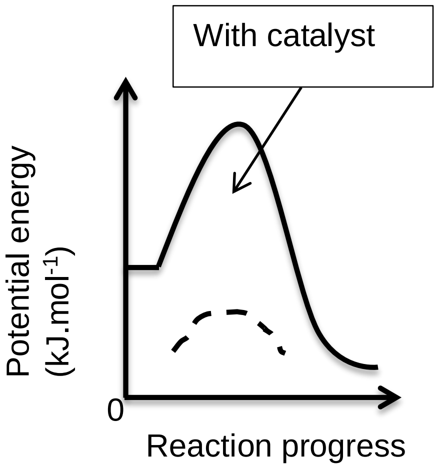
Here are the properties of the energy profile graph for the endothermic reaction:

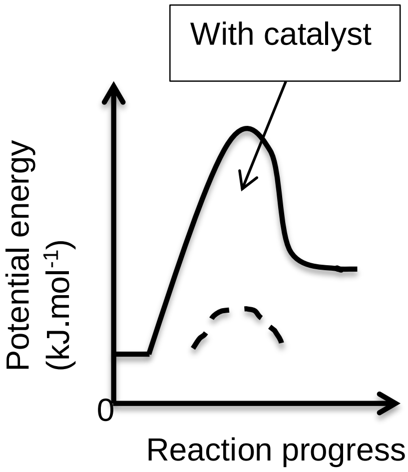
- An **exothermic reaction** is a reaction that releases energy to its surroundings
- The energy of the products ($H_{PRODUCTS}$) is less than the energy of the reactants ($H_{REACTANTS}$)
- The **Heat of reaction** or **Enthalpy change (ΔH)** is the difference between the energy of the products and the energy of the reactants

$$\Delta H = H_{PRODUCTS} - H_{REACTANTS} \qquad \mathbf{[\Delta H < 0]}$$

- The activation energy is the difference between the energy of the activated complex and the energy of the reactants.

The effect of a catalyst on the energy profile graph





NB: The addition of a catalyst does not affect ΔH, it only affects the activation energy

RATE OF REACTIONS

Chemical reactions occur at different rates. Some reactions happen faster (take shorter periods of time) while some reactions occur slower (take longer periods of time).

For example, when you drop an effervescent tablet in water it will react fast (in a short period of time). On the other hand, the reaction of iron with oxygen in the atmosphere to form iron oxide (rust) is a very slow reaction (takes a long time). The shorter the time the reaction takes, higher the rate of reaction.

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

CALCULATING THE RATE OF REACTION

TWO similar formulae are used for calculating rate of reaction depending on whether we are using change in reactants or change in products.

$$\text{Rate} = \frac{\Delta concentration\ of\ products}{\Delta time}$$

$$\text{Rate} = -\left(\frac{\Delta concentration\ of\ reactants}{\Delta time}\right)$$

NB: Quantities can be concentration (mol.dm^{-3}), mass (g), number of moles (mol) or volume (dm^3/cm^3) and change in time in (s) or (min)

THE COLLISION THEORY

The collision theory suggests that in order for particles to react, they need to collide, and these collisions have to be effective in order to result in a successful reaction. Some collisions are effective and some collisions are ineffective.

Effective collisions are determined by:

- Activation energy; sufficient kinetic energy of the reacting particles is required
- Correct orientation

The **rate of reaction** is determined by the number of effective collisions occurring per unit time.

FACTORS THAT AFFECT THE RATE OF REACTION

1. **Temperature**

Temperature is a measure of the average kinetic energy of the particles.

When the temperature is increased, the reaction rate also increases. When the temperature decreases, the reaction rate also decreases. This is why:

- An increase in temperature increases the average kinetic energy of the particles.
- More particles with enough kinetic energy
- More collisions and more effective collisions of particles with correct orientation per unit time.
- The reaction rate increases.

2. **Concentration**

Concentration is the number moles of solute per unit volume of solvent

When the concentration of a substance is increased, the rate of reaction also increases. When the concentration of a substance is decreased, the rate of reaction also decreases. This is why:

- An increase in concentration increases the number of particles per unit volume.
- More collisions and more effective collisions of particles with enough energy and correct orientation.
- The reaction rate increases.

3. **Surface area / State of division**

When the solid is divided into smaller pieces the surface area is greater than when it is not divided. This means powders have greater surface area than granules, lumps and ribbons. When the surface area is increased, the rate of reaction increases. This is why:

- An increase in surface area increases in the number of particles exposed at the surface for collisions to occur
- More collisions and more effective collisions of particles with enough energy and correct orientation per unit time.

- The reaction rate increases.

4. **Pressure of a gas**

When pressure of a gas is increased (by decreasing the volume of the container), the rate of reaction increases. This is why:

- An increase in pressure of a gas increases the number of gas particles per unit volume.
- More collisions and more effective collisions of particles with enough energy and correct orientation per unit time.
- The reaction rate increases.

5. **Nature of reacting substances**

Some chemical compounds are more reactive than others because of their differences in (for example) bond strength, reactivity trends, electronegativity and molecular mass (size). The more reactive a substance is, the faster it will react, the higher the reaction rate.

6. **Catalyst**

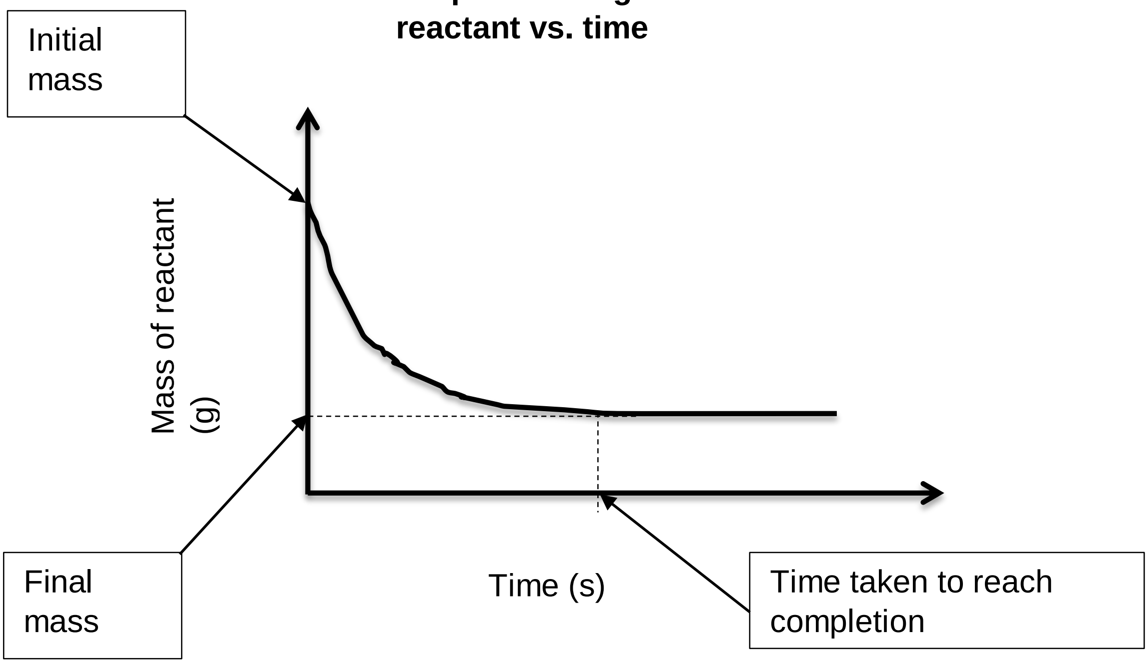
A **catalyst** is a substance that affects the rate of reaction without being consumed or undergoing any permanent change in the chemical reaction.

When a catalyst is added in a chemical reaction, the rate of reaction increases. This is why:

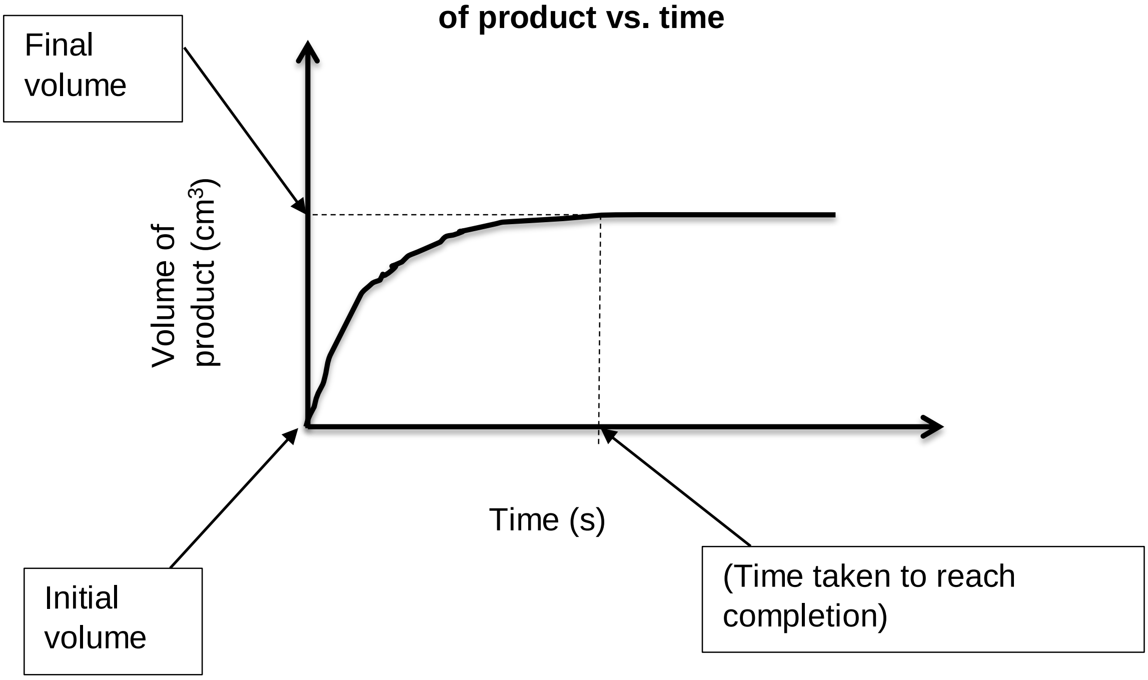
- The catalyst provides an alternative path of lower activation energy.
- More particles have energy greater than activation energy
- More collisions and more effective collisions of particles with enough energy and correct orientation per unit time.
- Reaction rate increases.

GRAPHS OF MASS OF REACTANTS/PRODUCTS vs. TIME

Graph of change in mass of reactant vs. time

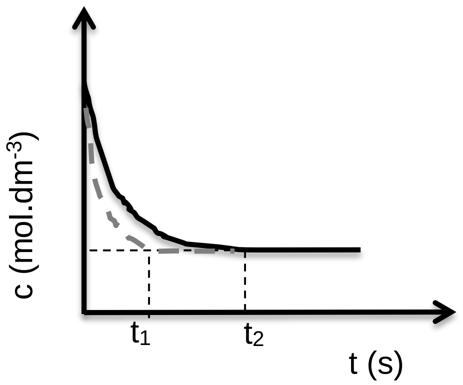


Graph of change in volume of product vs. time

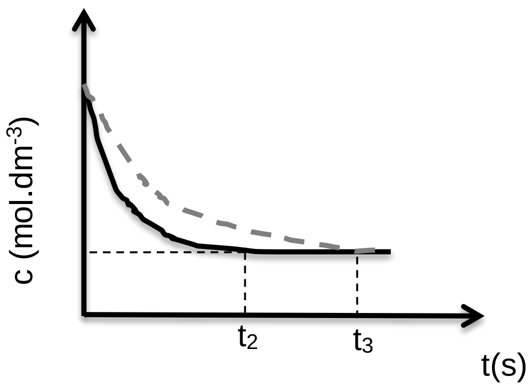


- **Showing the effect of changes in rate of reaction on the concentration of reactant vs time graph**

Graph 1: Increased rate



Graph 2: Decreased rate



In graph 1, the dashed line shows the reaction that has a higher rate:

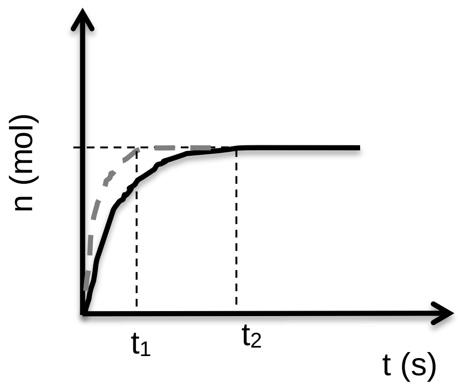
- The higher the rate of reaction, the shorter the time it takes for the reaction to reach completion.
- The dashed lines become horizontal earlier (time = t_1) than the solid line (time = t_2)

In graph 2, the dashed line shows the reaction that has a lower rate:

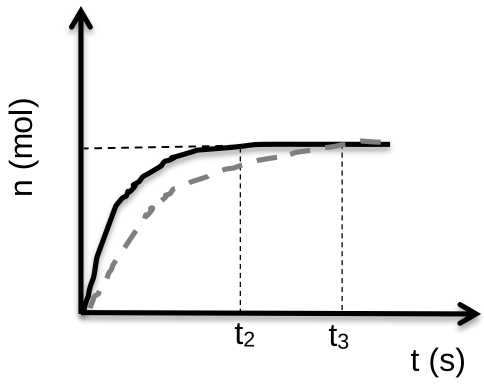
- The lower the rate of reaction, the longer the time it takes for the reaction to reach completion.
- The dashed lines become horizontal later (time = t_3) than the solid line (time = t_2)

- **Showing the effect of changes in rate of reaction on the number of moles product vs. time graph**

Graph 1: Increased rate



Graph 2: Decreased rate



In **graph 1**, the dashed line shows the reaction that has a higher rate:

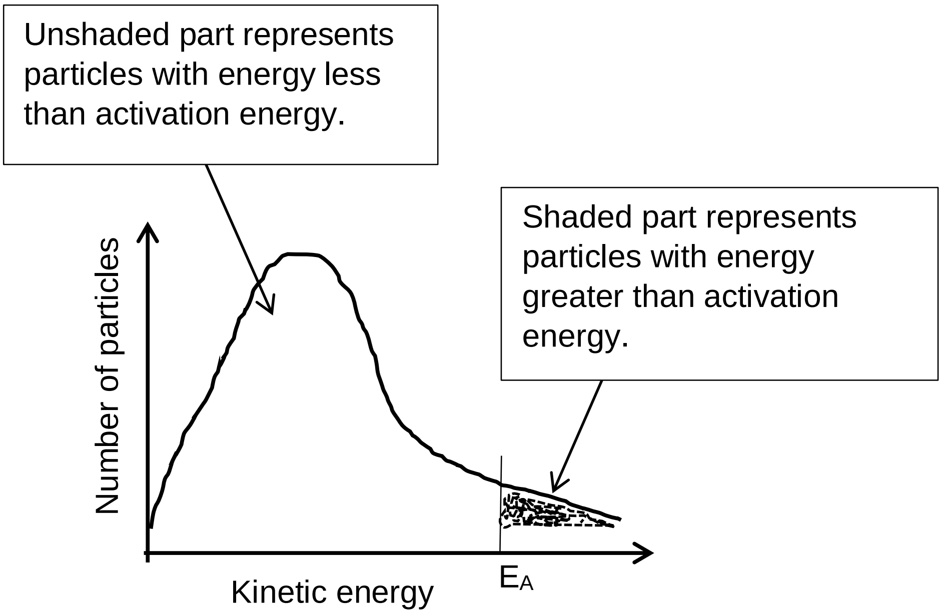
- The higher the rate of reaction, the shorter the time it takes for the reaction to reach completion.
- The dashed lines become horizontal earlier (time = t_1) than the solid line (time = t_2)

In **graph 2**, the dashed line shows the reaction that has a lower rate:

- The lower the rate of reaction, the longer the time it takes for the reaction to reach completion.
- The dashed lines becomes horizontal later (time = t_3) than the solid line (time = t_2)

THE MAXWELL-BOLTZMANN DISTRIBUTION CURVE

The Maxwell-Boltzmann distribution curve shows the distribution of particles along an energy scale. The curve shows the number of particles that have a certain value of energy in a system. The area below the curve is equal to the number of particles in the curve.



The Maxwell-Boltzmann distribution curve is affected by changes in **temperature** and **concentration**. The addition of a **catalyst** will affect the activation energy mark (E_A).

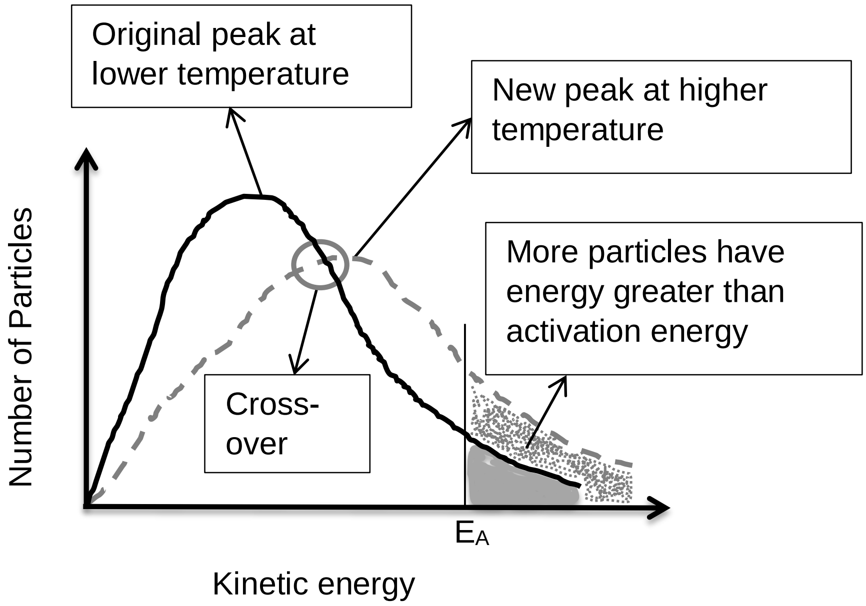
(a) The effect of temperature

An increase in temperature increases the average kinetic energy of the particles. This means that particles will move to the left of the energy scale or x-axis (higher energy values). The graph below shows the effect of an increase in temperature on the curve.

Take note of all the visible changes:

- The two curves cross-over to show that temperature is the factor that was changed

- The number of particles remains the same
- The peak of the curve at higher temperature is lower than the peak at lower temperature.
- The peak at higher temperature is more to the left while the peak at lower temperature is more to the right.

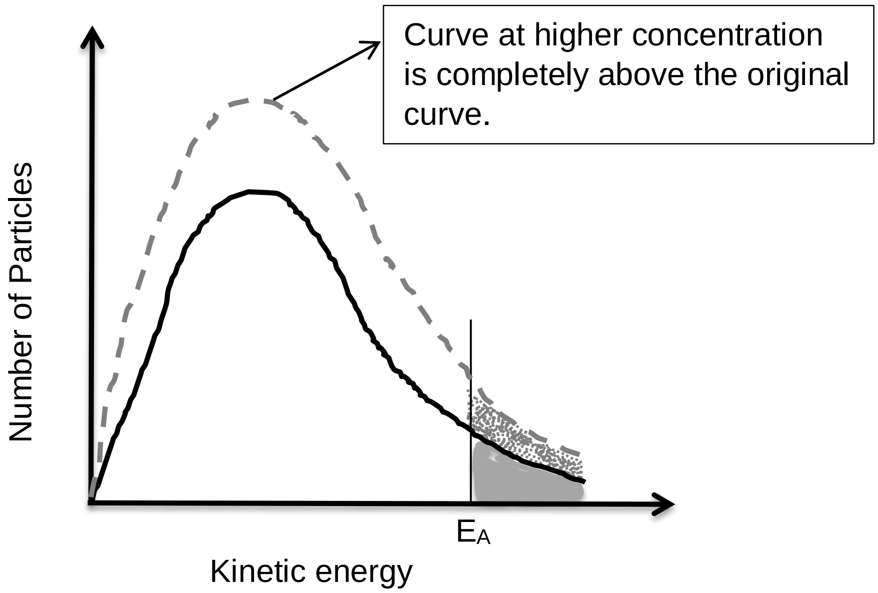


(b) The effect of concentration

An increase in concentration of the particles increases the number of particles per unit volume. This means that there will be more particles per energy value on the energy scale. This means the curve will shift vertically upwards.

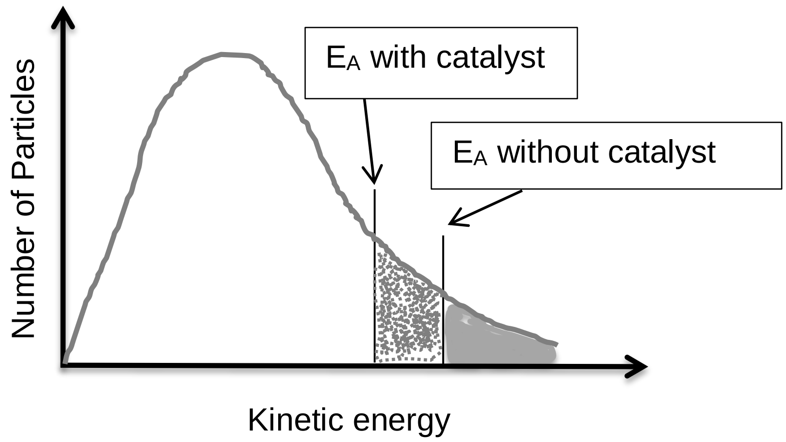
Take note of all the visible changes:

- The two curves do not cross-over like in temperature, but the curve at higher concentration is above the curve at lower concentration at all points
- The new peak does not shift to the left as in temperature.



(c) The effect of the catalyst

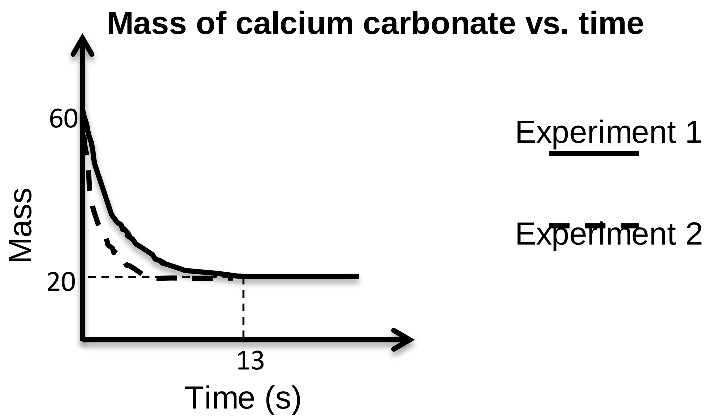
The addition of a catalyst provides an alternative path of low activation energy in the reaction. The addition of a catalyst will not affect the curve, but this will only affect the activation energy mark on the curve. The activation energy mark will shift to the left in the presence of a catalyst and to the right in the absence of a catalyst. In the presence of a catalyst, there will be more particles that have energy greater than the activation energy.



WORKED EXAMPLES

- **Worked Example 1:**

The reaction of calcium carbonate ($CaCO_3$) and hydrochloric acid is used to investigate the factors that affect the rate of reaction. In one experiment, powdered calcium carbonate is used and in another, lumps of calcium carbonate are used. The graph below shows the change in the mass of calcium carbonate with time.



1.1. Which experiment (1 or 2) used powdered calcium carbonate? Explain by referring to the collision theory.

1.2. Calculate the rate of reaction for experiment 1 during the first 3 seconds.

Solutions

1.1. Experiment 2.

The graph show experiment 2 reached completion faster than experiment 1, meaning experiment 2 has a higher rate.

- An increase in surface area increases in the number of particles exposed at the surface for collisions to occur
- More effective collisions of particles with enough energy and correct orientation per unit time.
- The reaction rate increases.

1.2. Rate = $\frac{-\Delta mass\ of\ reactants}{\Delta time}$

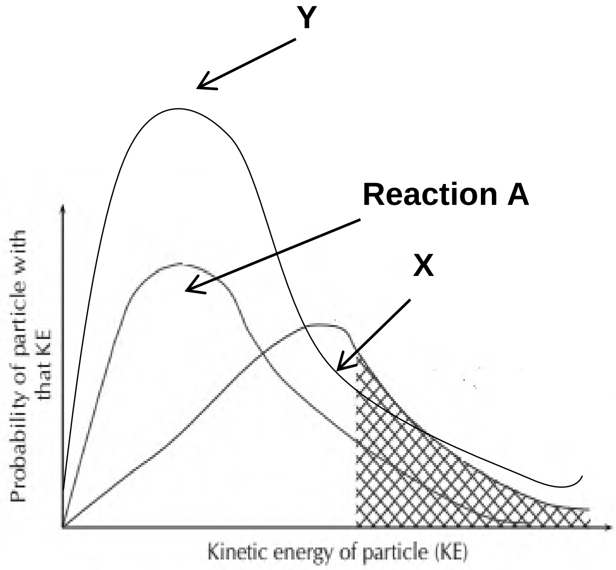
Rate = $\frac{-(20-60)}{13-0}$

Rate = $3.07 g.s^{-1}$

- **Worked example 2**

The Maxwell-Boltzmann curve below was obtained for three reactions where:

- Reaction A: 0.2 $mol.dm^{-3}$ of sulphuric acid was used at 30^0C.
- Reaction B: 0.2 $mol.dm^{-3}$ of sulphuric acid was used at 40^0C
- Reaction C: 0.35 $mol.dm^{-3}$ of sulphuric acid was used at 30^0C



2.1. Which graph (**X** or **Y**) represents reaction B? Explain your answer.

Solution:

2.1. Reaction X.

- When temperature is increased from 30^0C to 40^0C, the particles' average kinetic energy increases.
- This means the new curve will shift to the left of the energy scale

- **Worked example 3**

Methanol and Hydrochloric acid react according to the following balanced equation:

$$CH_3OH_{(aq)} + HCl_{(aq)} \rightarrow CH_3Cl_{(aq)} + H_2O_{(l)}$$

3.1. State two factors that increase the rate of reaction for THIS reaction.

3.2. The rate of the reaction between methanol and hydrochloric acid is investigated. The concentration of HCℓ(aq) was measured at different time intervals. The following results were obtained:

TIME (MINUTES)	HCℓ CONCENTRATION ($mol{\cdot}dm^{-3}$)
0	1,90
15	1,45
55	1,10
100	0,85
215	0,60

Calculate the mass of $CH_3Cl_{(aq)}$ produced in at the end of 215 minutes if the volume of the contents at this stage is $60cm^3$.

Solutions:

3.1. Temperature and concentration.

3.2.
- Concentration of HCl reacted = 1.90 – 0.60 = 1.30mol.dm^{-3}
- Moles HCl reacted:

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

$$1.30 = \frac{n}{0.06}$$

n = 0.078mol

- Moles of CH_3Cl produced = 0.078mol (ratio 1:1)
- Mass of CH_3Cl produced:

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

$$0.078 = \frac{m}{50.5}$$

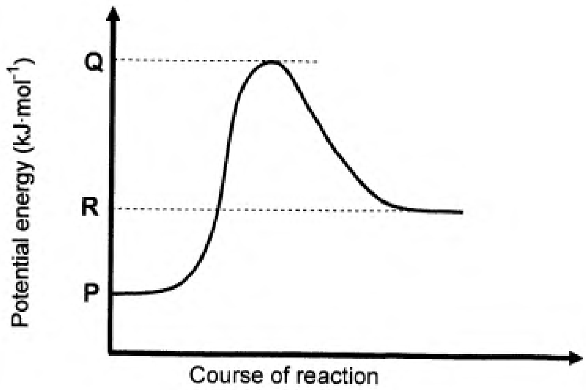
m = 3.94 g

REACTION RATES MULTIPLE CHOICE QUESTIONS

1. According to the Collision theory, reaction rate increases when decreases.

   A. Temperature
   B. Concentration
   C. Activation Energy
   D. Kinetic molecular energy (2)

2. Consider the potential energy graph for the reaction shown below.



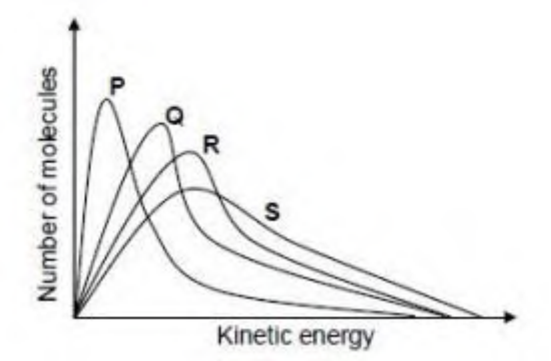
The activation energy for the forward reaction in terms of **P, Q** and **R** is:

   A. Q
   B. R – P
   C. Q – R
   D. Q – P (2)

3. The activation energy can be best described as the minimum energy required to…

   A. Cause effective collisions.
   B. Make reactant molecules collide
   C. Change the orientation of the molecules (2)
   D. Increase the kinetic energy of reactant molecules

4. The graphs below represent the molecular distribution for a reaction at different temperatures.



Which ONE of the graphs represents the reaction at the highest temperature?

   A. P
   B. Q
   C. R
   D. S (2)

5. The activation energy for a certain reaction is 50 kJ.mol^{-1}. Energy is absorbed when this reaction takes place. Which ONE of the following is CORRECT for the REVERSE reaction?

	ACTIVATION ENERGY (E_A)	HEAT OF REACTION (ΔH)
A	$E_A > 50$ kJ·mol^{-1}	$\Delta H > 0$
B	$E_A > 50$ kJ·mol^{-1}	$\Delta H < 0$
C	$E_A < 50$ kJ·mol^{-1}	$\Delta H < 0$
D	$E_A < 50$ kJ·mol^{-1}	$\Delta H > 0$

(2)

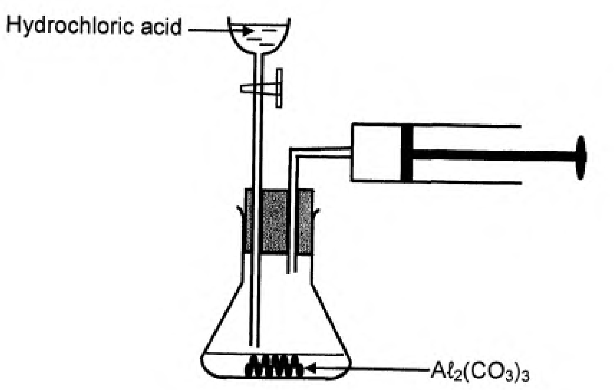
REACTION RATES LONG QUESTIONS

QUESTION 1

Two experiments, **I** and **II**, are conducted to investigate one of the factors that affects the rate of 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 $mol.dm^{-3}$ $HCl_{(aq)}$ reacts with 0, 016 mol $Al_2(CO_3)_3$ granules at 25^{0}C.

EXPERIMENT II:

50 cm^3 of 2 $mol.dm^{-3}$ $HCl_{(aq)}$ reacts with 0, 016 mol $Al_2(CO_3)_3$ granules at 25^{0}C.

1.1 Define the term reaction rate. (2)

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

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

1.4 The average rate of the reaction in **EXPERIMENT II** during the first 2, 5 minutes is 4, 4 x 10^{-3} $mol.min^{-1}$. Calculate the number of moles of $Al_2(CO_3)_3$ that remains in the flask after 2, 5 minutes. (3)

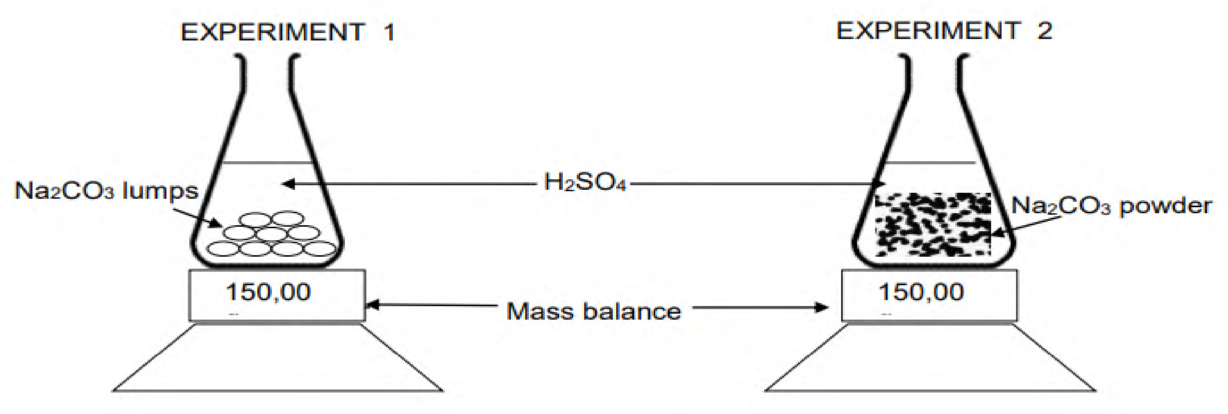
1.5 Calculate the maximum volume of $CO_{2(g)}$ that can be prepared at 25^{0}C in **EXPERIMENT I.** Take molar gas volume at 25^{0}C as 24 000 $cm^{3.}$ mol^{-1}. (3)

QUESTION 2

The reaction between **sodium carbonate (Na_2CO_3)** and **sulphuric acid (H_2SO_4)** was used to investigate one of the factors affecting reaction rate. The balanced equation is given below.

$$Na_2CO_{3(s)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Two experiments are conducted as illustrated below.



In both experiments the same amount of sodium carbonate is added to excess of sulphuric acid solution in a conical flask placed on a mass balance. The mass of the flask together with its contents is recorded every 15 s.

2.1 Define the term reaction rate. (2)

2.2 For this investigation described above, write down:

2.2.1. The dependent variable (1)

2.2.2. The independent variable (1)

2.2.3. One controlled variable (1)

The results obtained in EXPERIMENT 1 are shown in the experiment below.

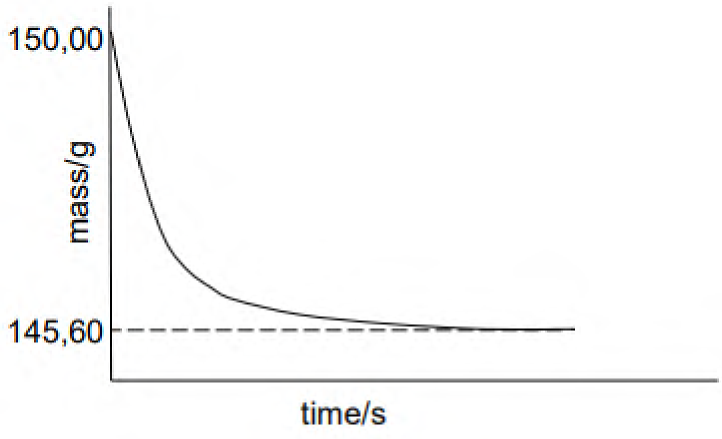
Time(s)	0	15	30	45	60	75	90	105	120
Mass(g)	150,0	147,5	146,6	146,0	145,8	145,7	145,6	145,6	145,6

2.3 Write down the NAME or FORMULA of the substance responsible for the decrease in mass. (1)

2.4 How long does it take for the reaction in EXPERIMENT 1 to be completed? (1)

2.5 How will the rate of the reaction in EXPERIMENT 2 compare to that in EXPERIMENT 1? Write down GRAETER THAN, SMALLER THAN or EQUAL TO. Briefly explain your answer by referring to the collision theory. (3)

2.6 The sketch graph below (**not drawn to scale**) represents the results obtained for EXPERIMENT 1.



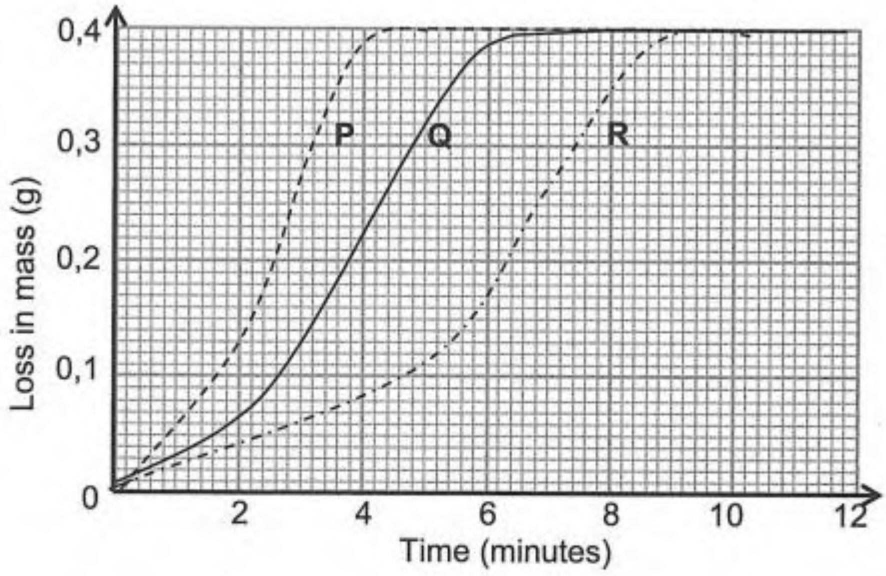
2.6.1. Use the information in the graph to determine the mass of sodium carbonate that has reacted in EXPERIMENT 1. (5)

2.6.2. Redraw the above sketch in your ANSWER BOOK. On the same set of axes, sketch the curve obtained for EXPERIMENT 2.Label your graph as **Exp 2.** (2)

[17]

QUESTION 3

Pieces of marble ($CaCO_3$) with a mass of 1,05 g are placed in a flask are placed in a flask and covered with 10 cm^3 of a 2 $mol.dm^{-3}$ hydrochloric acid solution at 20^0C. The flask is weighed every 2 minutes to determine the loss in the mass due to the production of carbon dioxide. Line graph Q is plotted from these results.



3.1 Define the term reaction. (2)

3.2 Write down the balanced equation for the reaction between the marble and hydrochloric acid. (3)

Use graph Q to answer the following questions.

3.3 What mass of carbon dioxide gas is formed after 8 minutes? (1)

3.4 During which ONE of the following time intervals is the reaction rate the highest? Choose from 0-2 minutes, 2-4 minutes, 6-8 minutes, 8-10 minutes. Briefly explain your choice. (2)

3.5 After how many minutes has half of the $CaCO_3$ reacted? (1)

3.6 Predict what will happen to the rate of reaction in each of the following cases:

(Choose from INCREASES, DECREASES or REMAINS THE SAME).

3.6.1. The marble pieces are replaced by marble powder. (1)

3.6.2. 20 cm^3 of a 2 $mol.dm^{-3}$ hydrochloric acid solution is used. (1)

The experiment is now repeated with a 1, 5 $mol.dm^{-3}$ hydrochloric acid solution. The reaction runs to completion.

3.7 Which graph**, P** or **R**, is obtained from this experiment? (1)

3.8 A potential energy diagram is drawn for the above reaction.

3.8.1. Is this reaction exothermic or endothermic? (1)

3.8.2. How will the heat of reaction change if the concentration of the hydrochloric acid is decreased? (1)

(Choose from INCREASES,DECREASES or REMAINS THE SAME)

3.8.3. A suitable catalyst is added to the reaction, WHICH quantity on the graph will change and HOW will it change? (1)

[16]

REACTION RATES

QUESTION 1

Two experiments, **I** and **II**, are conducted to investigate one of the factors that affects the rate of 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 $mol.dm^{-3}$ $HCl_{(aq)}$ reacts with 0, 016 mol $Al_2(CO_3)_3$ granules at 25^0C

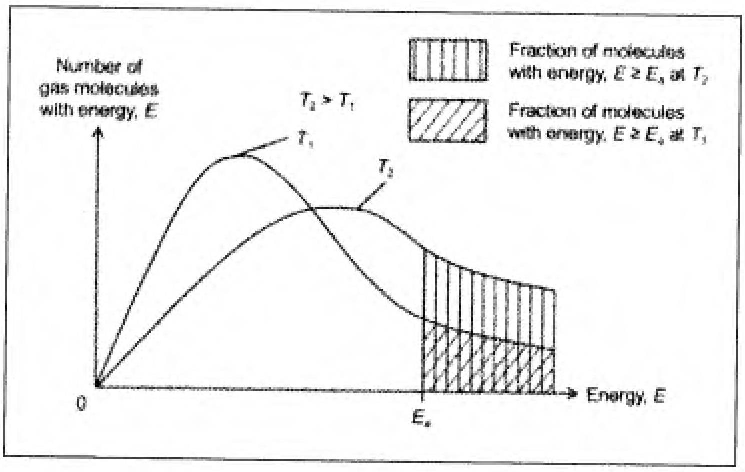
EXPERIMENT II:

50 cm^3 of 2 $mol.dm^{-3}$ $HCl_{(aq)}$ reacts with 0, 016 mol $Al_2(CO_3)_3$ granules at 25^0C

1.1 Define the term reaction rate. 2

QUESTION 4

The following diagram shows a Maxwell-Boltzmann distribution curve of a gas sample at temperatures T_1 and T_2.



4.1 Provide labels for the x and y axes of the graph, respectively. (2)

4.2 Which graph (T_1 or T_2) represents the gas at a higher temperature? (1)

4.3 What does the shaded area to the right of **label P** represent? (1)

4.4 What would happen to the area under the graph T_1 when a catalyst is added to the reaction mixture? Give a reason. (2)

4.5 Give a reason why the curve goes through the origin? (1)

[7]

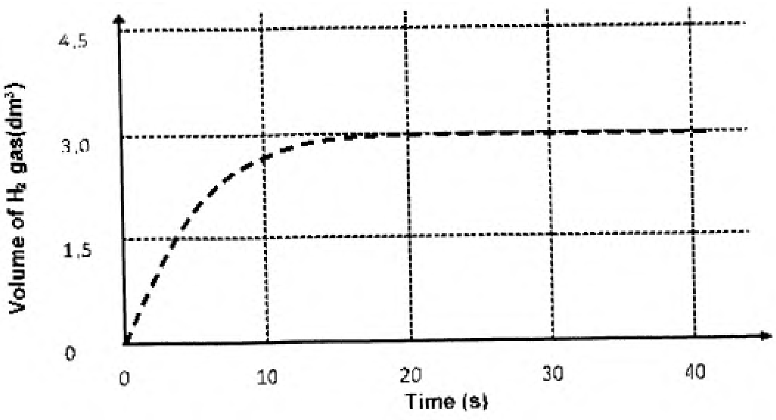
QUESTION 5

A group of learners perform a series of experiments to test the effect of certain factors on reaction rate when magnesium metal is added to EXCESS hydrochloric acid.

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow 2MgCl_{2(aq)} + H_{2(g)} \qquad \Delta H<0$$

EXPERIMENT	**STATE OF MAGNESIUM**	**MASS OF MAGNESIUM(g)**	**TEMPERATURE (^{0}C)**
1	ribbon	6,0	25
2	ribbon	6,0	15
3	fine powder	4,5	25

The results of **EXPERIMENT 1** were collected and plotted on the graph below:



5.1 Define reaction rate. (2)

5.2 What volume of hydrogen gas was collected in EXPERIMENT 1 after 40s? (1)

5.3 Calculate the average rate of reaction (in $dm^3.s^{-1}$) for experiment 1 over the first 20s. (3)

5.4 How will the rate of reaction be affected if a higher concentration of $HCl_{(aq)}$ is used. Assume that the temperature remains constant. (Choose from INCREASES, DECREASES or REMAIN THE SAME). Explain the answer in terms of the Collision Theory. (3)

5.5 Redraw the above graph of EXPERIMENT 1 in your answer book and on the same system of axes sketch the graphs that will be obtained for EXPERIMENTS 2 and 3. Clearly label your graphs **for each EXPERIMENT as Exp 2 and Exp 3.** (4)

[13]

QUESTION 2

The reaction between sodium carbonate (Na_2CO_3) and sulphuric acid (H_2SO_4) was used to investigate one of the factors affecting reaction rate. The balanced equation is given below.

$$Na_2CO_{3(s)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Two experiments are conducted as illustrated below.

EXPERIMENT 1 EXPERIMENT 2

In both experiments the same amount of sodium carbonate is added to excess of sulphuric acid solution in a conical flask placed

on a mass balance. The mass of the flask together with its contents

Is recorded every 15 s.

2.1 Define the term reaction rate. 2

2.2 For this investigation described above, write down:

2.2.1 The dependent variable 1

2.2.2 The independent variable 1

2.2.3 One controlled variable 1

The results obtained in EXPERIMENT 1 are shown in the experiment below.

Time(s)	0	15	30	45	60	75	90	105	120
Mass(g)	150,0	147,5	146,6	146,0	145,8	145,7	145,6	145,6	145,6

2.3 Write down the NAME or FORMULA of the substance responsible for

the decrease in mass. 1

2.4 How long does it take for the reaction in EXPERIMENT 1 to be completed? 1

2.5 How will the rate of the reaction in EXPERIMENT 2 compare to that in

EXPERIMENT 1? Write down GRAETER THAN, SMALLER THAN or

EQUAL TO. Briefly explain your answer by referring to the collision theory 3

2.6 The sketch graph below (**not drawn to scale**) represents the results

obtained for EXPERIMENT 1.

2.6.1 Use the information in the graph to determine the mass of sodium

carbonate that has reacted in EXPERIMENT 1 5

2.6.2 Redraw the above sketch in your ANSWER BOOK. On the same set of axes, sketch the curve obtained for EXPERIMENT 2.**Label your graph as Exp 2** 2

[17]

QUESTION 4

The following diagram shows a Maxwell-Boltzmann distribution curve of a gas

sample at temperatures T_1 and T_2

4.1 Provide labels for the x and y axes of the graph, respectively. 2

4.2 Which graph (T_1 or T_2) represents the gas at a higher temperature?

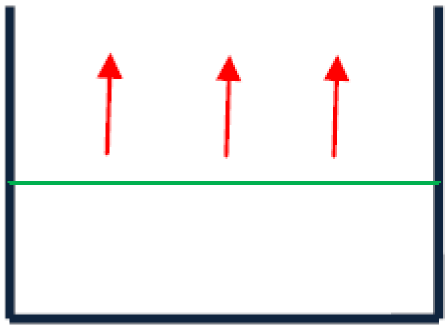
4.3 What does the shaded area to the right of **label P** represent? 1

4.4 What would happen to the area under the graph T_1 when a catalyst is added to the reaction mixture? Give a reason. 2

4.5 Give a reason why the curve goes through the origin? 1

CHEMICAL EQUILIBRIUM

The mass and energy of a closed system remains constant. Table salt dissolved in water is a closed system.
If a beaker containing some water is left standing for a few days, the level of the water in the beaker drops until there is no more water left. The water has escaped into the atmosphere. This is an example of an open system because the mass of the system decreases.



Open system

If the beaker was covered with a bell jar, then it would be closed system. In this case, the level of the water in the beaker decreases for a while. Evaporation takes place. Also droplets of water from on the inside of the bell jar. Condensation occurs. Eventually the level of the water in the beaker becomes constant. At this stage equilibrium is reached. The rate of the evaporation is equal to the rate of condensation. This is an example of dynamic phase equilibrium.

H_2O(liquid) $\rightleftharpoons$ H_2O(water vapour)
Remember the following:

- "$\rightleftharpoons$" means **reversible reaction.**
- **"Equilibrium"** means that the rate of forward reaction is equal to the rate of the reverse reaction.
- **Conditions for equilibrium**: The chemical reaction must be reversible and the system must be closed.

Consider a situation where some **H_2(g)** and **I_2(g)** are sealed in a flask. Initially, there will be a fast forward reaction. However, as the **H_2(g)** and **I_2(g**) are used up, their concentrations decrease. Therefore, the rate of the forward reaction **decreases**.

Initially there is **no product**. Therefore, the rate of **the reverse reaction is zero**. As more and more product is formed, the **concentration of the product increase**s. Therefore, the **rate of the reverse reaction increases.**

There will be a time when **the rate of the forward reaction** is equal to the **rate of the reverse** reaction. When this happens, the system has reached **dynamic chemical equilibrium.**

At **a macroscopic level**, the reactions appear to have stopped. The macroscopic physical properties such as **temperature, pressure, concentration and colour become constant.**

However, at a microscopic level the **particles are still in continuous random motion** and both the **forward and the reverse reactions occur at precisely the same rate.**

- **Macroscopic** level: Visible to the naked eye,
- **Microscopic** : So small as to be visible only with a microscope

FACTORS AFFECTING EQUILIBRIUM

- Concentrations
- Temperature
- Pressure(gases only)

If any of the conditions (factors) are changed, the forward or reverse reaction will be favoured until a new equilibrium is established.

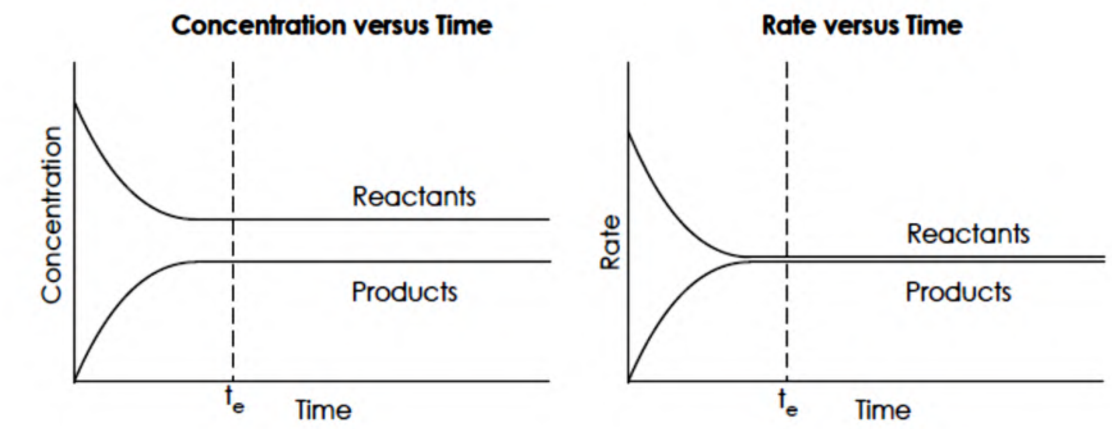
Le Chatelier's Principle: When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favoring the reaction that will oppose the disturbance.

Graphs

How systems achieve equilibrium can be demonstrated through concentration

Versus time graphs and rate versus time graphs, such as the following.

- At equilibrium the **concentrations of both the products and reactants remains constant**, while the **rate of forward and reverse reactions are equal.**



General application of Le Chatelier's Principle

- When the **temperature is increased**, energy is added to the system. To maintain equilibrium, some of this energy must be used up (absorbed). Therefore, the **endothermic reaction is favoured**.
- **Increasing temperature favours the endothermic reaction.**

- When the **temperature is decreased**, energy is removed from the system. In order to restore equilibrium, the system must replace this lost energy. Hence, the exothermic reaction is favoured.
- **Decreasing temperature favours the exothermic reaction.**

- If the **pressure is increased**, then the reaction producing **fewer gas particles is favoured.**
- If the pressure **is decreased**, then the reaction producing **more gas particles is favoured.**

- If a suitable **catalyst** is added to a system in equilibrium, then the **rate of both the forward and reverse reactions increases equally.**
- Therefore, **the equilibrium position** is unaltered (NOT CHANGED).

NB: If a catalyst is added initially, then the **equilibrium position is reached much quicker.**
The addition of an inert gas does not alter the equilibrium position.
INERT GAS: A gas that does not undergo chemical reactions under a set of given conditions

Practical demonstration of the common-ion effect
Place a large amount of sodium chloride in a beaker containing a small amount of water and stir continuously for about five minutes until no more of the salt will dissolve. Filter the solution into a clean dry test tube.
Add a few drops of conc. hydrochloric acid solution to the clear filtrate. You will observe tiny drops of sodium chloride crystals form and settle at the bottom of the test tube.
A saturated sodium chloride solution is in dynamic equilibrium i.e. the rate of dissolution is equal to the rate of the precipitation.

$NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$
By adding conc. HCl, the concentration of $Cl^-(aq)$ increases. According to LCP, the reaction using some of the added Cl-(aq) is favoured. In this case the reverse reaction is favoured (i.e. the reverse reaction is faster than the forward reaction for a short while until a new equilibrium is established). Therefore the formation of NaCl(s) is observed.

WORKED EXAMPLES
QUESTION 1
When ammonia is prepared in the industry, the following DYNAMIC equilibrium is achieved:

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ ΔH -92 KJ

1.1 Why is it called a 'dynamic equilibrium? 1
1.2 Is the forward reaction exothermic or endothermic? Give a reason for your answer. 2
1.3 Determine the value ΔH of per mol of ammonia formed 2
1.4 Explain how each of the situations below will affect the equilibrium concentration of ammonia (answer by simply writing INCREASE, DECREASE or REMAINS THE SAME).
1.4.1 The temperature of the system is increased. 1
1.4.2 More $H_2(g)$ is added to the system. 1
1.4.3 A catalyst is added. 1
1.4.4 The pressure in the system is reduced. 1

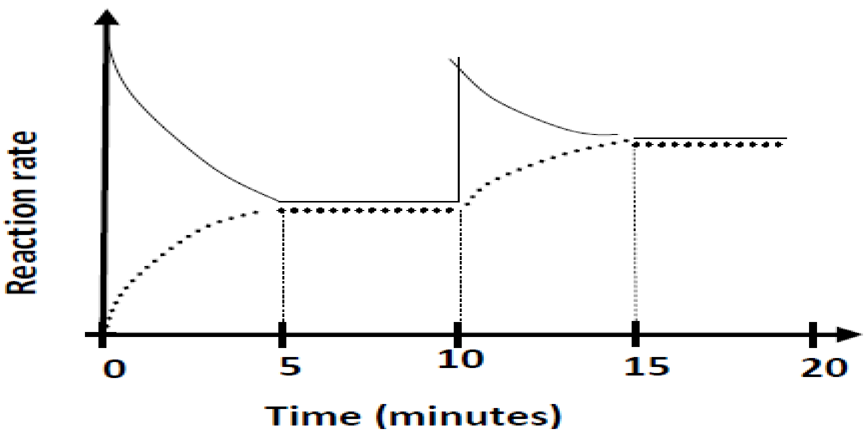
ANSWERS
1.1 Both the forward and reverse reactions take place at the same rate.✓ 1
1.2 Exothermic. ✓ ΔH -92 KJ indicates a release of energy by the system✓ 2
1.3 -92 Kj for 2 moles✓ 2

ΔH=-46 kJ.mol^{-1}✓
1.4.1 Decrease✓ 1
1.4.2 Increase✓ 1
1.4.3 Stays the same✓ 1
1.4.4 Decrease✓ 1

WORKED EXAMPLE 2

QUESTION 2

A quantity of SO_3 is sealed in a container at 400^{0}C and the following reversible reaction occurs :
$2SO_3(g) \rightleftharpoons SO_2(g) + O_2(g)$ $\Delta H > 0$
The accompanying graph shows how the rate of the reaction changes over time.



2.1 State, giving a reason, whether the forward reaction is homogeneous or heterogeneous. 2

2.2 Write down the equation for the reaction represented by the solid line on the graph. 1

2.3 How long does it take, from the start of the reaction, for first equilibrium to be established? 1

2.4 What could possibly have happened to the system during the tenth minute? 2

2.5 Why is the horizontal part of the graph at a higher level between the fifteenth and twentieth minute compared to between the fifth and tenth minute 2

2.6 Will an increase in pressure influence the amount of $SO_2(g)$ present at equilibrium? 1

ANSWERS

2.1 reaction is homogeneous because all the reactants are in the same phase(gas)✓✓ 2

2.2 $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$ ✓ 1

2.3 5 minutes (forward reaction=reverse) ✓ 1

2.4 The temperature is increased. Because ΔH > (endothermic) the rate of forward reaction will increase more than the rate of reverse reaction✓✓ 2

2.5 At a higher temperature, more molecules have more energy than the activation energy and both reactions will be faster than before the temperature was increased

2.6 Decrease. According to Le Chatelier's Principle increasing pressure favors the less particles side which is reverse reaction will be favoured.

EQUILIBRIUM CONSTANT(K_C)

The equilibrium constant (Kc) indicates the **yield of a reaction**. A large Kc value indicates a large yield. The equilibrium position is **concentration of products compared to reactants.**

A **small Kc indicates a low yield**. The equilibrium position is for to the left i.e. at equilibrium there is a relatively small amount of products compared to the reactants.

The equilibrium constant (Kc) is **temperature dependent.**

When writing the Kc expression, **first balance the equation** and then ignore all **solids** and **pure liquids** since their **concentrations are constant**.

Kc is a number without units.

Consider the following chemical reaction that reached equilibrium 90^0C

$2A(g) + 3B(g) \rightleftharpoons 3C(g) + D(g)$

At equilibrium the concentrations of reactants and products in the chemical system remain constant. Therefore, the mathematical product of the concentrations of the products is also constant.

$[C][C][C][D] = [C]^3[D]$

$=K_1(K_1$ is a constant)

Also, the mathematical product of the concentrations of the reactants remains constant:

$[A][A][B][B][B] = [A]^2.[B]^3$

$= K_2(K_2$ is a constant)

Therefore the ratios of these products will also be constant and is known as the equilibrium constant Kc i.e

$$\frac{[\boldsymbol{C}]^3[\boldsymbol{D}]}{[\boldsymbol{A}]^2[\boldsymbol{B}]^3} = \frac{\boldsymbol{K_1}}{\boldsymbol{K_2}} = \boldsymbol{K_C}$$

The subscripts ‘c’ indicates concentrations.

$\frac{[\boldsymbol{C}]^3[\boldsymbol{D}]}{[\boldsymbol{A}]^2[\boldsymbol{B}]^3}$ is the expression of mass action.

The equilibrium constant Kc indicates the relationship between the product and reactant concentrations at equilibrium, and is constant at a specific temperature.

Consider the following chemical reactions:

1. $N_2(g)+3H_2(g) \rightleftharpoons 2NH_3(g)$

Kc = $\frac{[NH3]^2}{[N2][H2]^3}$

This is an example of a homogeneous equilibrium because all the substances in the system are in the same phase.

2. $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

Kc = $[CO_2]$

The concentrations of all the solids are constant and taken as 1, it will not change the Kc value.

---

3. $HCl(aq) + H_2O(l) \rightleftharpoons Cl^-(aq) + H_3O^+(aq)$

KC = $\frac{[Cl^-][H_3O^+]}{[HCl]}$

Solvents of dilute solutions remain constant and are taken as 1; [H_2O] remains constant and as a rule does not appear in the Kc expression.

If substances of different phases occur in the system, we say it is a heterogeneous equilibrium.

IMPORTANT:

1. The Kc value indicates to what extent reactants have changed into products by the time equilibrium is reached.
2. This is of particular importance in the evaluation of the efficiency of industrial processes:

1. A high Kc value (Kc>1) indicates that's a lot of product has been formed and there is higher concentration of products than reactants(the equilibrium lies to the right)
2. A low Kc value (Kc<1) indicates that's a higher concentration of reactants than products are present (the equilibrium lies to the left).
3. Kc = 1 indicates equal concentrations of reactants and products.

WORKED EXAMPLES

QUESTION 1

A 2 g sample of ammonium hydrogen sulphide is sealed in a 2 dm^3 flask at a temperature of 375K. it dissociates as follows:

$$NH_4HS(s) \rightleftharpoons H_2S(g) + NH_3(g)$$

At equilibrium it is found that the concentration of ammonia is equal to $1,82 \times 10^{-3}$ $mol.dm^{-3}$

1.1 Calculate the equilibrium constant for this reaction. 3

1.2 It is found that by repeating the experiment at a higher temperature the equilibrium constant increases. Is the forward reaction exothermic or endothermic? 1

1.3 Give an explanation for your answer to 1.2 2

ANSWERS

1.1 H_2S: NH_3

1:1

$[H_2S] = 1,82\times10^{-3}$

$Kc = [H_2S][NH_3]$ (solids are excluded)

$= 1,82\times10^{-3}.1,82\times10^{-3}$

$= 3,3\times10^{-6}$ 3

1.2 Endothermic 1

1.3 To obtain a larger Kc value, more $H_2S(g)$ and $NH_3(g)$ should be produced. According to Le Chatelier's Principle an increase in temperature favors the endothermic reaction.

Therefore the forward reaction

will be endothermic and $\Delta H > 0$ 2

WORKED EXAMPLE 2

QUESTION 2

Consider the following hypothetical reaction.

$A(g) + 2\,B(g) \rightleftharpoons C(g)$ $\Delta H > 0$

Initially 5 mol of A and 10 mol of B are pumped into a 4 dm^3 reaction flask at 650 K. At equilibrium the concentration of C was found to be 1,2 $mol.dm^{-3}$

2.1 Calculate:

The concentration of A at equilibrium. 3

2.2 The concentration of B at equilibrium. 1

2.3 The equilibrium constant for this reaction. 3

ANSWERS

2.1

RATIO	1	2	1
INITIAL MOL	5	10	0
CHANGE(mol)	-4,8	-9,6	+4,8 √
MOLES AT EQUIL(mol)	0,2	0,4 √	4,8
CONCERNTRATION AT EQUILIBRIUM($mol.dm^{-3}$)	0,05	0,1	1,2

$[A]_{Equilibrium}$= 0,05 $mol.dm^{-3}$ √

3

2.2 $[B]_{Equilibrium}$= 0,1 mol.dm-3√ 1

2.3 $K_C = \frac{[C]}{[A][B]^2}$

$= \frac{(1{,}2)}{(0{,}05)(0{,}1)^2}$

= 2400

3

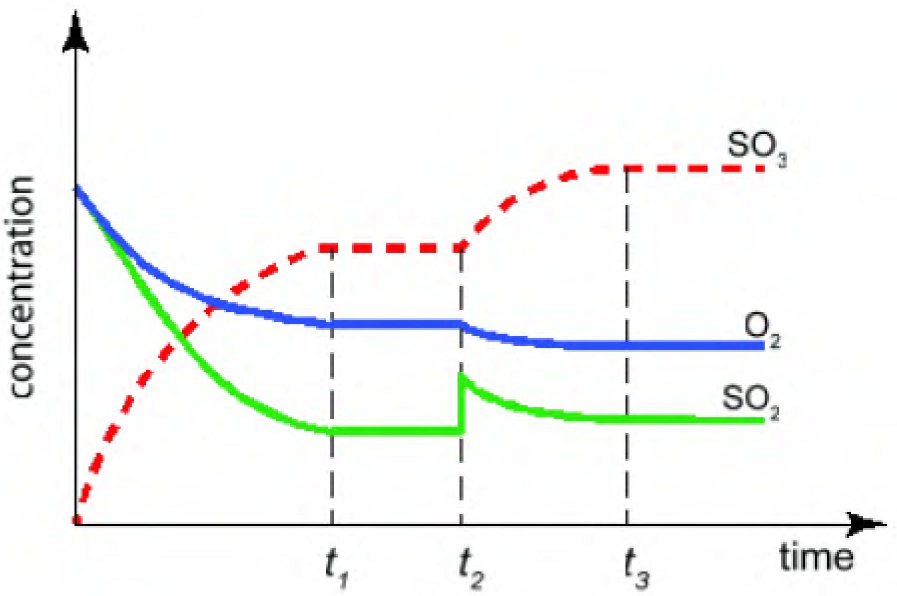
GRAPHS FOR CHEMICAL EQUILIBRIUM

1.Changing the concentration of reactants or products:

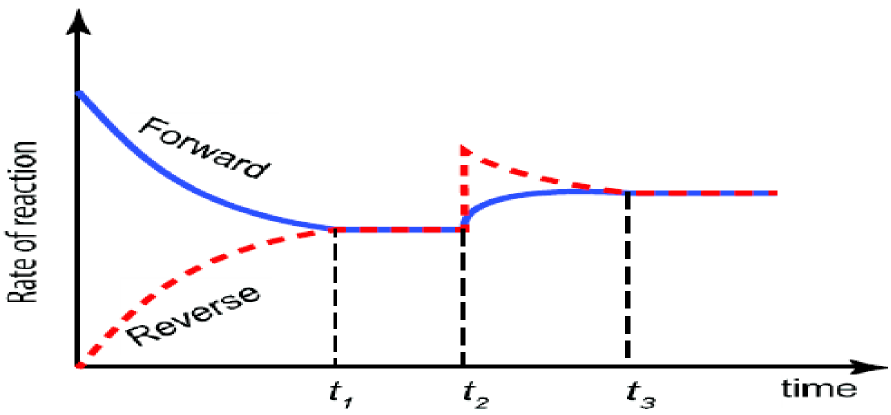
1. Increasing concentration of a reactant will favor up the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. Forward reaction will be favoured to re-establish the equilibrium at a higher rate.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

At time t2 , the concentration of SO2 is increased



Forward reaction will be favoured to re-establish the new equilibrium at a higher rate.



N.B "Notice that an increase in a concentration looks like  and

notlike  "

Also, a decrease in concentration looks like  and **not** like 

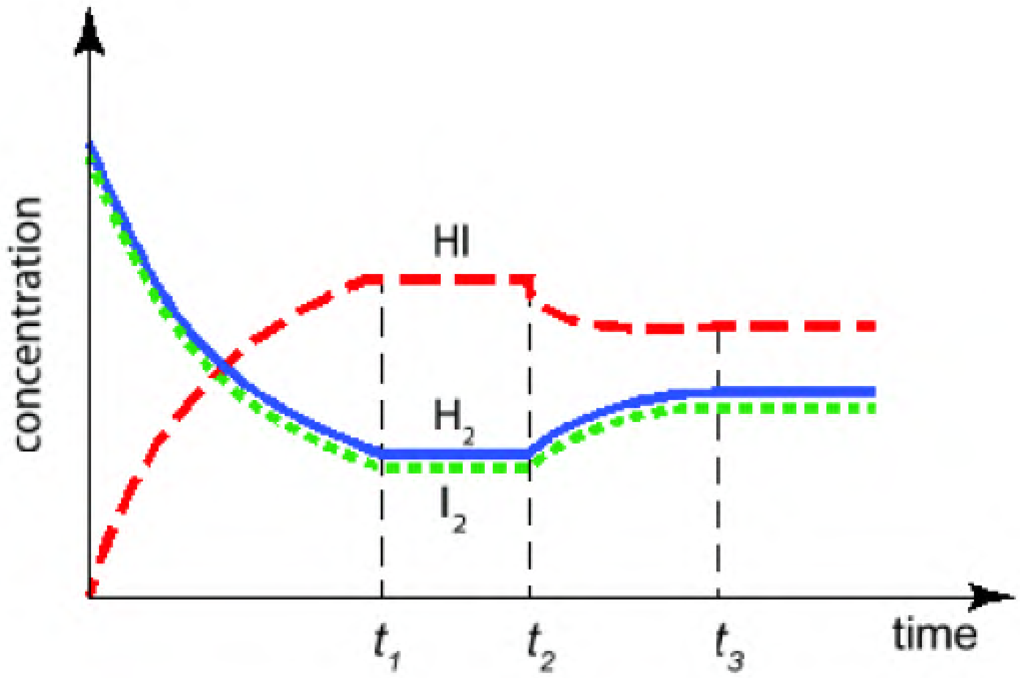
Changing the temperature

Increasing temperature increases the rates of both reactions but the rate of the endothermic reaction increases more than the rate of the exothermic reaction. An increase in a temperature will favour the endothermic reaction to reestablish a new equilibrium at a higher rate.

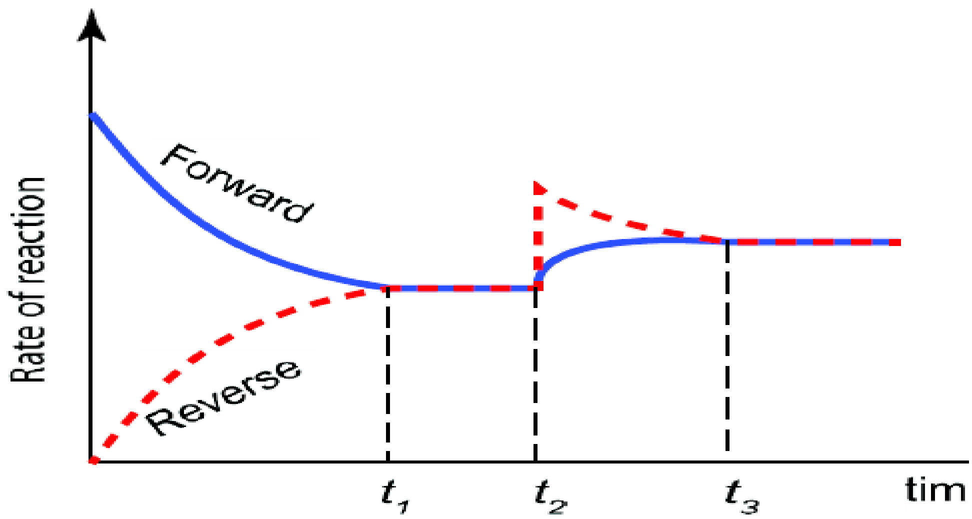
A decrease in temperature decreases the rates of both reactions, but the rate of endothermic reaction decreases more than the rate of exothermic reaction.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H < 0$$

At time t_2, the temperature of the container is increased. Increase in temperature favours endothermic reaction, therefore the reverse reaction is favoured, concentration of the reactants will increase and that of products will decrease.



Both the rate of forward and reverse reactions will increase, but the rate of reverse reaction will be the most favoured, the new equilibrium will be at a higher rate.(increase in temperature favours the endothermic reaction



Changing the pressure

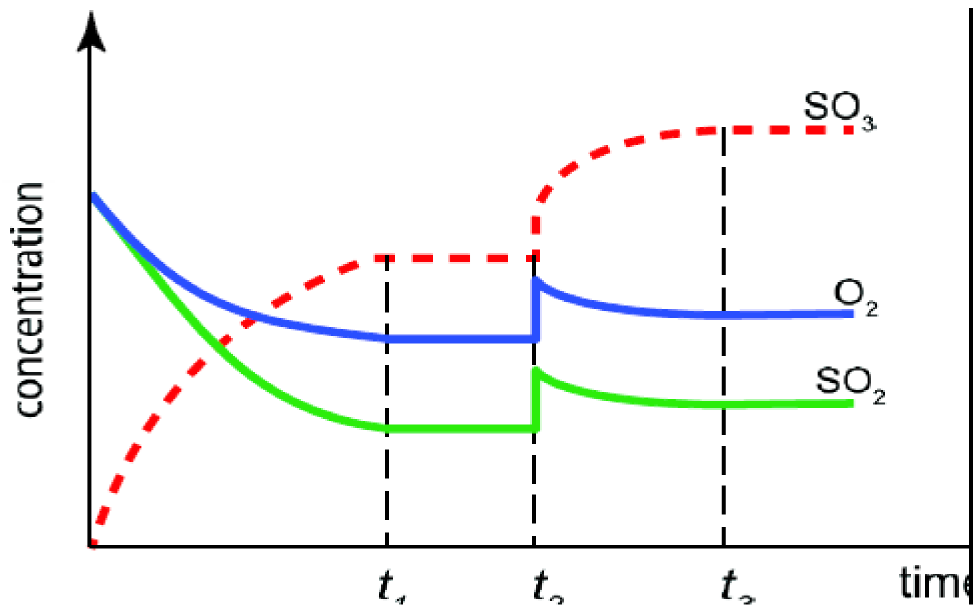
Changing the volume of the gases will change the pressure in system. But this change will also change the concentration of both reactants and products.

If the **pressure is increased** by decreasing the volume of the container, concentration of both reactants and products are increased{ c=n/v}. The reaction with **the fewer mole sides will be favoured** to re-establish the new equilibrium.

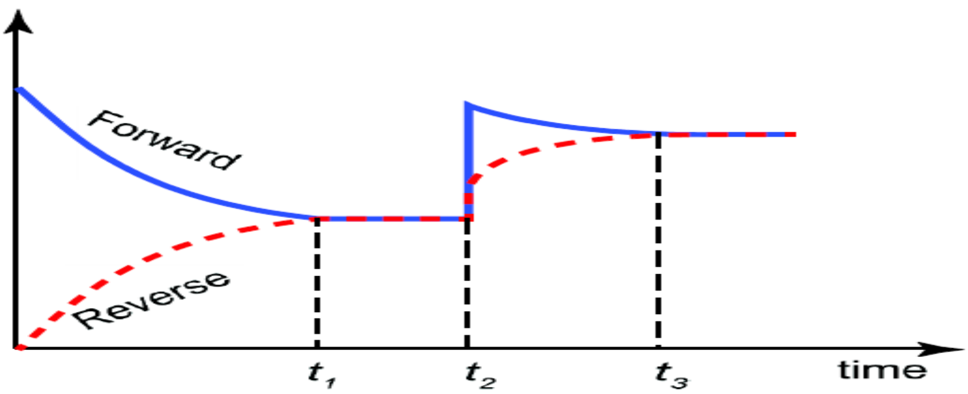
When the **pressure is decreased** by increasing the volume, concentrations of both the reactants and products are decreased. The reaction with the **higher moles sides will be favoured** to re-establish the new equilibrium Pressure is only for gases.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

In this example when the pressure is increased, the rates of both reactions will increase but forward reaction will increase more than the reverse reaction.

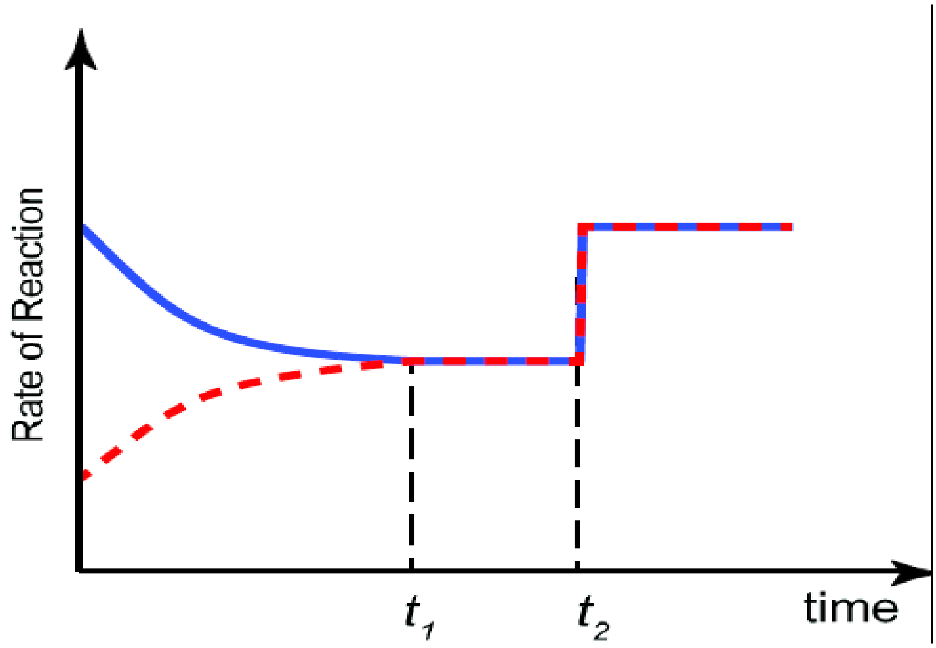


Increase in pressure increases the rates of both the forward and reverse reaction, but the forward reaction is most favoured , the new equilibrium will be at a higher rate



Use of a catalyst

A catalyst increases the rate of both the forward and the reverse reactions equally so that the equilibrium position won't be changed. The reaction will takes place at a higher rate. No change in the concentration.



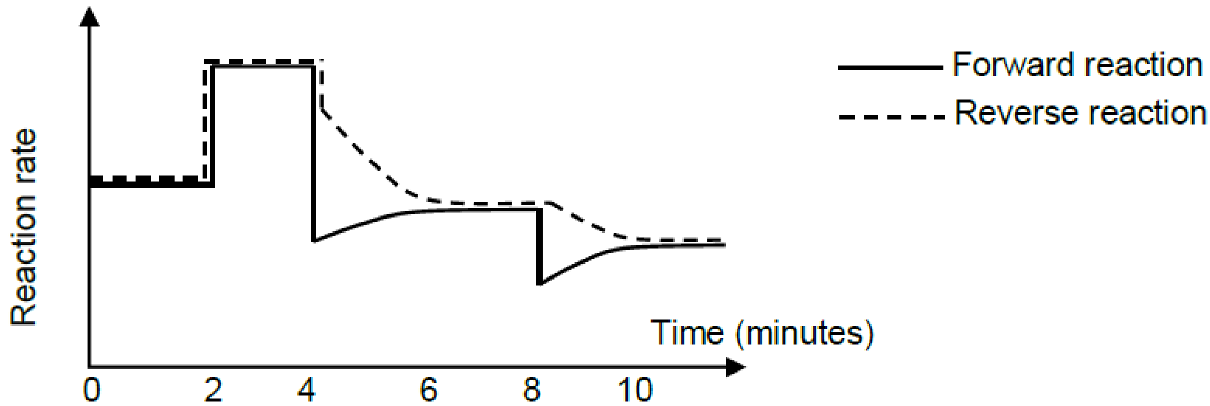
Worked examples

QUESTION 1

Hydrogen and iodine are sealed in a 2 dm^3 container. The reaction is allowed to reach equilibrium at 700 K according to the following balanced equation: $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

1.1 Give a reason why changes in pressure will have no effect on the equilibrium position. 1

The reaction rate versus time graph below represents different changes made to the equilibrium mixture.



1.2 What do the parallel lines in the first two minutes indicate? 1

1.3 State TWO possible changes that could be made to the reaction conditions at t = 2 minutes 2

1.4 The temperature of the equilibrium mixture was changed at t = 4 minutes.

1.4.1 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Fully explain the answer. 3

1.4.2 How will this change influence the Kc value? Choose from INCREASES, DECREASES or REMAINS THE SAME 1

1.5 What change was made to the equilibrium mixture at t = 8 minutes? 1

ANSWERS

1.1 Amount / number of moles / volume of (gas) reactants equals amount/number of moles/volume of (gas) products. 1

1.2 Chemical/dynamic equilibrium 1

1.3 Addition of a catalyst and Increase in pressure 2

1.4.1 Endothermic

2. The rate of the forward reaction decreases more/ The rate of the reverse reaction decreases less.

3. A decrease in temperature favours the exothermic reaction 3

1.4.2 Decreases 1

1.5 Reactants / H_2 / I_2 removed 1

ACTIVITIES

QUESTION 1

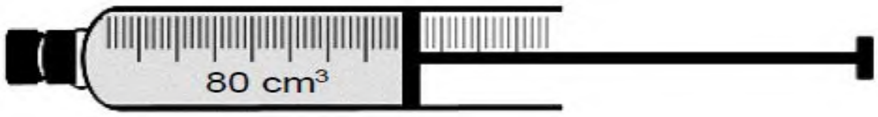
A certain amount of nitrogen dioxide gas (NO_2) is sealed in a gas syringe at 25 °C. When equilibrium is reached, the volume occupied by the reaction mixture in the gas syringe is 80 cm^3. The balanced chemical equation for the reaction taking place is:

$2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H < 0$

dark brown colourless

1.1 Define the term *chemical equilibrium*. 2

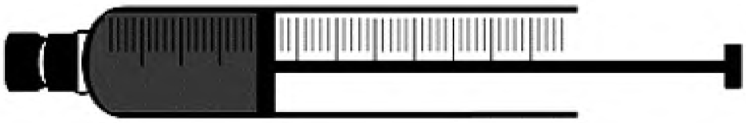
1.2 At equilibrium the concentration of the $NO_2(g)$ is 0,2 mol·dm-3. The equilibrium constant for the reaction is 171 at 25 °C. Calculate the initial number of moles of $NO_2(g)$ placed in the gas syringe 8



1.3

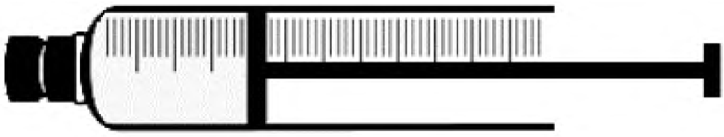
The diagram shows the reaction mixture in the gas syringe after equilibrium is established.

The pressure is now increased by decreasing the volume of the gas syringe at constant temperature as illustrated in the diagram below



1.3.1 IMMEDIATELY after increasing the pressure, the colour of the reaction mixture in the gas syringe appears darker than before. Give a reason for this observation. 1

After a while a new equilibrium is established as illustrated below. The colour of the reaction mixture in the gas syringe now appears lighter than the initial colour.



1.3.1 Use Le Chatelier's principle to explain the colour change observed in the gas syringe. 3

1.4 The temperature of the reaction mixture in the gas syringe is now increased and a new equilibrium is established. How will each of the following be affected?

1.4.1 Colour of the reaction mixture

Write down only DARKER, LIGHTER or REMAINS THE SAME. 1

1.4.2 Value of the equilibrium constant (Kc)

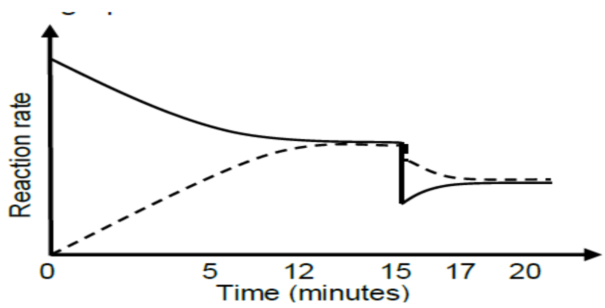
Write down only INCREASES, DECREASES or REMAINS THE SAME 1

QUESTION 2

Pure hydrogen iodide, sealed in a 2 dm^3 container at 721 K, decomposes according to the following balanced equation:

$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ $\Delta H = +26$ $kJ \cdot mol^{-1}$

The graph below shows how reaction rate changes with time for this reversible reaction.



2.1 Write down the meaning of the term *reversible reaction*. 1

2.2 How does the concentration of the reactant change between the 12th and the 15th minute? Write down only INCREASES, DECREASES or NO CHANGE. 1

2.3 The rates of both the forward and the reverse reactions suddenly change at t = 15 minutes.

2.3.1 Give a reason for the sudden change in reaction rate. 1

2.3.2 Fully explain how you arrived at the answer to QUESTION 2.3.1 3

2.4 The equilibrium constant (Kc) for the forward reaction is 0,02 at 721 K. At equilibrium it is found that 0,04 mol HI(g) is present in the container. Calculate the concentration of H_2(g) at equilibrium. 6

2.5 Calculate the equilibrium constant for the reverse reaction. 1

2.6 The temperature is now increased to 800 K. How will the value of the equilibrium constant (Kc) for the forward reaction change? Write down only INCREASES, DECREASES or REMAINS THE SAME 1

QUESTION 3

Initially excess NH_4HS(s) is placed in a 5 dm^3 container at 218 °C. The container is sealed and the reaction is allowed to reach equilibrium according to the following balanced equation:

$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$ $\Delta H > 0$

3.1 State Le Chatelier's principle. 2

3.2 What effect will each of the following changes have on the amount of NH3(g) at equilibrium? Write down only INCREASES, DECREASES or REMAINS THE SAME.

3.2.1 More NH_4HS(s) is added 1

3.2.2 The temperature is increased 1

3.3 The equilibrium constant for this reaction at 218 °C is $1,2 \times 10^{-4}$. Calculate the minimum mass of NH_4HS(s) that must be sealed in the container to obtain equilibrium.

The pressure in the container is now increased by decreasing the volume of the container at constant temperature. 6

3.4 How will this change affect the number of moles of $H_2S(g)$ produced? Fully explain the answer. 3

QUESTION 4

Initially 2, 2 g of pure $CO_2(g)$ is sealed in an empty 5 dm^3 container at 900 °C.

4.1 Calculate the initial concentration of $CO_2(g)$. 4

4.2 Give a reason why equilibrium will not be established. 1

$CaCO_3(s)$ is now added to the 2,2 g $CO_2(g)$ in the container and after a while equilibrium is established at 900 °C according to the following balanced equation:

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

The equilibrium constant for this reaction at 900 °C is 0, 0108.

4.3 Give a reason why this reaction will only reach equilibrium in a SEALED container. 1

4.4 Calculate the minimum mass of CaCO3(s) that must be added to the container to achieve equilibrium. 7

4.5 How will EACH of the following changes affect the amount of $CO_2(g)$? Write down only INCREASES, DECREASES or REMAINS THE SAME.

4.5.1 More CaCO3(s) is added at 900 °C 1

4.5.2 The pressure is increased 1

4.6 It is found that the equilibrium constant (Kc) for this reaction is $2,6 \times 10^{-6}$ at 727 °C. Is the reaction EXOTHERMIC or ENDOTHERMIC? Fully explain how you arrived at the answer. 4

QUESTION 5

Carbon dioxide reacts with carbon in a closed system to produce carbon monoxide, CO(g), according to the following balanced equation:

$CO_2(g) + C(s) \rightleftharpoons 2CO(g)\ \Delta H > 0$

5.1 What does the double arrow indicate in the equation above? 1

5.2 Is the above reaction an EXOTHERMIC reaction or an ENDOTHERMIC reaction? Give a reason for the answer. 2

Initially an unknown amount of carbon dioxide is exposed to hot carbon at 800 °C in a sealed 2 dm^3 container. The equilibrium constant, Kc, for the reaction at this temperature is 14.
At equilibrium it is found that 168, 00 g carbon monoxide is present.

5.3 How will the equilibrium concentration of the product compare to that of the reactants? Choose from LARGER THAN, SMALLER THAN or EQUAL TO.

Give a reason for the answer. (No calculation is required.) 2

5.4 Calculate the initial amount (in moles) of $CO_2(g)$ present. 9

ACIDS AND BASES

- Acids and bases are chemicals that exhibit their chemical behaviour when dissolved in water.
- Acids and bases produces ions when dissolved in water; therefore, are called electrolytes.

acid (Arrhenius) is a substance that produces hydrogen ions (H^{+}) / hydronium ions (H_3O^{+}) in aqueous solution.

$HCl_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^{+}_{(aq)} + Cl^{-}_{(aq)}$

base(Arrhenius) is a substance that produces hydroxide (OH^{-}in aqueous solution

$NH_{3(g)} + H_2O_{(l)} \rightleftharpoons NH_4^{+}{}_{(aq)} + OH^{-}{}_{(aq)}$

Acid(Lowry-Bronsted) An **acid** is a proton (H^{+} ion) donor.

$HCl_{(aq)} + NH_{3(l)} \rightleftharpoons NH_4^{+}{}_{(aq)} + Cl^{-}_{(aq)}$

base(Lowry-Bronsted) A **base** is a proton (H^{+} ion) acceptor.

$HCl_{(aq)} + NH_{3(g)} \rightleftharpoons NH_4^{+}{}_{(aq)} + Cl^{-}_{(aq)}$

strong acid → will **ionise** completely in water to form a high concentration of hydronium ions(H_3O^{+}) e.g HCl , HNO_3 , H_2SO_4 etc

A strong base will **dissociate** completely in water to form a high concentration of hydroxide ions. (OH^{-}) e.g. NaOH , KOH , $Mg(OH)_2$,$Ba(OH)_2$

Weak acid will partially ionises in water to form a low concentration of hydronium ions (H_3O^{+}) CH_3COOH , $(COOH)_2$ etc

Aweak base will **dissociate partially** in water to form a low concentration of hydroxide ions (OH^{-}) NH_3,

Concentrated acid/base contains a large amount of acid/base in proportion to the volume of water.

Dilute acid/base contains a small amount of acid/base in proportion to the volume of water.

Monoprotic an acid that donates with one proton. eg HCl , HNO_3 , CH_3COOH etc

Diprotic an acid that donates with two protons. H_2SO_4 , H_2CO_3, $(COOH)_2$ etc

Triprotic an acid that donates with three protons. H_3PO_4 etc

Worked example 1 Conjugate acid -base pair

$$H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3^{-}{}_{(aq)} + H_3O^+{}_{(aq)}$$

$$NH_{3(g)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

Activity 1

1. Write down the conjugate acid -base pairs

   1.1 $H_3PO_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + H_2PO_4^{-}{}_{(aq)}$

   1.2 $HS^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_2S_{(g)} + OH^-{}_{(aq)}$

2. Write down the conjugate base of the following

   2.1 H_2CO_3

   2.2 CH_3COOH

   2.3 HX

Ampholyte A substance that can act either as a base or as an acid. e.g H_2O , HCO_3^{-} ,HSO_4^- etc refer to the above example for water.

Hydrolysis is a reaction of salt and water.

A salt from a strong acid and a weak base will be acidic (pH < 7). Consider the hydrolysis of NH_4Cl below

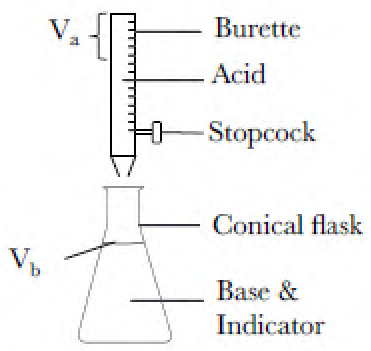
$$NH_4^+{}_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(g)} + H_3O^+{}_{(aq)}$$

A salt from a weak acid and a strong base will be basic (pH > 7). Consider the hydrolysis of CH_3COONa

$$CH_3COO^{-}{}_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COOH_{(aq)} + OH^-{}_{(aq)}$$

Titration is a technique of finding the unknown concentration using a solution of known concentration (standard solution)

Apparatus used for titration



1 .Strong acid + weak base → acidic salt + water

The pH of the resulting solution will be less than seven and the suitable indicator is **methyl orange.**

2 .weak acid + Strong base → basic salt + water

The pH of the resulting solution will be greater than seven and the suitable indicator **phenolphthalein**

3.Strong acid + Strong base → neutral salt + water

The pH of the resulting solution will be equal to seven and the suitable indicator **bromothymol blue.**

The end point is a point whereby the indicator changes colour.

Equivalent point is a point whereby the acid or a base has reacted completely with a base or acid

pH scale is a scale of numbers from 0 to 14 used to express acidity or alkalinity of a solution.

To calculate the pH use a formula

pH = -log [H_3O^+]

worked example 2

1. calculate the pH of 0.1mol.dm^{-3} of HCl

$HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-_{(aq)}$

Ratio HCl : H_3O^+

1 : 1

pH = -log [H_3O^+]

pH = -log([0.1)

pH = 1

2. calculate the pH of 0,02 mol.dm^{-3} H_2SO_4

$H_2SO_{4(aq)} + H_2O_{(aq)} \rightleftharpoons 2H_3O^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

Ratio H_2SO_4 : H_3O^+

1 : 2

pH = -log [H_3O^+]

pH = -log([0.04)

pH = 1.40

Auto-ionisation of water

$H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$

Equilibrium constant of water(K_w)

$K_w = [H_3O^+][OH^-] = 1x10^{-14}$

Calculating the pH of a base

1. Calculate the pH of a 0.1 mol.dm^{-3} of KOH.

   [KOH] = $[OH^-]$

   $[H_3O^+][OH^-] = 1x10^{-14}$

   $[H_3O^+](0.1 = 1x10^{-14}$

   $[H_3O^+] = 1x10^{-13}$ mol.dm^{-3}

pH = -log $[H_3O^+]$

pH = -log($1x10^{-13}$)

pH = 13

Worked example 3

A standard solution is prepared by adding 4.5 g of oxalic acid into a 250 cm^3 of distilled water. 25 cm^3 of this solution is then neutralised by 20 cm^3 of sodium hydroxide. The balanced equation for the reaction is

$(COOH)_{2(aq)} + 2NaOH_{(aq} \rightarrow (COONa)_{2(s)} + 2H_2O_{(l)}$

1. What is meant by standard solution?
2. Will the pH of solution at the end point be less than 7, greater than 7 or equal to 7? Justify your answer with a relevant equation.
3. Write down a suitable indicator for the above titration
4. Calculate the concentration of sodium hydroxide neutralised by 25cm^3 of this standard solution

Solution

1. Is a solution of known concentration
2. Greater than 7

   $C_2O_4^{2-}{}_{(aq)} + H_2O_{(l)} \rightleftharpoons C_2HO_4^-{}_{(aq)} + OH^-_{(aq)}$
3. Phenolphthalein

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

   = 4.5/90

   = 0.05 mols

   25/250 X 0.05

   0.005 mols

   Ratio (COOH)2 : NaOH

   1 : 2

   2 n(NaOH) = 0.01 mol

c = n/v

= 0.01/0.02

= 0.5 $mol.dm^{-3}$

worked Example 4: percentage purity

Learners conduct an experiment to find the percentage purity of calcium carbonate. They add 3.5 g sample of calcium carbonate to a 100 cm^3 of a 0.5 $mol.dm^{-3}$ of hydrochloric acid solution. The equation for this reaction is

$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(s)} + H_2O_{(l)} + CO_{2(g)}$

Step 1: $c = \frac{n}{v}$

$0.5 = \frac{n}{0.1}$

n = 0.05 mol

step 2: you must not convert 3.5 g mass to number of moles since it is impure.

Step 3: ratio $CaCO_3$: HCl

1 : 2

n(0.025) : 0.05

step 4: $n = \frac{m}{M}$

$0.025 = \frac{m}{100}$

m = 2.5 g

percentage purity = $\frac{pure}{impure}$ x 100

= $\frac{2.5}{3.5}$ x 100

= 71.43%

ACTIVITIES

Activity 1 Titration

1 During a titration experiment 0.2 $mol.dm^{-3}$ nitric acid with a volume of $50cm^3$ react with 0.5 $mol.dm^{-3}$ of sodium hydroxide with volume of 80 cm^3.

1.1 Will the nitric acid used be able to fully neutralize the solution of sodium hydroxide? Show your calculations.

1.2 Which indicator is suitable for the above titration? give a reason for your answer.

1.3 Calculate the pH at the end of the reaction

2 **Activity 2**

2.1 Define a *strong acid*. (2)

2.2 A solution of an unknown, monoprotic acid has a concentration of 0,01 $mol{\cdot}dm^{-3}$ and a pH of 3

2.2.1 .Calculate the concentration of the hydrogen ions in this solution. (2)

2.2.2 How will the strength of this unknown acid compare to that of hydrochloric acid of the same concentration?
Write down only STRONGER THAN, WEAKER THAN or EQUAL TO (1)

2.2.3 Give a reason for your answer in QUESTION 2.2.2. (2)

2.3 Ammonium chloride is an example of a salt that can undergo hydrolysis.

2.3.1 Define the underlined term. (2)

2.3.2 Write an equation to show the hydrolysis of ammonium chloride. (3)

2.3.3 Methyl orange is red in an acidic medium and yellow in an alkaline medium. What will the colour of methyl orange be in an ammonium chloride solution? (2)

2.4 A learner adds a sample of calcium carbonate to 50,0 cm^3 of sulphuric acid. The sulphuric acid is in excess and has a concentration of 1,0 $mol{\cdot}dm^{-3}$.
The balanced equation for the reaction that takes place is:
$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$ **…………**
The reaction is allowed to proceed until all the $CaCO_3$ is used up.
The H_2SO_4 **left over** from REACTION 1 is now neutralised by 28,0 cm^3 of a 0,5 $mol{\cdot}dm^{-3}$ sodium hydroxide solution.
The balanced equation for this reaction is:
$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$ **…………..** (10)
Calculate the **mass** of calcium carbonate in the sample in REACTION 1. **[24]**

Activity 3

3.1 Sulphuric acid is a strong acid and an example of an <u>acid which can donate *protons* *per molecule two*</u>.

3.1.1 Write down one word or term for the underlined phrase. (1)
The equations below represent the ionisation of sulphuric acid.

Equation **I**: $H_2SO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$
Equation **II**: $HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$

3.1.2 Write down the FORMULA of a species that acts as ampholyte in the above reactions. (1)

3.1.3 Write down the NAME of the conjugate base of the hydrogen sulphate ion (1)

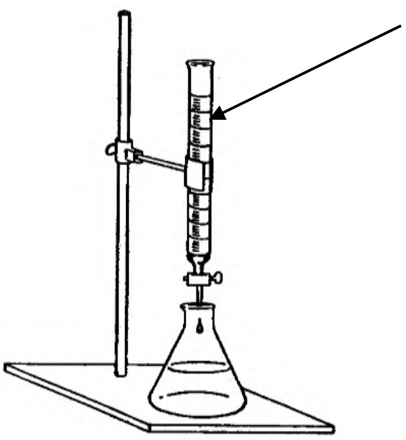
3.2 A learner adds an impure sample of sodium carbonate into a flask containing 50 cm^3 of a hydrochloric acid solution with a pH = 0. The hydrochloric acid is in excess. The balanced equation for the reaction that takes place is:

$Na_2CO_{3(s)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(s)} + CO_{2(g)} + H_2O_{(l)}$

3.2.1 Calculate the number of moles of hydrochloric acid present in the flask. (5)

3.2.2 Write down a balanced equation that explains why a sodium carbonate solution has a pH greater than 7. (3)

3.2.3 The apparatus illustrated below is used during a titration to determine the mass of sodium carbonate present in the sample. (1)
Write down the name of the apparatus labelled **A**.



3.2.4 During the titration, the excess hydrochloric acid is neutralised by 30 cm^3 of a 0,4 $mol.dm^{-3}$ sodium hydroxide solution. Calculate the mass of sodium carbonate in the sample. (6)

[18]

Activity 4

4 You are given the following ionisation reaction of ethanoic acid in water:

$CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$ $K_a = 1,8 \times 10^{-5}$

4.1 What does the ionisation constant indicate about the strength of the acid? (1)

Ka is very low therefore acid is weak

4.2 What is meant by a *concentrated acid*? (2)

More acid in proportion to the volume of water

4.3 $H_2PO_4^-$ $\rightarrow$- is an ampholyte. (2)

Write an equation to indicate its role as a base.

$H_2PO_4^{--}{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3PO_{4(aq)} + OH^-_{(aq)}$

4.4 Write down a conjugate acid/base pair from your equation in QUESTION 4.3. (1)

$H_2O \rightarrow OH^-$

4.5 Milk of Magnesia has been used over the ages to relieve stomach ailments caused by excess stomach acid. The active ingredient in Milk of Magnesia is magnesium hydroxide ($Mg(OH)_2$).

A group of learners prepare a solution of magnesium hydroxide.

4.5.1 What mass of $Mg(OH)_2$ must be dissolved in distilled water to prepare 500 cm^3 of a solution with a concentration of 0,20 $mol\cdot dm^3$? (5)

c= m/Mv

0.2 =m/(58)(0.5)

m = 5.8 g

4.5.2 What will the concentration of the hydroxide ions in the solution be? Assume 100% dissociation of magnesium hydroxide in water. (2)

$[OH^-]$ =2(O.20)

$[OH^-]$ = 0.4 $mol.dm^{-3}$

4.5.3 The pH of any medicine safe for human consumption must lie between pH = 4 and pH =9. (5)

Will this solution that the learners prepare be safe for human consumption? Show all calculations.

$[H_3O^+][OH^-] = 1 \times 10^{-14}$

$[H_3O^+](0.4) = 1 \times 10^{-14}$

$[H_3O^+] = 2,5 \times 10^{-14}$

pH = 13.60

5 Anhydrous oxalic acid is an example of a diprotic acid and thus ionises in two steps as represented by the equations below:

I: $(COOH)_2\,(aq) + H_2O\,(l) \rightleftarrows H_3O^+\,(aq) + H(COO)^{-}\,(aq)$

II: $H(COO)^{-}\,(aq) + H_2O\,(l) \rightleftarrows H_3O^+\,(aq) + (COO)^{2-}\,(aq)$

5.1 Write down:

5.1.1 what is meant by a diprotic acid ? (1)

5.1.2 the FORMULAE of each of the TWO bases in reaction II. (2)

5.1.3 the FORMULA of the substance that acts as an ampholyte in reactions I and II. (1)

5.1.3 the FORMULA of the substance that acts as an ampholyte in reactions I and II. (1)

5.2 "*Oxalic acid is a weak acid and thus will always form a dilute solution.*"

5.2.1 Is a weak acid always a dilute acid? (1)

5.2.2 Explain your answer to QUESTION 5.2.1 (2)

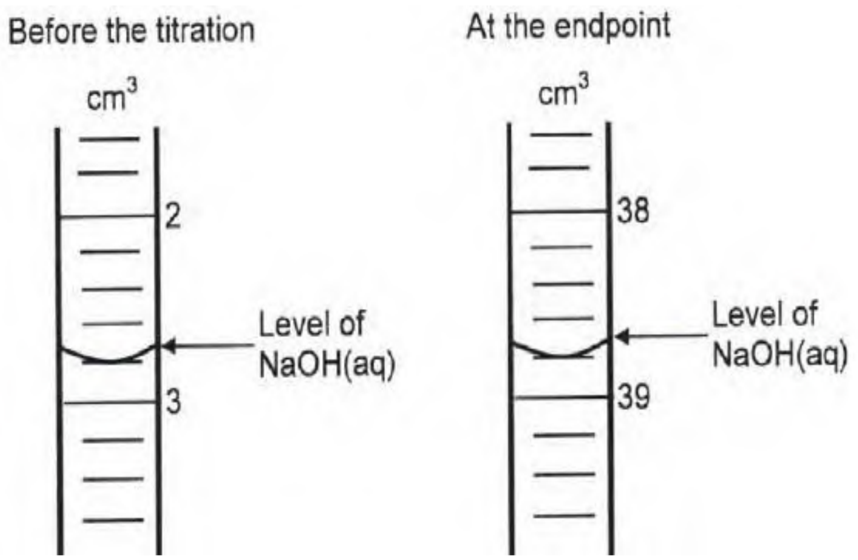
5.3 A standard solution of $(COOH)_2$ of concentration 0,2 $mol\cdot dm^{-3}$ is prepared by dissolving a certain amount of hydrous oxalic acid, $(COOH)_2\bullet 2H_2O$, in water in a 250 cm^3 volumetric flask. Calculate the mass of oxalic acid needed to prepare the standard solution. (4)

5.4 During a titration 25 cm^3 of the standard solution of $(COOH)_2$ prepared in QUESTION 5.3 is neutralised by a sodium hydroxide solution from a burette.

The balanced equation for the reaction is:

$(COOH)_2$ (aq) + 2 NaOH (aq) → $(COONa)_2$ (aq) + 2 H_2O (l)

The diagrams below show the burette readings before the titration commenced and at the endpoint respectively.



5.4.1 Explain what is meant by the endpoint of a titration? (1)

5.4.2 Which indicator is most suitable for this titration?

Choose from: *phenolphthalein / bromothymol blue / methyl orange*. (1)

5.4.3 Use the burette readings and calculate the concentration of the sodium hydroxide solution. (5)

5.4.4 What will be the pH of the solution at the endpoint? Write only

less than 7 / equal to 7 / greater than 7. (1)

5.4.5 Write down a balanced equation that explains your answer to QUESTION 5.4.4. (3)

5.4.6 Use the answer obtained in QUESTION 5.4.3 to calculate the pH of the sodium hydroxide solution. (4)

[26]

ELECTROCHEMISTRY

Understanding of the processes and redox reactions taking place in galvanic cells

• Describe the movement of ions in the solutions.

• State the direction of electron flow in the external circuit.

• Write down the half-reactions that occur at the electrodes.

• State the function of the salt bridge.

• Use cell notation or diagrams to represent a galvanic cell. When writing cell notation, the following convention should be used:

o The $H_2|H^+$ half-cell is treated just like any other half-cell.

o Cell terminals (electrodes) are written on the outside of the cell notation.

o Active electrodes: reducing agent | oxidised species || oxidising agent | reduced species o Inert electrodes (usually Pt or C):

Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt

Example: Pt | $C\ell^-$ (aq) |$C\ell_2$(g) || F_2(g) | F^- (aq) | Pt

• Predict the half-cell in which oxidation will take place when two half-cells are connected. • Predict the half-cell in which reduction will take place when connected to another half-cell.

• Write down the overall cell reaction by combining two half-reactions.

• Use the Table of Standard Reduction Potentials to calculate the emf of a standard galvanic cell.

• Use a positive value of the standard emf as an indication that the reaction is spontaneous under standard conditions. Standard electrode potentials

• Write down the standard conditions under which standard electrode potentials are determined.

• Describe the standard hydrogen electrode and explain its role as the reference electrode.

• Explain how standard electrode potentials can be determined using the reference electrode and state the convention regarding positive and negative values. Electrolytic cells

• Define the **electrolytic cell** as a cell in which electrical energy is converted into chemical energy

• **Electrolysis**: The chemical process in which electrical energy is converted to chemical energy

- OR the use of electrical energy to produce a chemical change
- Understanding the processes and redox reactions taking place in electrolytic cells

- Describe the movement of ions in the solution.
- State the direction of electron flow in the external circuit.
- Write equations for the half-reactions taking place at the anode and cathode.
- Write down the overall cell reaction by combining two half-reactions.
- Describe, using half-reactions and the equation for the overall cell reaction as well as the layout of the particular cell using a schematic diagram, the following electrolytic processes:

o The decomposition of copper (II) chloride
o Electroplating, e.g., the electroplating of an iron spoon with silver/nickel
o Refining of metals, e.g., copper
o the electrolysis of a concentrated solution of sodium chloride

ELECTROCHEMISTRY

Some terms and definitions …

• ***Oxidation***: the *loss* of electrons (OIL), e.g., $Zn \rightarrow Zn^{2+} + 2e^-$ and an increase in the oxidation number of the element

• ***Reduction***: the *gain* of electrons (RIG), e.g., $Cu^+ + e^- \rightarrow Cu$ and a decrease in the oxidation number of the element

• ***Oxidising agent***: the element or compound that oxidises another, and is itself reduced (i.e., gains electrons)

• ***Reducing agent***: the element or compound that reduces another, and is itself oxidised (i.e., losses electrons)

• ***Anode***: the electrode where oxidation takes place

• ***Cathode***: the electrode where reduction takes place

• ***Electrolyte***: the solution / liquid / dissolved substance that conducts electricity through the movement of ions.

• ***Electrolysis***: the chemical process in which electrical energy is converted to chemical energy / OR the use of electrical energy to produce chemical change.

TRANSFER OF ELECTRONS

• ***Half-cell***: a single electrode, generally a metal, immersed in a container with an electrolyte – two half-cells joined by a salt bridge form a galvanic cell that may produce a flow of electrons.

• ***Half-reaction***: the reaction taking place in one half-cell, as defined above

• ***Redox reaction***: a reaction where there is a change in the oxidation numbers of the species involved - generally this involves a direct transfer of electrons

We deal in electrochemistry. with reactions that have ***A TRANSFER OF ELECTRONS***

(i.e., redox reactions), as for example in:

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$$

This reaction can be written in **different forms** …

• in *ionic* form: $Zn + Cu^{2+} + SO_4^{2-} \rightarrow Zn^{2+} + SO_4^{2-} + Cu$

• as *oxidation half- reaction*: $Zn \rightarrow Zn^{2+} + 2e^-$

• as *reduction half- reaction*: $Cu^{2+} + 2e^- \rightarrow Cu$

• as ***net ionic equation***:

$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$ *(here excluding spectator ions)*

Electrochemical Cells

Electrochemical cells are based on Redox reactions; therefore they can't be dealt with without considering the core of their existence.

REDOX REACTIONS

- **Redox reaction** is defined as transfer of electrons.
- Reduction and oxidation reactions are two concurrent reactions that are mothers of electrochemical cell. These reactions occur simultaneously at the same rate and that means there is a constant change in electrolyte concentration.

Reduction reaction

- **Reduction reaction** is defined as gaining of electrons,

- can also be defined as a decrease in an **oxidation number**.
- An element that undergoes reduction facilitates the loss of electrons of another element therefore it's called an **oxidizing agent**.
- This half reaction is located at an electrode called cathode.

Then reduction reaction is written as follows:

$M^{2+} + 2e^- \rightarrow M$

.Oxidation reaction

- **Oxidation reaction** is defined as losing of electrons,
- can also be defined as an increase in an **oxidation number**.
- An element that undergoes **reduction facilitates the gain of electrons** therefore it's called a **reducing agent**.
- This oxidation half reaction is located at an electrode called Anode: for example

$$M \rightarrow M^{2+} + 2e^-$$

Oxidation the loss of electrons **Reduction** the gaining of electrons

TYPES OF ELECTROCHEMICAL CELLS

There are two types of electrochemical cells …

- A **GALVANIC CELL** (also referred to as a voltaic or wet cell) – in which chemical potential energy converted to electrical potential energy –
- An **ELECTROLYTIC CELL** – in which electrical potential energy converted into chemical potential energy

Exam guideline on the Galvanic Cell

- Galvanic cell is an electrochemical cell that converts chemical energy into electrical energy.
- This cell must be **spontaneous** which could be observed by a positive E^o_{cell} being positive.

- Also, it's made up of the following major components: salt bridge, conducting wire, and voltmeter.
- Salt bridge connects a chamber with a cathode with the one that has an anode. Salt bridge is made up of very stable salt usually KNO_3.
- The salt bridge is used to:
  - Complete the circuit
  - Neutralises solutions by allowing the flow of ions in between solutions.
- Conducting wire is used to transport electrons that are being transferred.
- Voltmeter is used to measure the potential difference across the cell.
- This cell uses the standard reduction potential tables to determine which substances shall undergo reduction as well as oxidation in a pair.

  NOTE: The element with a smaller E value always undergoes oxidation.
  - Which means it must be located on an ANODE which is a negative electrode for this cell.
  - Whereas, an element with a bigger E value will always undergo reduction and that is located on the positive electrode called Cathode for this cell.

e.g., given the following pair Zn / Cu

E value for Zn is -0.76V

E value for Cu is +0.34V

- When comparing both values its evident that Zn has a smaller value and that means in this pairing it shall undergo oxidation.
- Then Cu must undergo reduction to complete redox reaction.

Oxidation half reaction: $Zn \rightarrow Zn^{2+} + 2e^-$

Reduction half reaction: $Cu^{2+} + 2e^- \rightarrow Cu$

- Also, from the same set of elements the net reaction could be derived.
- A net reaction is the sum of both half reactions.
- Before the net reaction could be done there must be an equal amount of electrons for both equations.

N.B. If they do not balance, they must be balanced before a net reaction is done.

Net reaction: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

Also, the potential difference of the cell could be calculated based on the pair given

$E_{cell} = E_{reduction} - E_{oxidation}$

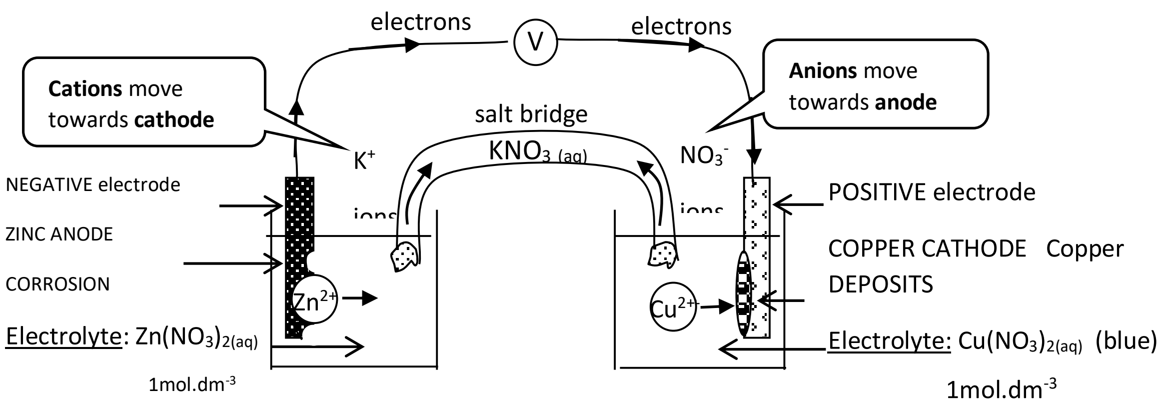
$= (+0.34) - (-0.76)$

$= +1.10V$

- In a cell notation anything with a charge must be accompanied by a standard concentration which is 1 $mol.dm^{-3}$.
- Also, in a cell notation electron transferred aren't shown however, the species of a substance are shown.
- The cell notation starts with an anode then double vertical lines that represent a salt bridge then a cathode

$Zn / Zn^{2+}(1\ mol.dm^{-3})\ II\ Cu^{2+}(1\ mol.dm^{-3}) / Cu$

The diagram below shows a standard Galvanic Cell.



NOTE: The same observations would be made if zinc metal was placed in a solution of copper sulphate. The zinc is oxidised and corrodes, red brown deposits of copper would form, the blue solution would turn colourless and the solution would become hot (exothermic reaction).

CELL NOTATION

By convention …

- the ***anode*** is always written on the ***left***, the ***cathode*** on the ***right***

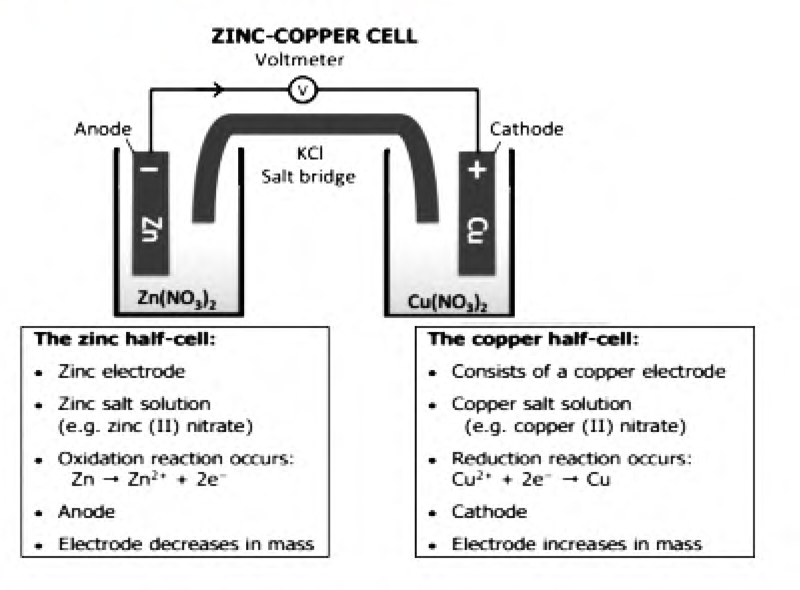
- the anode & cathode are *separated by a* **||** (which represents the salt bridge) while the different phases in a half-cell are separated by a single **|**.
- The cell notation follows the reaction sequence …

Pt **|** reducing agent **|** oxidised species **||** oxidising agent **|** reduced species **|** Pt

- **(Pt (or C) appears only if an inert electrode is used, as in the stand**. $H_2|H^+$ half-cell.)

(a way of checking your work – if the cell notation is correct, the electrodes will *appear on the outside, e.g.,* $Zn(s)|Zn^{2+}||Cu^{2+}|Cu(s)$)

FOR THE ZINC-COPPER CELL:



For the zinc-copper cell:

Oxidation half-reaction: $Zn\ (s) \rightarrow Zn^{2+}(aq) + 2e^-$

Reduction half-cell: $Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$

Nett cell: $Zn\ (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$

Cell notation is written as follows:

Anode Salt-bridge Cathode

↓ ↓ ↓

$Zn(s)\ /Zn^{2+}(aq)\ (1\ mol{\cdot}dm^{-3})\ //\ Cu^{2+}(aq)\ (1\ mol{\cdot}dm^{-3})\ /\ Cu(s)$

Worked examples

1.1 Consider the electrochemical cell represented by the cell notation below, where X is an unknown metal: Pt(s) | Fe^{2+}(aq), Fe^{3+}(aq) || X^{+}(aq) | X(s) The cell potential of this cell was found to be 0,03 V.

1.1.1 Write down the type of electrochemical cell illustrated above. (1)

1.1.2 What does the single line (|) in the above cell notation represent? (1)

1.1.3 Write down the half-reaction that takes place at the anode in the above cell. (2)

1.1.4 Identify X with the aid of a calculation. (5)

1.2 A Pt(s) | Fe^{2+}(aq), Fe^{3+}(aq) half-cell is connected to a Cu(s) | Cu^{2+}(aq) half-cell.

Write down:

1.2.1 The chemical symbol for the electrode in the cathode half-cell. (1)

1.2.2 The NAME of the oxidising agent. (1)

1.2.3 The overall balanced cell reaction that takes place in this cell. (3)

[14]

SOLUTIONS

1.1

1.1.1 Galvanic cell ✓

1.1.2 Indicates phase boundary/ interphase / phase separator. ✓

1.1.3 $Fe^{2+} \rightarrow Fe^{3+} + e^-$ ✓✓

1.1.4 $E^{\ominus}_{cell} = E^{\ominus}_{reduction} - E_{oxidation}$ ✓

$0,03$ ✓ $= E^{\ominus}_{reduction} - (0,77)$ ✓

$E^{\ominus}_{reduction} = 0,80$ V ✓

$= E^{\ominus}\ X / X^{+}$

∴ X = Silver/Ag✓

1.2.1 Pt ✓ (1)

1.2.2 Iron (III) (ions)/ ferric ions ✓ (1)

1.2.3 $2Fe^{3+} + Cu$ ✓$\rightarrow 2Fe^{2+} + Cu^{2+}$✓ balancing ✓ (3)

[14]

Exam Guideline on the Electrolytic Cell

- Electrolytic cell is an electrochemical cell whereby electrical energy is converted to chemical energy.
- **Electrolysis** is breaking down of
- using electricity and is a non-spontaneous.
- The electrical energy source for this cell must be DC supply.

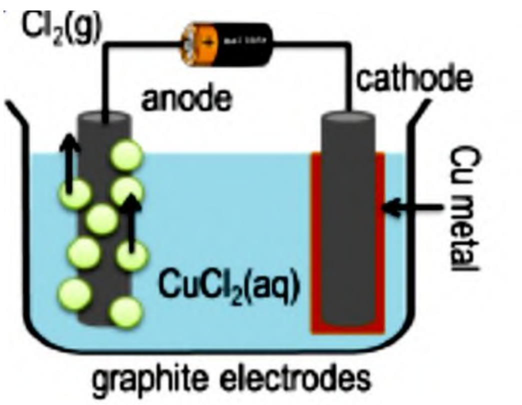
The following types of electrolytic cells are the only ones required for examination purposes:

- Decomposition of copper chloride,
- electroplating,
- electro-refining and
- electrolysis of NaCl

ELECTROLYTIC PROCESSES/ APPLICATIONS

1. DECOMPOSITION OF COPPER CHLORIDE

As seen in the decomposition of $CuCl_2$, the cathode is covered with a coating of copper metal. This property of electrolytic cells is widely used in industry, in electroplating and electro-refining.



The principles of electrochemistry (as above) are used in a variety of industrial processes. One is the decomposition of copper chloride ($CuCl_2$).

$CuCl_2$ ionises in water to form Cu^{2+} and Cl^- ions.

When a current is passed through the solution, Cu^{2+} is reduced, forming a metal layer around the cathode

$Cu^{2+} + 2e^- \rightarrow Cu$ (reduction reaction)

At the same time, Cl^- ions migrate to the positive anode, losing the extra electron to be oxidised forming chlorine gas.

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$ (oxidation reaction)

The **net reaction**: $CuCl_2(aq) \rightarrow Cu(s) + Cl_2(g)$

$E°_{(cell)} = E°_{(cath.)} - E°_{(anode)}$

$= +0,34 - (+1,36)$

$= -1,02\ V$

The reaction is *non-spontaneous*, as the need for a battery implies.

ELECTROLYSIS (the process described here) may be used to produce oxygen and hydrogen gas from water, or to produce chlorine gas and sodium hydroxide, as in the chlor-alkali industry (discussed more fully later.

Electrolysis is also used to purify metals (in a process called **ELECTROREFINING**, or **ELECTRO-PURIFICATION**)

2. ELECTROPLATING occurs when an electrically conductive object is coated with a layer of a different metal using an electrical current.

Electroplating is used for a variety of purposes …

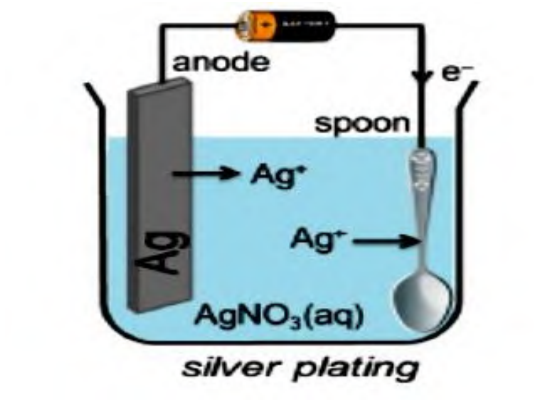
• for *decorative* purposes (a silver spoon) looks much nicer than a cheap nickel one

• to provide a *rust-resistant, protective* layer

• *chrome-plating* an iron object places a thin coating of chrome (which does not rust) over the iron, thus protecting the iron underneath

• *galvanising* a steel product implies coating it with a thin protective layer of ***zinc*** – this usually happens using the hot-dip method, when parts are submerged in a bath of molten zinc.

The diagram below shows a simple electroplating cell



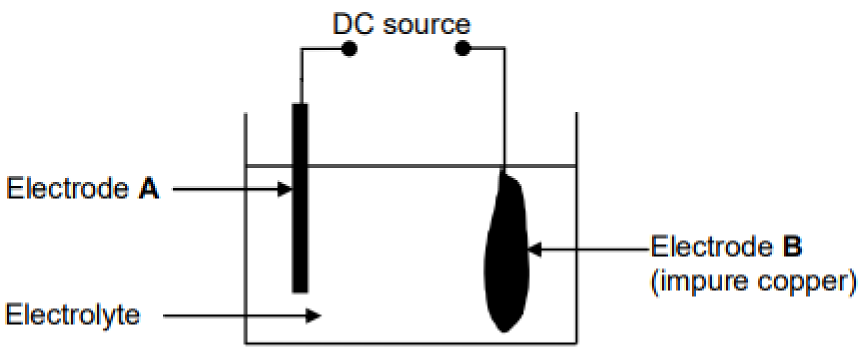
Anode: $Ag \rightarrow Ag^{+} + e^{-}$ (silver metal is oxidised to Ag^{+} ions $\therefore$ anode corrodes)

Cathode: $Ag^{+} + e^{-} \rightarrow Ag$ (silver ions are reduced to silver metal which deposits on spoon)

NOTE: The concentration of the electrolyte remains the same during electroplating process.

Worked example

1. The simplified diagram below represents an electrochemical cell used for the purification of copper.



1.1	Define the term electrolysis.	(2)
1.2	Give a reason why a direct-current (DC) source is used in this experiment.	(1)
1.3	Write down the half-reaction which takes place at electrode	(2)
1.4	Due to small amounts of zinc impurities in the impure copper, the electrolyte becomes contaminated with Zn^{2+} ions. Refer to the attached Table of Standard Reduction Potentials to explain why the Zn^{2+} ions will not influence the purity of the copper obtained during this process.	(3)

SOLUTIONS

1.1 The chemical process in which electrical energy is converted to chemical energy / The use of electrical energy to produce a chemical change/ The process during which an electric current pass through a solution / molten ionic compound ✓✓ (2)

1.2 To keep the polarity of the electrode's constant. / To prevent the anode and cathode from swopping. / DC provides a one-way flow of electrons ensuring that the same chemical reaction occurs all the time at the same electrodes ✓ (1)

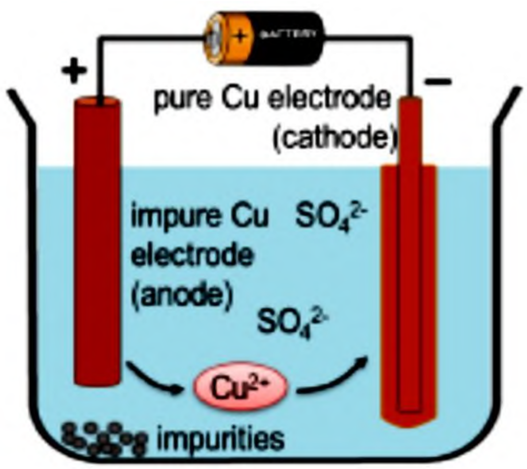
1.3 Cu^{2+} (aq) + $2e^-$ → Cu(s) ✓✓ (2)

1.4 Cu2+ is a stronger oxidising agent ✓ than Zn^{2+} ./Cu^{2+} will be reduced to Cu. ✓ OR Zn is a stronger reducing agent than Cu. / Cu^{2+} will be reduced to Cu (3)

3. Electro-refining

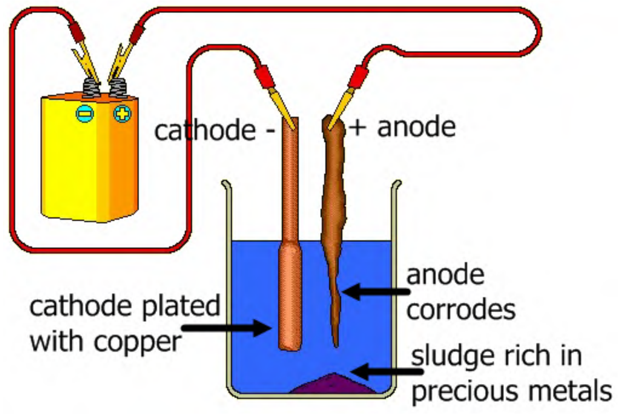
- Electro-refining is the process whereby metals are purified from their ores.
- Electro-refining is used to extract that metal from others.
- In this cell both electrodes i.e., pure and impure electrodes and an electrolyte they are made up of the same metal (Cu), but one of these electrodes is an ore (impure).
- In electro-refining an impure electrode is always an anode then a pure electrode is always a cathode.

Diagram below shows a simplified Cu purification cell.



- An impure Cu anode & a pure Cu cathode are connected in a solution of aqueous $CuSO_4$ and H_2SO_4. as electrolyte.
- The impure Cu is oxidised and enters the solution as Cu^{2+} – the anode will lose mass, and impurities in the electrode will drop to the bottom.

- At the cathode, the Cu^{2+} ions are reduced to Cu, and attach themselves to the cathode (the pure Cu electrode): $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$. Cu with a purity > 99% is formed.



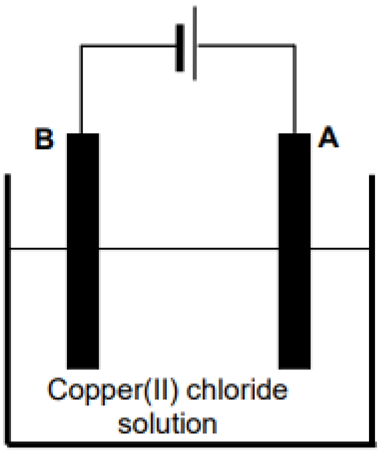
Anode (impure copper): $Cu \rightarrow Cu^{2+} + 2e^{-}$

Cathode (pure copper): $Cu^{2+} + 2e^{-} \rightarrow Cu$

- Precious metals such as silver and gold are not oxidised (since they have higher positive reduction potentials, E°, than copper
- They sink to the bottom with other impurities where they form sludge.

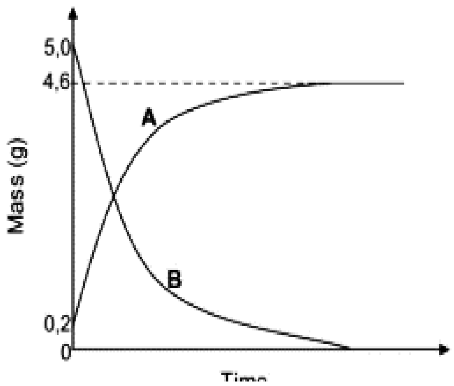
Worked example

The electrochemical cell below is set up to demonstrate the purification of copper.



1.1 Write down the type of electrochemical cell illustrated above. (1)

The graph below represents the changes in mass that occur at electrode A and electrode B in an electrolytic cell during purification of copper.



1.2 Define electrolysis.

1.3 Which graph, A or B, represents the change in mass of the anode during electrolysis? Motivate your answer.

1.4 Write down the equation of the half-reaction that takes place at the cathode of this cell.

1.5 Use the information in the graph to calculate the percentage purity of the impure copper.

SOLUTIONS

1.1 Electrolytic cell ✓

1.2 The chemical process by which electrical energy is converted to chemical energy.✓✓

OR The use of electrical energy to produce a chemical change.

1.3 B. ✓ The anode where oxidation takes place will be eroded and becomes small in size. ✓

1.4 $Cu^{2+} + 2e^- \rightarrow Cu$ ✓✓

1.5 $\% \text{ Purity} = \frac{m(Cu)}{\text{impure } m(Cu)} \times 100\ \%$

$= \frac{4,4✓}{5✓} \times 100$ ✓

% Purity = 88%✓

4. ELECTROLYSIS of sodium chloride (NaCl) solution in the **CHLOR-ALKALI INDUSTRY** produces **Cl_2**, **NaOH** (sodium hydroxide) and **H_2**

Chlorine can be manufactured by the electrolysis of brine (saturated sodium chloride solution). At the anode, **$C\ell^-$ (aq)** is oxidised to **$C\ell_2$(g).**

$$2C\ell^- (aq) \rightarrow C\ell_2(g) + 2e^-$$

At the cathode, H_2O is reduced to OH^- (aq) and H_2(g)

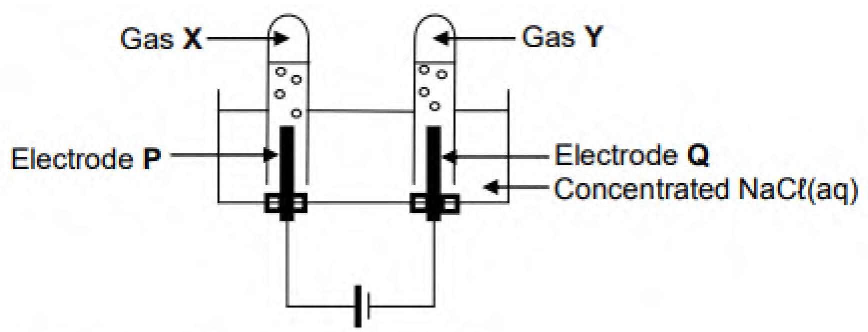
$$2H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

The overall reaction is:

$$2NaC\ell (aq) + 2H_2O(\ell) \rightarrow C\ell_2(g) + H_2(g) + 2NaOH(aq)$$

Worked example

In the electrochemical cell below, carbon electrodes are used during the electrolysis of a concentrated sodium chloride solution.



The balanced equation for the net (overall) cell reaction is: $2H_2O(\ell) + 2C\ell^-(aq) \rightarrow C\ell_2(g) + H_2(g) + 2OH^-(aq)$

1.1 Is the reaction EXOTHERMIC or ENDOTHERMIC? (1)

1.2 Is electrode P the ANODE or the CATHODE? Give a reason for the answer. (2)

1.3 Write down the:

1.3.1 NAME or FORMULA of gas X (1)

1.3.2 NAME or FORMULA of gas Y (1)

1.4 Is the solution in the cell ACIDIC or ALKALINE (BASIC) after completion of the reaction? Give a reason for the answer. (2)

[9]

SOLUTIONS

1.1 Endothermic ✓ (1)

1.2 Anode ✓ connected to the positive terminal of the battery.✓ (2)

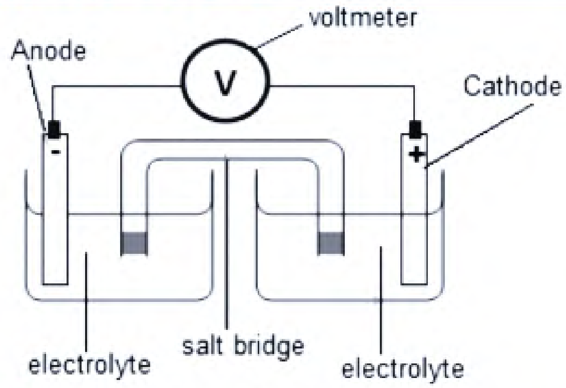
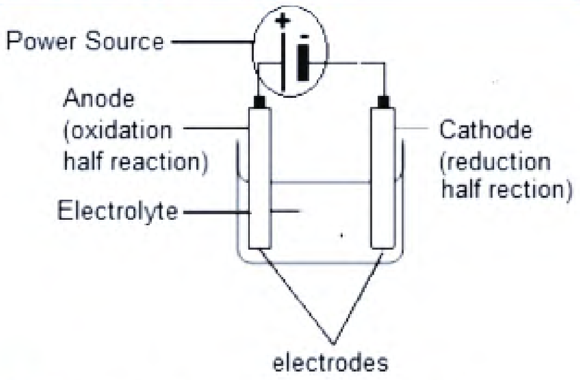
1.3.1 Chlorine gas / $C\ell_2$ ✓ (1)

1.1.2 Hydrogen gas /H_2 ✓ (1)

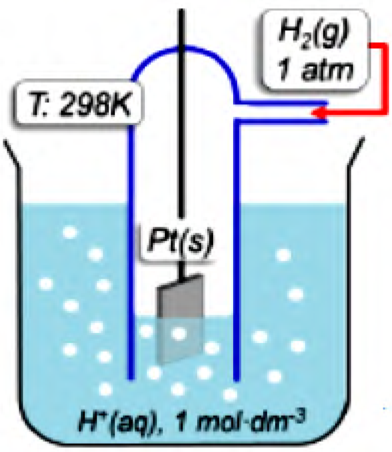
1.1.3 $2H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ ✓✓ (2)

1.4 Basic / alkaline ✓ OH^- ions form / NaOH forms✓ (2)

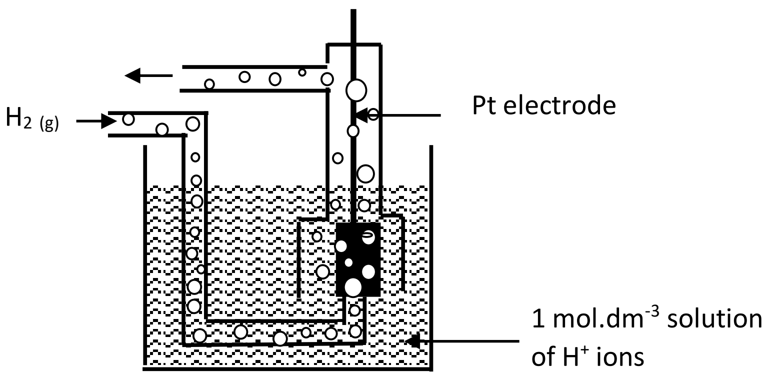
[9]

GALVANIC CELL	ELECTROLYTIC CELL
	
A cell in which chemical energy is converted into electrical energy.	A cell in which electrical energy is converted into chemical energy.
Spontaneous: has self-sustaining electrode reactions.	Non-spontaneous: needs a continuous supply of (electrical) energy.
Exothermic reactions.	Endothermic reactions.
Salt bridge	No salt bridge.
Positive electrode: **C**athode: Redu**C**tion	Positive electrode: An**O**de: Oxidation
Negative electrode: An**O**de: Oxidation	Negative electrode: **C**athode: Redu**C**tion
Two half-cells are placed in separate containers.	Two electrodes are in the same container.
Emf is always positive.	Emf is always negative.

STANDARD HYDROGEN ELECTRODE (SHE) AND STANDARD CONDITIONS



OR



- The potential of a particular half-cell is always determined relative to the ***Standard Hydrogen Electrode (SHE)*** (with E° = 0,00 V), under standard conditions.

- The SHE consists of a/an:
- acid solution with $[H^+] = 1\ mol\cdot dm^{-3}$,
- a platinum electrode and wire.
- $H_2(g)$ that is bubbled over the electrode.

The reaction is $2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$.

- Note that the reaction is reversible, with an assigned electrode. potential: E° = 0,00 V.
- The ***standard conditions*** referred to above, and applicable to all reference tables that we use (e.g.: **Table 4A**: Standard Electrode Potentials) are ….
- a **temperature** of half-cell is kept **at 25°C (or better, *298 K*** (kelvin))
- a solution of H^+ ions of **concentration 1 mol.dm^{-3}** *e.g. I mol.dm^{-3} HCl ; 0,5mol.dm^{-3} H_2SO_4*
- H_2 gas bubbled at a **pressure** (for gases) of ***101,3 kPa* (1 atm)**

Considering the TABLE OF STANDARD ELECTRODE POTENTIALS (**Table 4A**)

increasing oxidising ability

Half-reactions			E° (V)
$F_2(g) + 2e^-$	$\rightleftharpoons$	$2F^-$	+ 2,87
$Au^{3+} + 3e^-$	$\rightleftharpoons$	Au	+ 1,50
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+ 0,80
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+ 0,77
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+ 0,34
$2H^+ + 2e^-$	$\rightleftharpoons$	$H_2(g)$	0,00
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	– 0,4
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr	– 0,7
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	– 0,7
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	Mn	– 1,1
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	– 2,3
$Na^+ + e^-$	$\rightleftharpoons$	Na	– 2,71
$K^+ + e^-$	$\rightleftharpoons$	K	– 2,93
$Li^+ + e^-$	$\rightleftharpoons$	Li	– 3,05

increasing reducing ability

Extract: Table 4A

- All reactions are written as reduction reactions (gaining electrons)
- A large **+** value implies the substance gains e^- easily (it is easily reduced and thus is a good oxidising agent)
- A large **–** (neg) value implies the substance readily oxidises (loses e^-, is ionised easily, will normally proceed to the right) and is thus a good reducing agent.

USING THE TABLE …

Worked example

1.Given two half-cells, Cu^{2+}/Cu & Mg^{2+}/Mg, which substance is reduced, which oxidised?

Cu^{2+} (a stronger oxidising agent than Mg^{2+}) will be reduced to Cu, and Mg (the stronger reducing agent) will be oxidised to Mg^{2+}.

2. Describe, in shorthand notation, a galvanic cell for which the cell reaction is:

$Cu(s) + 2Fe^{3+}(aq) \rightarrow Cu^{2+}(aq) + 2Fe^{2+}(aq)$

Solution:

First divide the cell reaction into half-equations

• oxidation: $Cu(s) \rightarrow Cu^{2+}(aq)+2e^-$

• reduction: $Fe^{3+}+e^- \rightarrow Fe^{2+}$

Then write the oxidation as the left-hand electrode, with the reduction on the right.

$Cu|Cu^{2+}||\ Fe^{2+}|\ Fe^{3+},Pt$

- Since both Fe^{2+} and Fe^{3+} are aqueous solutions, a Pt electrode is used.
- Fe^0 is the only oxidation state that is not aqueous for this metal.

EMF OF A CELL

- The **Emf** of a cell is the maximum potential difference between two half cells in a galvanic cell. If determined *under standard conditions*,
- it is referred to as the ***standard Emf : $E°_{cell}$***

The standard emf of a cell can be determined from Table 4A (or 4B), by applying one of the following formulae (*these are given on exam info sheet*)

$E°_{cell} = E°_{reduction} - E°_{oxidation}$

Or

$E°_{cell} = E°_{oxidising\ agent} - E°_{reducing\ agent}$

Or

$E°_{cell} = E°_{cathode} - E°_{anode}$

Worked example

1 An electrochemical cell is constructed using the following half reactions:

$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$ and $Au^{3+}(aq) +3e^- \rightleftharpoons Au(s)$

1.1 Which is the anode and which the cathode?

1.2 What is the standard cell potential?

1.3 Calculate emf if the cell

Solution

1.1 Using our simple rule …

Anode – oxidation: Pb (lead)

1.2 Cathode – reduction: Au (gold)

1.3 $E°_{cell} = E°_{(cathode)} – E°_{(anode)}$

$= + 1,50 – (–0,13)$

$= 1,63$ V

Remember:

- When the cell **Emf** is **POSITIVE**, the reaction is **SPONTANEOUS**.
- If the Emf is NEGATIVE, the reaction is NON-SPONTANEOUS

Consider for a moment the Cu half-cell in the Cu-Zn cell. Electrons that arrive at the Cu electrode (cathode) must be accepted by Cu^{2+} ions in the electrolyte.

CELL POTENTIAL AND EQUILIBRIUM

- When [Cu^{2+}] (the concentration of ions), is high, the reduction reaction:

  $Cu^{2+} + 2e^- \rightarrow Cu(s)$ readily takes place.
- The *reaction potential* is **high**.
- As the reaction continues, the [Cu^{2+}] decreases. As a result, the reaction slows - the *reaction potential* is **much lower**.
- Something similar happens in the Zn half-cell. As the [Zn^{2+}] increases in the electrolyte, the reaction potential decreases, and the oxidation reaction,
  - $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$, slows.
- Eventually both half reactions stop – equilibrium is reached.
- As a result, the [Zn^{2+}] and [Cu^{2+}] become constant, no electrons are released / accepted in the half-cells, there is no potential difference between the two half-cells and therefore no current flows.

To summarise:

- When equilibrium is reached between the half-cells reactions, the potential difference of the cell (E_{cell}) is zero, the battery is flat and no current will flow. Using a zinc half-cell connected to a hydrogen half-cell we find that the voltmeter reads

- -0,76 V, thus E° for Zn/Zn^{2+} = - 0,76 V (the negative sign is given to the zinc half-cell because when connected to the hydrogen electrode, it will be the source of electrons). Using a copper half-cell connected to the hydrogen electrode the value of
  E° = + 0,34 V.
- If Zn^{2+} ions are added to the zinc half-cell then the zinc electrode will have less tendency to oxidise, i.e., reverse reaction favoured, therefore less electrons transferred and emf decreases.

ACTIVITIES

QUESTION 1: (Multiple Choice Questions)

1.1 Which of the following standard electrochemical cells would have the highest emf?

A $2I^- | I_2 || Ag^+ | Ag$
B $Cr | Cr^{2+} || Cu^{2+} | Cu$
C $Mg | Mg^{2+} || Mn^{2+} | Mn$
D $Pb | Pb^{2+} || Hg^{2+} | Hg$ (2)

1.2 $Mg(s) | Mg^{2+}(aq) || H^+(aq) | H_2(g) |Pt$. Which of the following half-reactions takes place at the cathode?
A $H_2(g) \rightarrow 2H^+(aq) + 2e^-$
B $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$
C $Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$
D $2H^+(aq) + 2e^- \rightarrow H_2(g)$ (2)

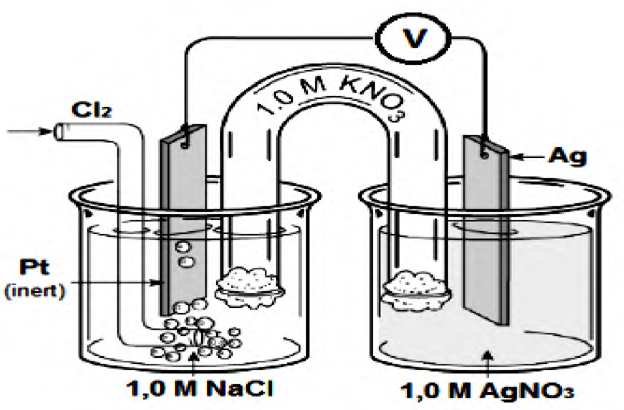
1.3 Which ONE of the following statements regarding an electrolytic cell is CORRECT?
A An electric current causes a chemical change to occur
B Reduction occurs at the anode
C A spontaneous chemical reaction produces an electric current
D Electrons flow to the electrode where oxidation occurs (2)

1.4 $Fe^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Fe(s)$. Identify the reducing agent in this reaction.
A Fe(s)
B $Fe^{2+}(aq)$
C Zn(s)
D $Zn^{2+}(aq)$

1.5 Which ONE of the following half-reactions occurs at the CATHODE during the electrolysis of a solution of $CuC\ell_2$?
A $C\ell_2 + 2e^- \rightarrow 2C\ell^-$
B $2C\ell^- \rightarrow C\ell_2 + 2e^-$
C $Cu \rightarrow Cu^{2+} + 2e^-$
D $Cu^{2+} + 2e^- \rightarrow Cu$

1.6 When a galvanic (voltaic) cell delivers current, the salt bridge …
A allows electrons to move in the cell.
B ensures electrical neutrality in the cell.
C prevents the two solutions from mixing.
D allows electrons to travel from the cathode to the anode.

1.7 The voltaic cell represented below functions at standard conditions. The diagram applies to this and the next two questions. Which of the following represents the anode half reaction?



A $Ag^+ + e^- \rightarrow Ag$

B $Ag \rightarrow Ag^+ + e^-$

C $2Cl^- \rightarrow Cl_2 + 2e^-$

D $Cl_2 + 2e^- \rightarrow 2Cl^-$ (2)

1.8 What changes in mass occur to the anode and cathode?

	Anode Mass	Cathode Mass
A	Increases	No change
B	Decreases	Increases
C	Decreases	No change
D	Increases	Decreases

(2)

QUESTION 2

Consider a voltaic cell that is set up between aluminium (Al) and lead (Pb)

2.1 What metal will form the cathode of this cell? (1)

2.2 Name a suitable electrolyte for the lead half-cell. (1)

2.3 Which metal electrode will corrode during the operation of this cell? (1)

2.4 Write the anode, cathode and nett reaction for this cell.

2.4.1 Anode (2)

2.4.2 Cathode (2)

2.4.3 Nett (3)

2.5 Why are the iron (Fe) atoms oxidised but not the silver (Ag) and gold (Au) atoms? (2)

2.6 Give the cell notation for this cell (include standard conditions). (3)

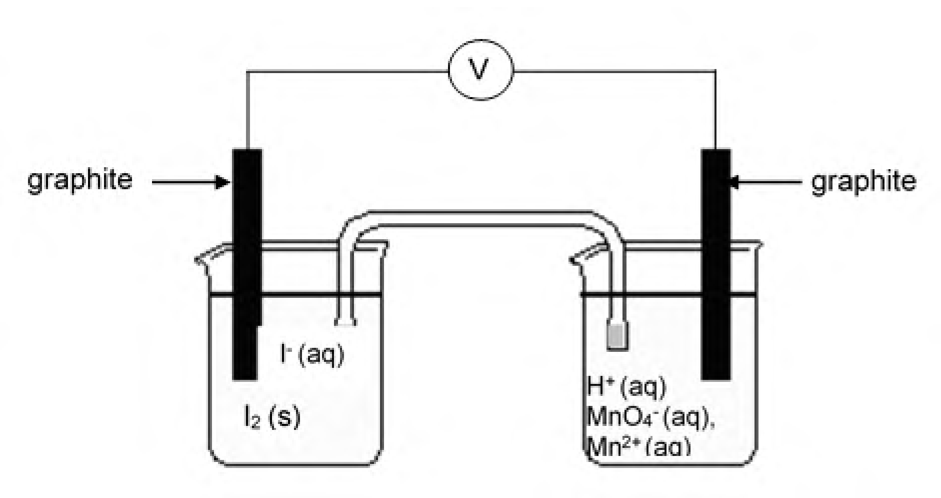
2.7 Calculate the emf (E^{o}_{cell}) of this cell. (4)

2.8 What will happen to the emf of this cell as the cell reaction approaches equilibrium? (1)

2.9 How will the emf of the cell be affected if the concentration of Al^{3+} ions is increased in the aluminium half-cell? Explain. (2)

[20]

QUESTION 3: DBE EXEMLPAR 2014



3.1 Write down the concentration of H^+ (aq) in the one half-cell. (1)

3.2 Solids present in half-cells are usually used as electrodes. Give a reason why I_2(s) is not suitable to be used as an electrode. (1)

3.3 Write down TWO properties of graphite, other than being a solid, that makes it suitable for use as electrodes in the above voltaic cell (2)

3.4 For the above voltaic cell, write down the:

3.4.1 NAME of the oxidizing agent (1)

3.4.2 Net cell reaction (3)

3.4.3 Cell notation (3)

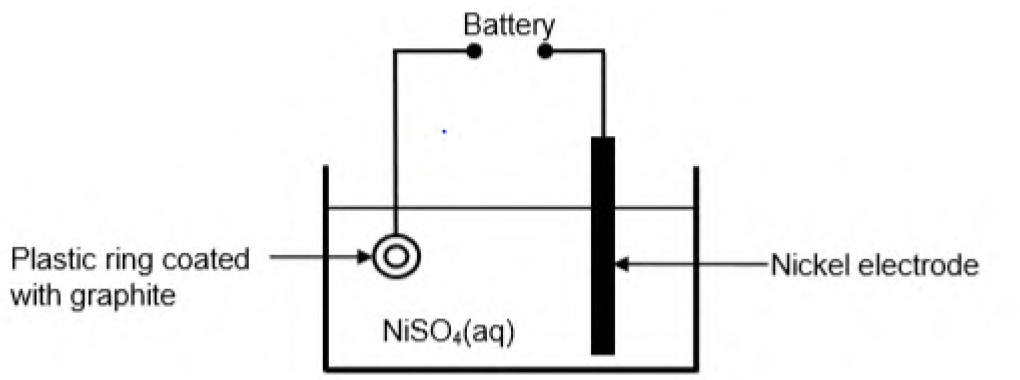
3.5 Calculate the cell potential of the above cell. (4)

3.6 How will the reading on the voltmeter be affected if the concentration of MnO_4^- decreases? Only write down INCREASES, DECREASES or NO EFFECT. (1)

[16]

QUESTION 4

The diagram below shows a simplified electrolytic cell that can be used to electroplate a plastic ring with nickel. Prior to electroplating the ring is covered with a graphite layer.



4.1 Define electrolyte (2)

4.2 Give One reason why plastic ring must be coated with graphite prior to electroplating (1)

4.3

4.3.1 Half-reaction that occurs at the plastic ring (2)

4.3.2 NAME or FORMULA of the reducing agent in the cell. Give a reason for the answer. (2)

4.4 Which electrode, the RING or NICKEL, is the cathode? Give a reason for the answer. (2)

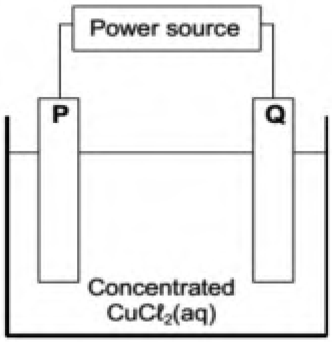
The nickel electrode is now replaced with a carbon rod.

4.5 How will the concentration of the electrolyte change during electroplating? Write down only INCREASES, DECREASES or NO CHANGE. Give a reason for the answer. (2)

[11]

QUESTION 5

The simplified diagram below represents an electrochemical cell used to refine copper. One of the electrodes consists of impure copper



5.1 What type of power source, AC or DC, is used to drive the reaction in this cell? (1)

5.2 When an electric current passes through the $CuC\ell_2$ (aq), the mass of electrode P increases. Is electrode P the cathode or the anode? Write down the relevant half-reaction to support your answer. (3)

5.3 The impure copper contains zinc impurities that are oxidised to zinc ions.Refer to the relative strengths of oxidising agents to explain why zinc ions will not influence the quality of the pure copper produced in this cell. (3)

5.4 Electrodes P and Q are now replaced by carbon electrodes

5.4.1 What will be observed at electrode Q? (2)

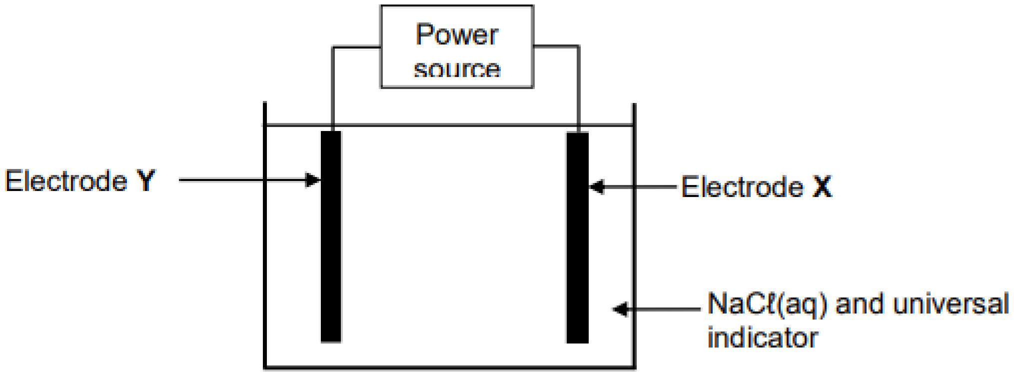
5.4.2 How will the concentration of the electrolyte change as the reaction proceeds? Choose from increases, decreases or remains the same (2)

[11]

QUESTION 6

The apparatus below is used to demonstrate the electrolysis of a concentrated sodium chloride solution. Both electrodes are made of carbon. A few drops of universal indicator are added to the electrolyte. The equation for the net cell reaction is:

$$2NaC\ell(aq) + 2H_2O(\ell) \rightarrow C\ell_2(g) + H_2(g) + 2NaOH(aq)$$



Initially the solution has a green colour. Universal indicator becomes red in acidic solutions and purple in alkaline solutions.

6.1 Define the term electrolyte. (2)

When the power source is switched on, the colour of the electrolyte around electrode Y changes from green to purple.

6.2 Write down the:

6.2.1 Half-reaction that takes place at electrode Y (2)

6.2.2 NAME or FORMULA of the gas released at electrode X (1)

6.3 Refer to the Table of Standard Reduction Potentials to explain why hydrogen gas, and not sodium, is formed at the cathode of this cell. (2)

[7]