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KWAZULU-NATAL PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS) SUPPORT

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PHYSICAL SCIENCES: PAPER 1 & 2

GRADE 12

2025

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PHYSICAL SCIENCES 2025 FINAL REVISION PROGRAMME

CUSTOMISED FOR SPRING CLASSES/ CAMPS

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VERTICAL PROJECTILE MOTION

Worked Example 1

Scenario 1 - Object thrown upwards and returns to starting point

An object is thrown vertically upwards, at a velocity of 12 m.s^{-1} and returns to the thrower's hand.

NOTE:

For a free-falling body that is thrown upwards and returns to the thrower's hand:

The time taken for the upward motion (from the starting point to maximum height) is equal to the time taken for the downward motion (from the maximum height back to the starting point).

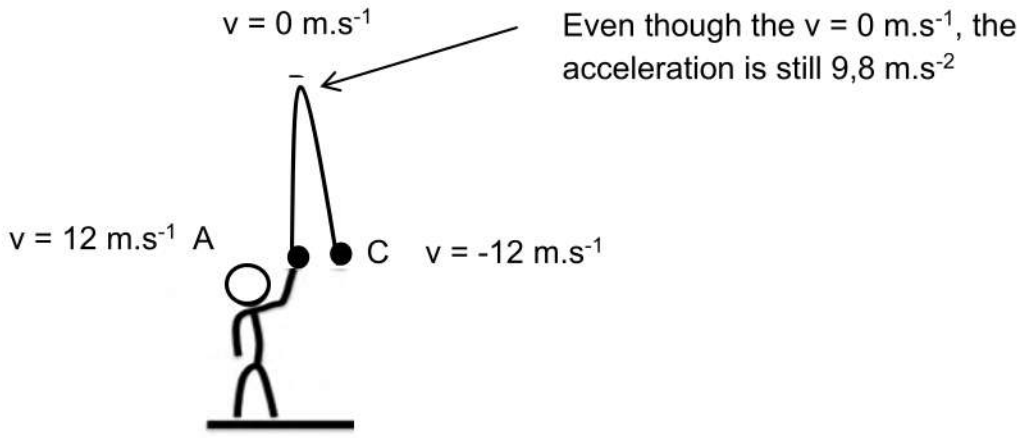
The magnitude of the velocity at which the object leaves the thrower's hand is equal to the velocity at which the object returns to the thrower's hand, although the velocities are in the opposite direction.

The velocity at the turning point (maximum height) is 0 m.s^{-1}

Step 1: Choose a positive direction [DO NOT CHANGE the positive sign convention during the question]

Upwards Positive [a = - 9.8 m·s^{-2}]

Step 2 Draw a sketch of the motion, indicating all known values



1.1 Calculate the:

1.1.1 Time taken to reach the highest point.

Solution:

[Motion from A – B]

V_i V_f

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$v_f = v_i + a\Delta t$
$0 = 12 + (-9{,}8)\,\Delta t$
$\Delta t = \underline{1{,}22\ s}$
<u>Additional Note:</u>

Since the time from A – B is 1,22 s, the time from B – C will also be 1,22 s

1.1.2 Distance of the maximum height above the thrower's hand.

Solution: [Motion from A – B]

$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$
$\Delta y = 12(1{,}22) + \frac{1}{2}(-9{,}8)(1{,}22)^2$
$\Delta y = 7{,}35\ m$
<u>Graphs for this motion</u>

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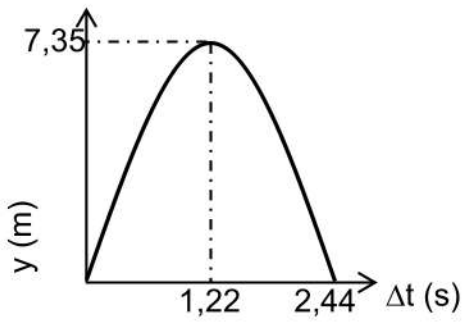
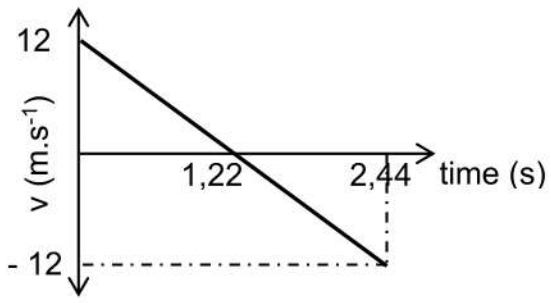
Position – Time Graph



Velocity – Time Graph



Worked Example 2

Scenario 2 - Object thrown upwards from some height above the ground. E.g from the top of a building or a cliff.

An object is thrown vertically upwards, at a velocity of 10 $m.s^{-1}$, from the edge of a 50m building and lands at the bottom of the building.

Step 1: Choose a positive direction [<u>DO NOT CHANGE</u> the positive sign convention during the question]

Upwards Positive [$a = -9.8\ m.s^{-2}$]

Step 2 Draw a sketch of the motion, indicating all known values

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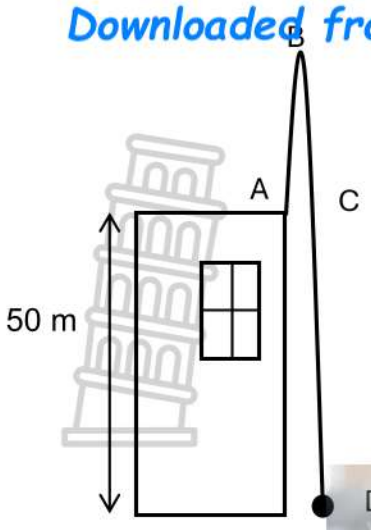

From the problem statement:

- $V_A = 10\ m.s^{-1}$

From previous example:

- $V_B = 0\ m.s^{-1}$
- $V_C = -\ 10 m.s-1$
- Time from A-B = Time from B-C

2.1 Calculate the:

2.1.1 Maximum height the object reaches above the ground

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Solution:

[Motion from A – B]

V_i V_f

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

$0^2 = 10^2 + 2(-9,8)\Delta y$

$\Delta y = 5,1$ m

[This is only the height from the top of the building to the max height. Since we require the <u>height above the ground</u>, we have to <u>add the height of the building</u>]

Height = **50 + 5,1** = 55,1 m

2.1.2 Velocity at which the object strikes the ground.

Solution:

[Motion from A – D]

V_i V_f

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

$v_f^2 = 10^2 + 2(-9,8)(-50)$

$v_f = -\ 32,86\ m.s^{-1}$

[Note: the negative answer obtained from the square root was taken since the object is moving downwards]

$V_f = 32,86\ m.s^{-1}$ downwards

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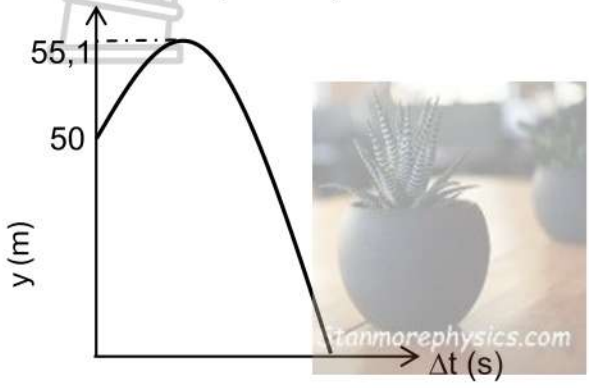
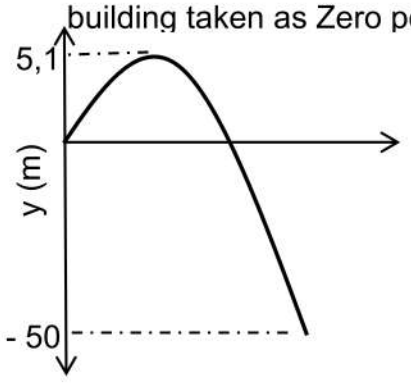
Graphs for this motion

The Position – Time Graph depends on the ZERO REFERENCE position. This indicates the point of the motion where the position of the object is 0 m.

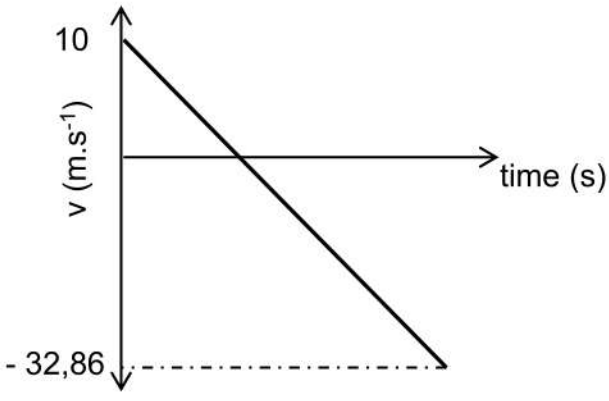
Position – Time Graph (Ground taken as Zero position)



Position – Time Graph (Top of the building taken as Zero position)



Velocity – Time Graph [The velocity- time graph will be the same regardless of the choice of zero position]



The line below the x-axis must be longer than the line above the x-axis

ADDITIONAL:

The displacement and velocity values used in the equations of motion will depend on the two points between which the object is moving. The acceleration value will stay the same. See the table below:

Motion	**Vi ($m.s^{-1}$)**	**Vf ($m.s^{-1}$)**	**Δy (m)**
A to B	$V_A = 10$	$V_B = 0$	5.1
B to C	$V_B = 0$	$V_C = -10$	- 5,1
B to D	$V_B = 0$	$V_D = -32,86$	- 55,1
A to D	$V_A = 10$	$V_D = -32,86$	- 50

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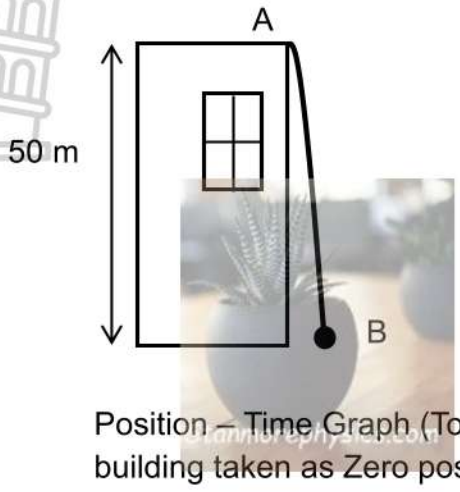
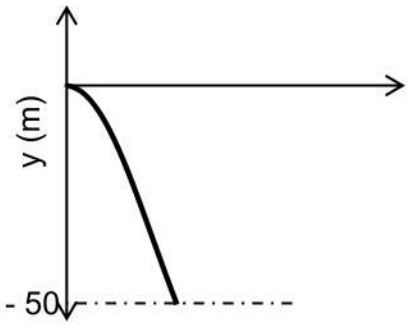
Scenario 3 – Object dropped below starting point [Upward taken as positive and the top of the building taken as the zero position

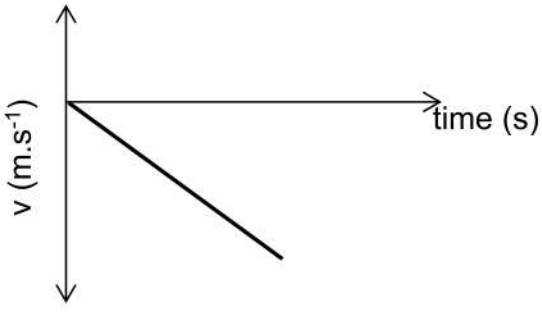


Since the object is DROPPED, the velocity at "A" is 0 $m.s^{-1}$.

Position – Time Graph (Top of the building taken as Zero position)



Velocity – Time Graph



NOTE: If and object is thrown downwards from some height above the ground :

Similar to Scenario 3, EXCEPT that the velocity at Point "A" will NOT be 0 $m.s^{-1}$. The velocity at "A" will be the velocity at which the object is thrown.

Acceleration – Time Graph

Constant Acceleration - Horizontal lines

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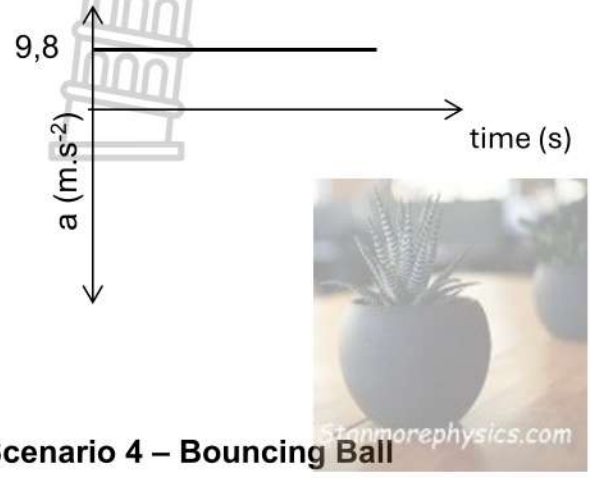
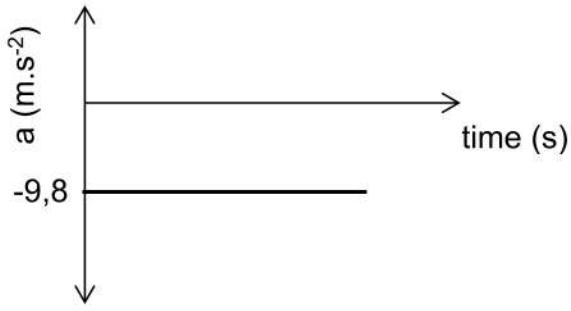
Acceleration – Time Graph

Downwards Positive



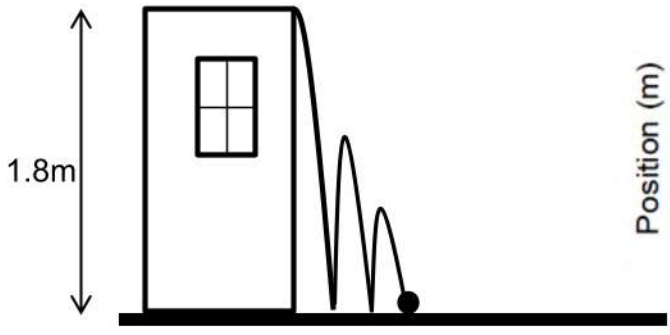
Acceleration – Time Graph

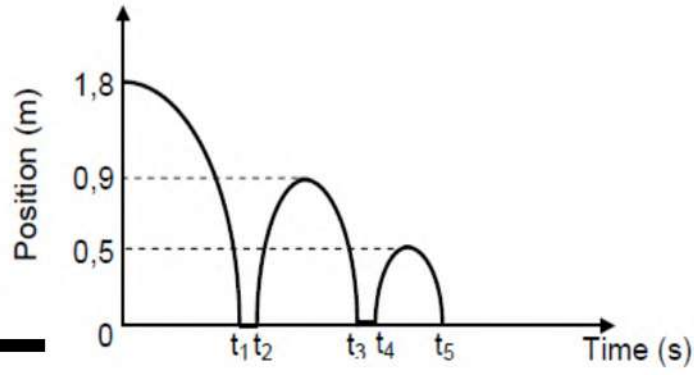
Upwards Positive



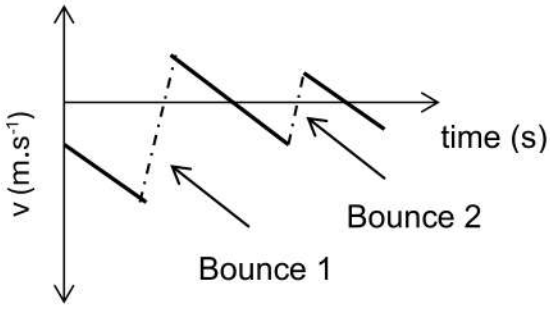
Scenario 4 – Bouncing Ball

An object is projected vertically downwards from the edge of a building and thereafter bounces on the ground below. Upward direction is taken as positive and the ground is taken as the Zero position.





Velocity – Time Graph



Note

(Refer to position – time graph):

The time from t_1 to t_2 is the contact time for the first bounce.

The time from t_3 to t_4 is the contact time for the second bounce.

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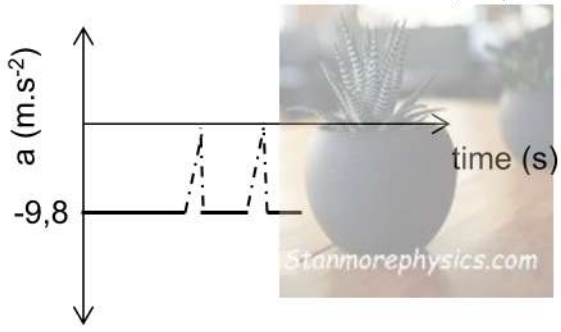
Note:

(Refer to the velocity – time graph)

- The lines must be drawn parallel.

Acceleration – Time Graph (Bouncing Ball)

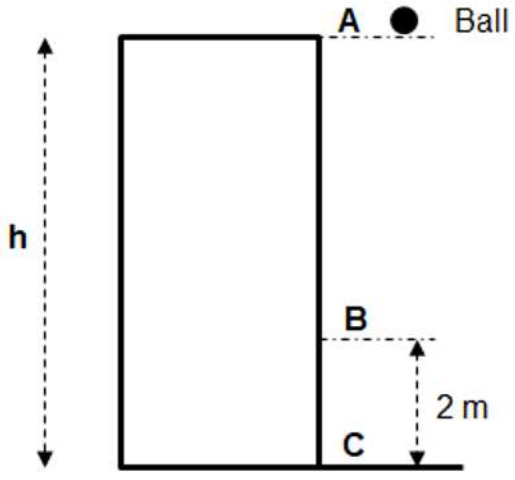


LONG QUESTIONS

QUESTION 1

An experiment is set up to determine the height **h** of a building. A tennis ball is dropped from point **A** at the top of the building as shown in the diagram below. Point **B** is 2 m above the ground and the ball takes 0,125 seconds to cover the distance from point **B** to point **C** on the ground.

Ignore the effects of air friction.



1.1 Write down the magnitude of the rate of change of velocity of the ball at point B. (1)

1.2 Calculate the:

1.2.1 Height, h, of the building (5)

1.2.2 Time taken for the ball to reach the ground (4)

1.2.3 Velocity with which the ball strikes the ground (3)

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1.3 Sketch the velocity versus time graph for the motion of the ball from the moment it was dropped until it strikes the ground.

Clearly indicate the following on your graph:
The initial velocity
The velocity with which the ball strikes the ground
Time when the ball strikes the ground (4)

[17]

QUESTION 2

A ball of mass 175 g falls from a tree and breaks the glass roof of a wooden cabin directly below it. The ball then continues to fall freely until it strikes the ground. The velocity-time graph below represents the motion of the ball when it left the tree until it strikes the ground.

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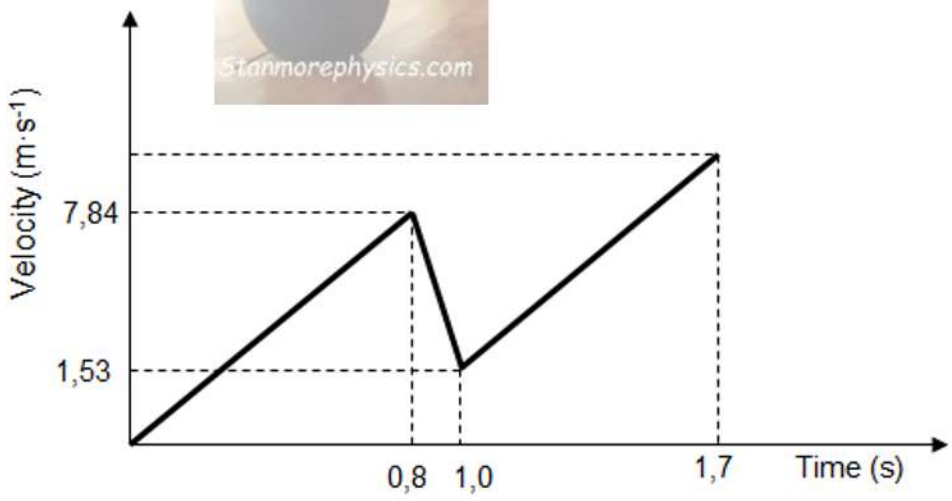

2.1 Define the term *projectile*. (2)

2.2 Calculate, WITHOUT USING EQUATIONS OF MOTION, the distance the ball fell from the instant it left the tree until it reaches the glass roof. (4)

2.3 Write down the time that the ball was in contact with the glass roof. (1)

2.4 Calculate the average net force acting on the ball while it was in contact with the glass roof. (4)

2.5 Calculate the speed with which the ball strikes the ground. (3)

2.6 How does the magnitude of the force exerted by the ball on the glass roof compare to that of the force exerted by the glass roof on the ball? Choose from GREATER THAN, LESS THAN or EQUAL TO. (1)

[15]

QUESTION 3

Ball **A** is thrown vertically upwards from the top of a building 15 m high. 1,5 seconds later ball **B** is launched upwards from the ground below at 18 $m \cdot s^{-1}$. BALL B IS MOVING UPWARDS when they pass each other at point **P**, 12 m above the ground.

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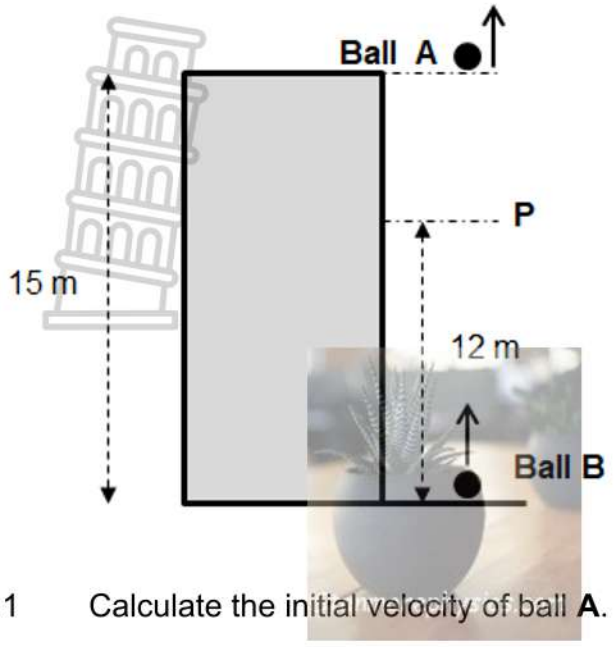


3.1 Calculate the initial velocity of ball **A**.

Hint: Pay careful attention to the significance of the two time values obtained for Ball B at point P. (6)

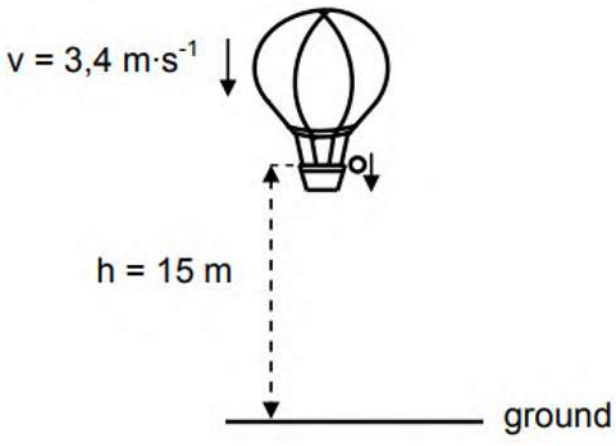
3.2 Sketch the position-time graph for both balls on the same set of axes. Use the letter **A** to label the graph for Ball A and the letter **B** to label the graph for Ball B. Take the ground as the zero-reference position.

Indicate the following on the graph:
The initial position of Ball A.
The position at which the balls meet.
The time when Ball B is launched. (5)

[11]

QUESTION 4

A hot-air balloon moves vertically downwards at a constant velocity of 3,4 $m \cdot s^{-1}$. When the balloon is 15 m above the ground, a small ball is dropped from the balloon. Refer to the diagram below.



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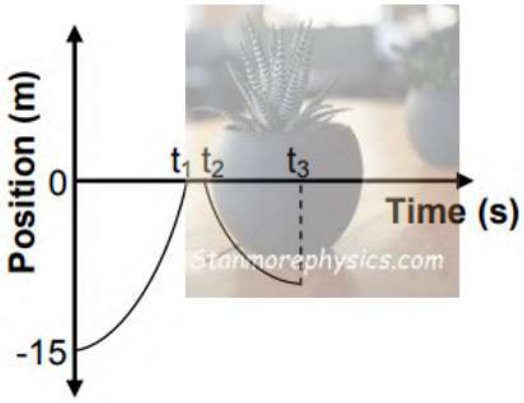
The ball strikes the ground and bounces vertically upwards. The hot-air balloon continues to move downwards at the same constant velocity.

Ignore the effects of air friction acting on the ball.

4.1 Define the term *free fall*. (2)

The sketch graph below (not drawn to scale) represents the positions of the ball relative to the ground from the time the ball is dropped until the time it reaches its maximum height after the first bounce.



4.2 Was the ball in free fall between t_1 and t_2 seconds? Write down either YES or NO. (1)

4.3 Use only EQUATIONS OF MOTION to calculate:

4.3.1 The value of t_1 indicated on the graph (3)

4.3.2 The height of the hot-air balloon above the ground at the instant when the ball struck the ground (4)

4.4 The ball was in contact with the ground for 0,2 s and left the ground with a vertical upward velocity of 7,2 $m \cdot s^{-1}$. (4)

Use only EQUATIONS OF MOTION to calculate the value of t_3 indicated on the graph.

[14]

QUESTION 5

A rubber ball is thrown vertically upwards at 5 $m \cdot s^{-1}$ from the top of a building of height **H**. The ball strikes the ground at time **T** and immediately bounces to a maximum height of $\frac{1}{4}$**H** 2,33 seconds after it was thrown

Ignore the effects of air friction. Neglect the time that the ball is in contact with the ground.

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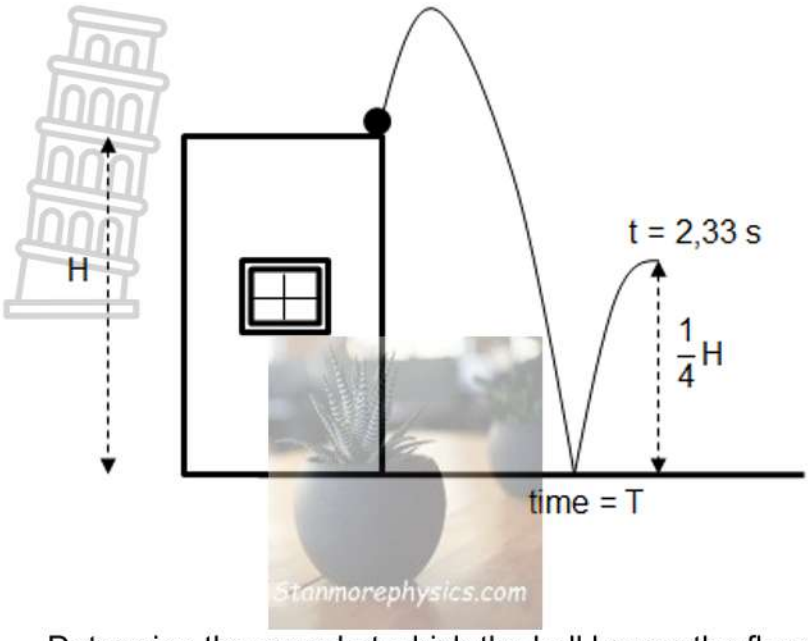


5.1 Determine the speed at which the ball leaves the floor in terms of:

5.1.1 H (4)

5.1.2 T (4)

5.2 Hence show that H in terms of T is written as: (1)

$$H = \frac{(22,834 - 9,8T)^2}{4,9}$$

5.3 Determine the height H in terms of T, for the motion before the ball strikes the ground. (3)

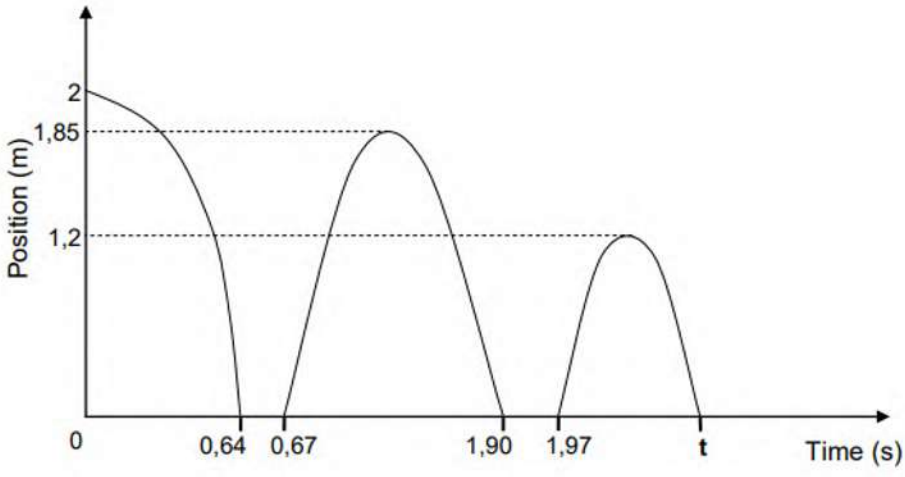
5.4 Hence calculate the value of T. (3)

[15]

QUESTION 6

A small ball is dropped from a height of 2 m and bounces a few times after landing on a cement floor. Ignore air friction.

The position-time graph below, not drawn to scale, represents the motion of the ball.



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6.1 Name the force acting on the ball while it is in free fall. (1)

6.2 Use the graph and determine:

6.2.1 The time that the ball is in contact with the floor before the first bounce (2)

6.2.2 The time it takes the ball to reach its maximum height after the first bounce (2)

6.2.3 The speed at which the ball leaves the floor at the first bounce (3)

6.2.4 Time **t** indicated on the graph (6)

[14]

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 A ball is thrown vertically upwards and returns to the starting point.

Which ONE of the following statements regarding *the rate of change of velocity* of the ball is TRUE?

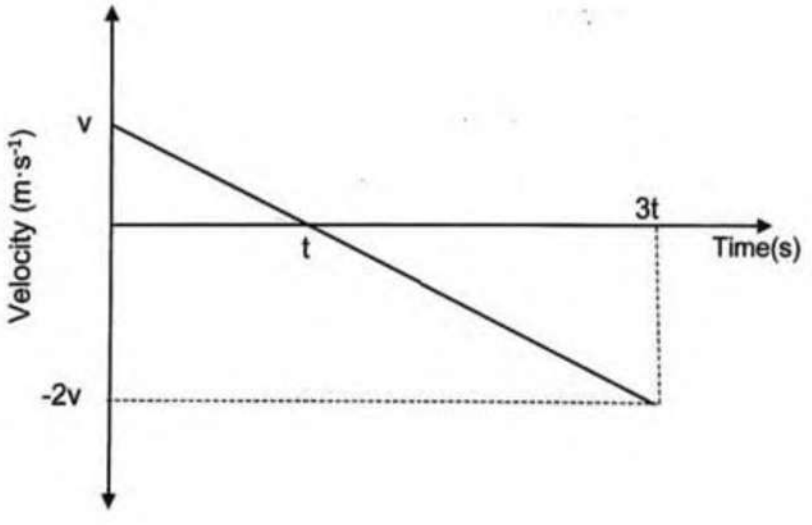
A Its direction when it is moving upward is opposite from the direction when it is moving downwards.

B It is always directed downwards during the motion.

C It is zero at the maximum height reached.

D It is always in the same direction as the velocity of the ball. (2)

1.2 The velocity-time graph below represents the motion of an object under the influence of gravitational force only.



The displacement of the object after 3t seconds is…

A vt

B -vt

C $-\frac{3}{2}vt$

D zero (2)

1.3 Ball **A** of mass **m** is projected vertically upwards from the ground with an initial velocity **v**. It rises to a maximum height **h** above the ground.

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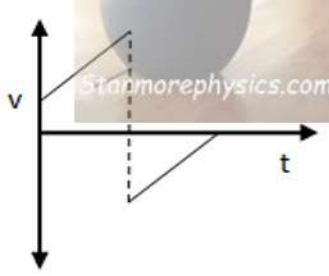
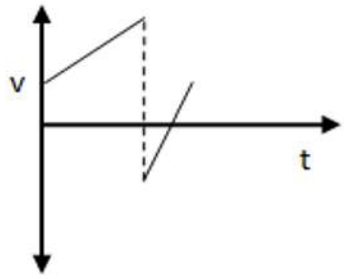
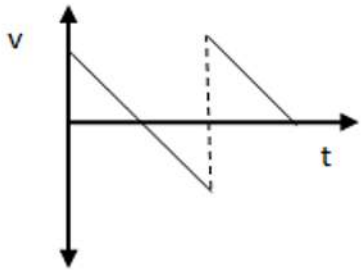
Ball **B** of mass **½m** is now projected vertically upwards from the ground with an initial velocity of **2v**. Ignore the effects of air friction.
What is the maximum height above the ground to which Ball B rises?

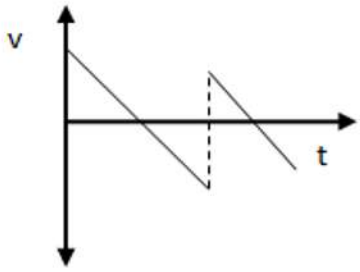
A h
B $\sqrt{2}h$
C 2h
D 4h (2)

1.4 An object is thrown vertically downwards towards the ground from height h, with a velocity v. The object strikes the ground and bounces upwards. It is caught when it reaches its maximum height after the bounce.
Which of the following graphs for velocity versus time best represents the motion of the object?

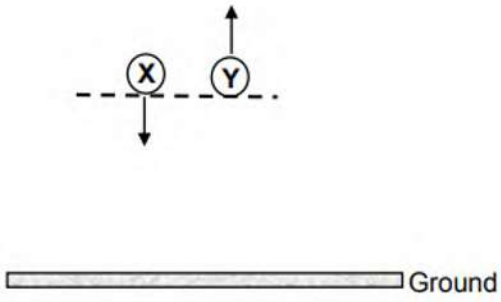
A


B


C


D


1.5 Balls X and Y have the same mass are thrown from a certain height. Ball X is thrown



How do the speeds, v_X and v_Y, and the kinetic energies, E_{kX} and E_{kY}, of the balls compare when they strike the ground?

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	SPEED	KINETIC ENERGIES
A	$v_X < v_Y$	$E_{kX} > E_{kY}$
B	$v_X > v_Y$	$E_{kX} > E_{kY}$
C	$v_X = v_Y$	$E_{kX} = E_{kY}$
D	$v_X < v_Y$	$E_{kX} < E_{kY}$

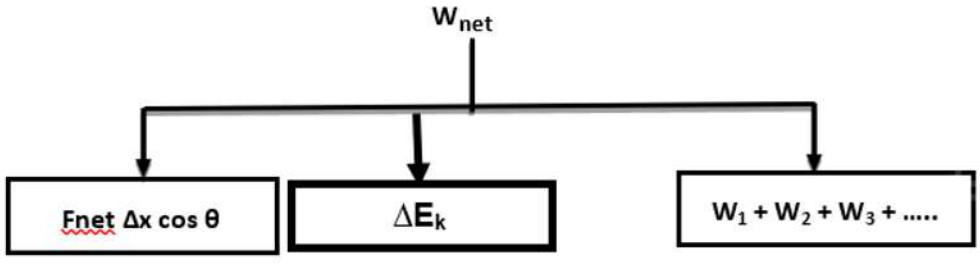
WORK, ENERGY AND POWER

The work done on an object by a constant force F is $F\Delta x\cos\theta$,
where F is the magnitude of the force (N)
Δx is the magnitude of the displacement (m)
θ is the angle between the force and the displacement. ($\theta = 0^0$ or $\theta = 180^0$)

ZERO WORK	POSITIVE WORK	NEGATIVE WORK
The net work done on an object that is moving at constant velocity is zero. No work is done when a force is exerted on the object, but the object does not move. No work is done by forces acting perpendicular to the surface. ($\theta = 90^o$)	Occurs when an object moves in the direction of the force. It occurs when $\theta = 0^o$ θ lies between = 0° & 90° When positive work is done on an object, the energy of the object increases.	Is done by the force which acts against the motion of an object, e.g., frictional force. $\theta = 180^o$ When negative work is done on an object, the energy of the object decreases.

NET WORK (W_{net})

It is the total work done by all the forces acting on an object.
Use any one of the methods given below.



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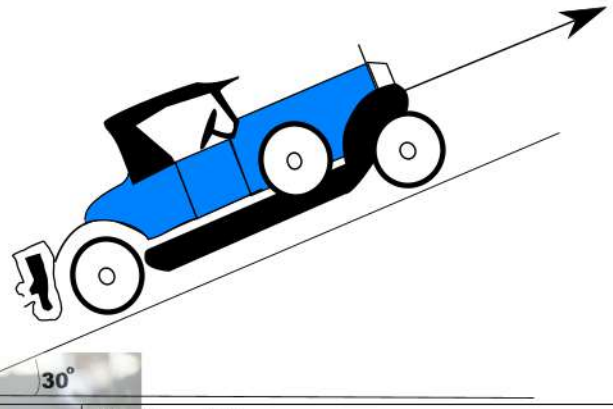
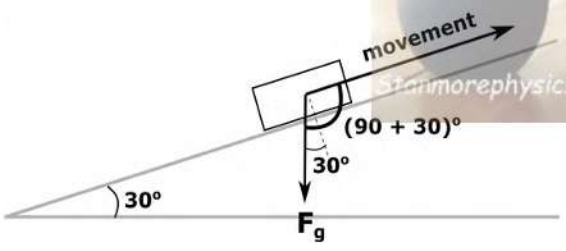
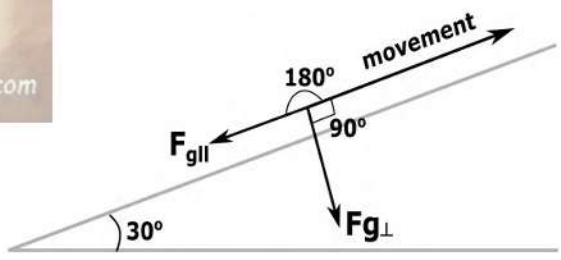
Example

A 10 kg toy car is pulled 3 m up an inclined plane. The plane is at a 30° angle to the ground and the height is
1,5 m. Calculate the work done by gravity.



Method 1	Method 2
	
$W_g = F_g\Delta x\cos\theta$ $= 98(3)\cos(90° + 30°)$ $= 98(3)\cos(120°)$ $= -147{,}00J$	$W_g = W_{g\parallel} + W_{g\perp}$ $= F_{g\parallel}\Delta x\cos\theta + 0$ $= (98\sin30°)(3)\cos 180°$ $= 49(3)\cos 180°$ $= -147{,}00J$

WORK-ENERGY THEOREM

States: The net work done on an object is equal to the change in the object's kinetic energy.

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

Work is ONLY done by forces acting parallel to the direction of motion of an object.
The net work done on an object that is moving at constant velocity is zero.
The net work done changes the motion of a body.

WHAT IS A CONSERVATIVE FORCE?

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

If a conservative force is the only force acting on an object during its motion, the mechanical energy of the object is conserved.

$$(U + k)_A = (U + K)_B$$

$$(mgh + \frac{1}{2}mv^2)_A = (mgh + \frac{1}{2}mv^2)_B$$

Examples of conservative forces are the gravitational force and electrostatic force.

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WHAT IS A NON-CONSERVATIVE FORCE?

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

If a non-conservative force acts on an object, the mechanical energy of the object will not be conserved.

Examples of non-conservative forces are **F**rictional force, air resistance, an **A**pplied pulling or pushing force or **T**ension in a rope. (**FAT**)

Work done by all non-conservative forces is equal to the change in the total mechanical energy of the object.

Wnc = ΔEp + ΔEk

POWER

Power is the rate at which work is done.

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

It is a scalar quantity with SI Units Watts (W)

The average power is the product of the force and the average speed of an object.

$$P_{ave} = F \cdot v_{ave}$$

Average power is required to keep an object moving at a constant velocity.

ENERGY PRINCIPLES

There are THREE energy principles.

Work-energy theorem	Principle of Conservation of Mechanical Energy	Work done by non-conservative forces
• $W_{net} = \Delta K$ • This one considers all forces acting on the object (conservative and non-conservative forces)	• The total mechanical energy in an isolated system remains constant. • A **system is isolated** when the net external force (excluding the gravitational force) acting on the system is zero. • **$(U + K)_A = (U + K)_B$** • This is ONLY applicable if all other forces are ignored, and the gravitational force is the only force acting.	• $W_{nc} = \Delta K + \Delta U$ • This one ignores conservative forces. • Only considers non-conservative forces.

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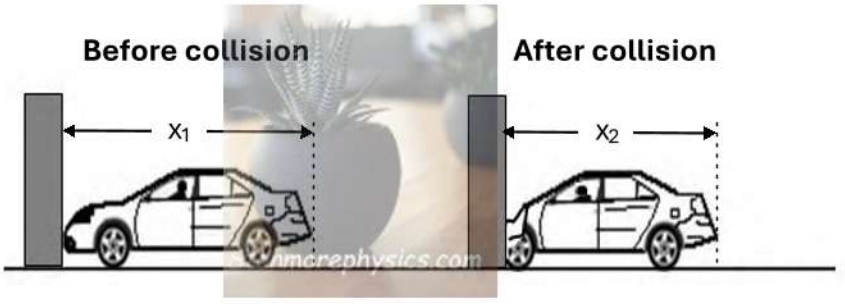
WORKED EXAMPLE 1

In order to measure the net force involved during a collision, a car is allowed to collide head-on with a flat, rigid barrier. The resulting crumple distance is measured. The crumple distance is the length by which the car becomes shorter in coming to rest.

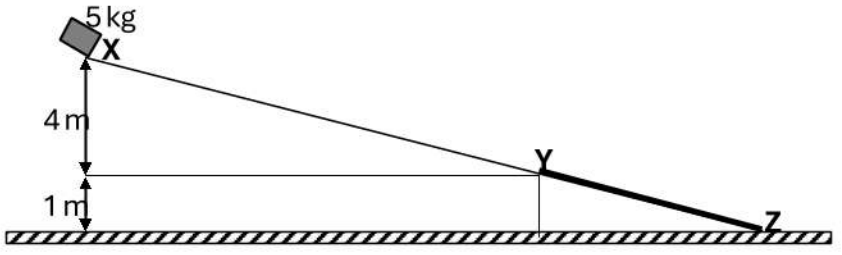
In one of the tests, a car of mass 1 200 kg strikes the barrier at a speed of 20 $m \cdot s^{-1}$. The crumple distance, $(x_1 - x_2)$, is measured as 1,02 m. (Ignore the effects of frictional forces during crumpling.)



1.1 Assume that the net force is constant during crumpling.

USE THE WORK-ENERGY THEOREM to calculate the magnitude of the net force exerted on the car as it is brought to rest during crumpling. (4)

1.2 A 5 kg rigid crate moves from rest down path **XYZ** as shown below (diagram not drawn to scale). Section **XY** of the path is frictionless. Assume that the crate moves in a straight line down the path.



K

1.2.1 Use the principle of the conservation of mechanical energy to calculate the speed of the crate when it reaches point **Y**. (4)

On reaching point **Y**, the crate continues to move down section **YZ** of the path. It experiences an average frictional force of 10 N and reaches point **Z** at a speed of 4 $m \cdot s^{-1}$.

1.2.2 Use the WORK-ENERGY THEOREM to calculate the length of section **YZ**. (5)

SOLUTION

1.1 $W_{net} = \Delta E_k$

$F_{net}\Delta x\cos\theta = ½ m(v_f^2 - v_i^2)$

$F_{net}(1,02)\cos180° = ½ (1\ 200)(0 - 20^2)$

$F_{net} = 235\ 294,12$ N (4)

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1.2.1 $E_{mechanical}$ at X = $E_{mechanical}$ at Y

$(E_p + E_k)_X = (E_p + E_k)_Y$

$(mgh + ½ mv^2)_X = (mgh + ½ mv^2)_Y$

$\underline{5(9,8)(5)} + ½(5)(0^2) = \underline{(5)(9,8)(1) + ½(5)v_f^2}$

$v = 8,85\ m\cdot s^{-1}$ (4)

1.2.2 $W_{net} = \Delta K$

$W_w + W_f = ½m(v_f^2 - v_i^2)$

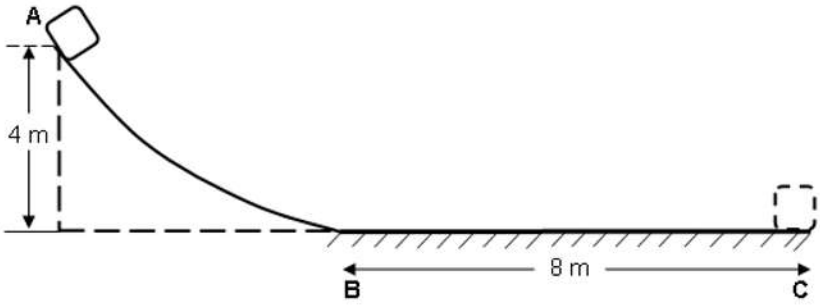
$mg\Delta y\cos 0° + f\Delta x\cos 180° = ½\ m(v_f^2 - v_i^2)$

$(5)(9,8)(1)(1) + (10)\Delta x(-1) = ½(5)(4^2 - 8,85^2)$

$\Delta x = 20,48\ m$ (5)

WORKED EXAMPLE 2

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

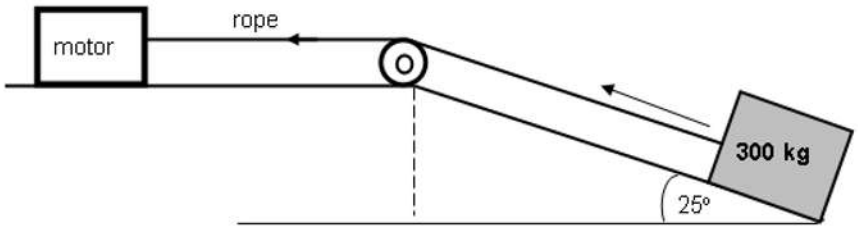


2.1.1 State the principle of conservation of mechanical energy in words. (2)

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

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

2.2 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.



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

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The crate moves up the incline at a constant speed of 0,5 $m \cdot s^{-1}$.

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

SOLUTION

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

2.1.2 No (1)

2.1.3 $(E_p + E_k)_A = (E_p + E_k)_B$

$(mgh + ½ mv^2)_A = (mgh + ½ mv^2)_B$

$(10)(9,8)(4) + 0 = 0 + ½ (10) v_f^2$

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

$W_{net} = \Delta K$

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

$f(8)\cos 180^o = ½ (10)(0 – 8,85^2)$

$f = 48,95 \ N$

(6)

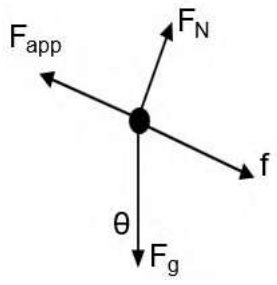
2.2.1 $f_k = \mu_k N$

$= \mu_k mg\cos\theta$

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

$= 506,26 \ N$ (3)

2.2.2



$F_{net} = 0$

$F_A + (-F\sin\theta) + (-f) = 0$ ✓

$F_A – (300)(9.8)\sin 25^o$ ✓ $– 506.26$ ✓ $= 0$

$F_A = 1748.76 \ N$

$P_{ave} = Fv_{ave}$ ✓

$= 1748.76 \times 0.5$ ✓

$= 874.38 \ W$ ✓

(6)

EXAMPLE 3

A skier of mass 100 kg starts from rest at point B, which is 30 m below point A, and moves down a frictionless curve to point C.

The skier passes point C and moves up a rough plane inclined at 30° to the horizontal. Ignore the effects of air friction.

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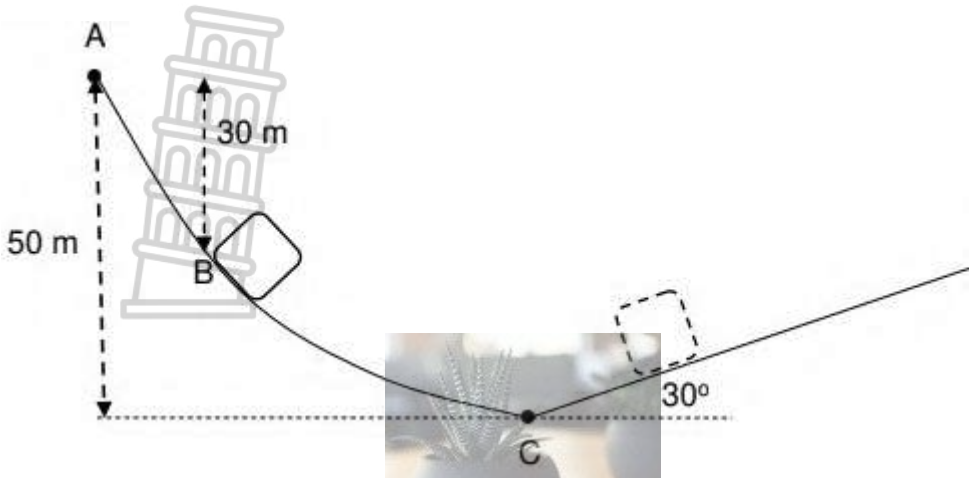

3.1 Write down the energy conversion of the skier from point B to C. (1)

3.2 Define the term isolated system. (2)

3.3 Use ENERGY PRINCIPLES to calculate the speed of the skier at point C. (4)

3.4 The skier experiences a frictional force of 200 N on the inclined plane.

3.4.1 Calculate the maximum height reached by the skier from point C. (6)

3.4.2 If the angle is reduced to 20°, will the maximum height be GREATER THAN, SMALLER THAN or EQUAL TO the maximum height calculated in QUESTION 3.4.1?
Give a reason for the answer. (2)

[13]

SOLUTIONS

3.1 Potential energy to kinetic energy (1)

3.2 A system in which the net external forces acting on the system is zero.✓✓ (2)

3.3 $\frac{1}{2} mv_i^2 + mgh_i = \frac{1}{2} mv_f^2 + mgh_f$✓

$(100)(9,8)(20) + 0$ ✓ $= 0 + (\frac{1}{2})(100)(v_f^2)$ ✓

$v_f = 19,80\ m.s^{-1}$✓ (4)

3.4.1 $W_{net} = \Delta E_k$ ✓

$W_{net} = (\frac{1}{2})(100)(0)^2 - (\frac{1}{2})(100)(19,80)^2$✓

$W_{net} = -19\ 602\ J$

$W_{net} = W_G + W_f$

$-19\ 602$✓ $= (100)(9,8)(\sin 30°)(\Delta x)(\cos 180°) + (200)(\Delta x)(\cos 180°)$✓

$\Delta x = 28,41\ m$

$h = (28,41)(\sin 30°)$✓

$h = 14,21\ m$✓ (6)

3.4.2 Smaller than✓

The net force acting on the object will decrease. (2)

[15]

ACTIVITIES

QUESTION 1: MULTIPLE CHOICE QUESTIONS

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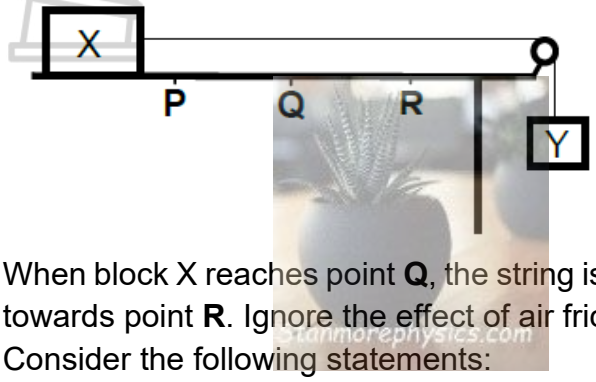
1.1 Block X is placed on a horizontal table and is connected to block Y by a light inextensible string passing over a frictionless pulley, as shown below.
A constant frictional force acts on block X while it moves to the right. **P**, **Q** and **R** are points on the table such that the distance from **P** to **Q** is equal to that from **Q** to **R**.



When block X reaches point **Q**, the string is cut and block X continues to move towards point **R**. Ignore the effect of air friction.
Consider the following statements:
(i) The work done by the frictional force acting on block X is greater when the block moves from point **P** to point **Q** than when the block moves from point **Q** to point **R**.
(ii) Both the momentum and kinetic energy of block X decrease when the block moves from point **Q** to point **R**.
(iii) The total mechanical energy of block X remains constant when the block moves from point **Q** to point **R**.

A (i) only
B (ii) only
C (i) and (ii) only
D (ii) and (iii) only (2)

1.2 A ball rolls from point **A** to **D** as shown in the diagram below. The sections **AB** and **CD** are frictionless, while **BC** is rough. Which ONE of the following statements is TRUE?

A The total mechanical energy changes when the ball rolls from B to C.
B The total mechanical energy of the ball decreases from C to D
C The total mechanical energy of the ball decreases from C to D
D Kinetic energy is conserved during the complete motion from A to D. (2)

1.3 A mass is lifted from rest on the ground to point H as shown below.

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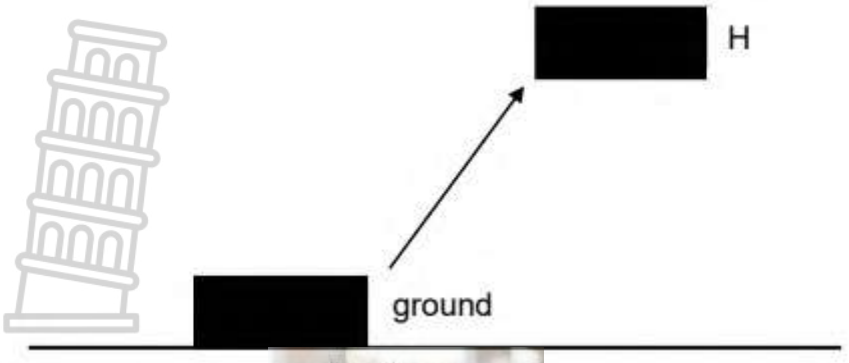
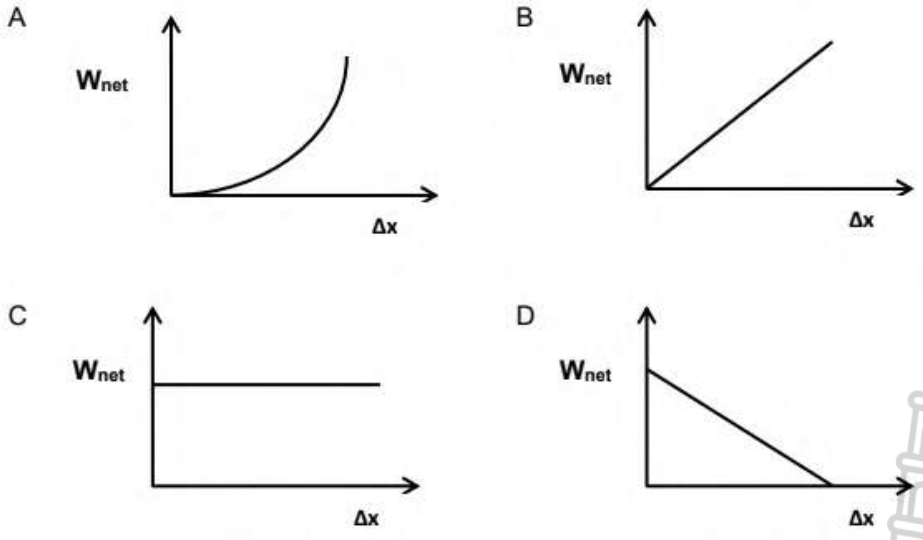


P is the increase in gravitational potential energy of the mass.
K is the kinetic energy of the mass at point H. (Ignore the effects of friction.)
Which expression is equal to the mechanical work done on the mass to move it from the ground to point H?

A P + K
B P – K
C K – P
D P x K (2)

1.4 A car moves from rest in a straight line under the influence of a constant net force.
Which ONE of the following graphs best represents the net work done (W_{net}) on the car in relation to its displacement (Δx)?



(2)
[8]

STRUCTURED QUESTIONS
QUESTION 2

A boy on roller-skates moves at a constant velocity in an easterly direction along a frictionless horizontal part AB of a track carrying a parcel. He decides to increase his velocity by throwing the parcel horizontally away from him.

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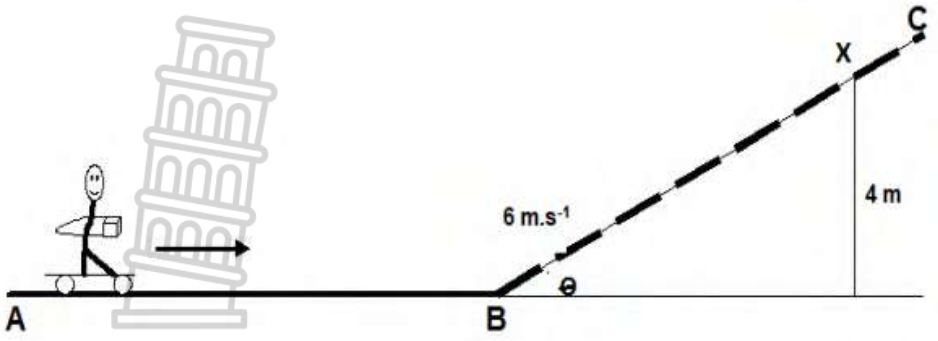


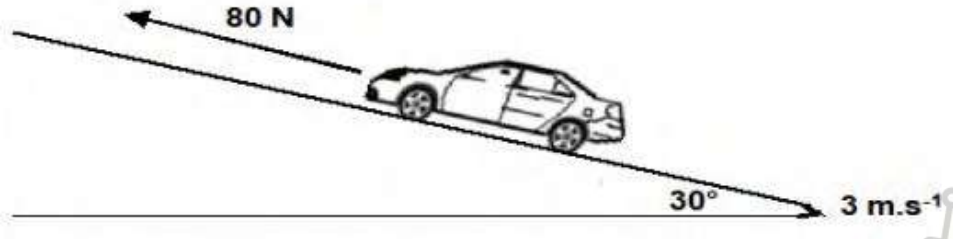
2.1 In which direction must the parcel be thrown to cause a maximum increase in the velocity of the boy? (1)

2.2 Name and define in words the Law of physics that was applied in QUESTION 2.1. (3)

He reaches point B at a velocity of 6 $m \cdot s^{-1}$ and continues to move up a rough section BC of the track and comes to rest at position X, 4 m above the ground as shown in the diagram below. A constant frictional force of 40 N acts on the roller skates. The combined mass of the boy and roller skates is 57 kg.

2.3 Calculate the value of Θ of the inclined plane. (5)

2.4 A remote-controlled car of mass 4 kg is driven up an inclined plane which makes an angle of 30° with the horizontal by an average forward force of 80 N as shown in the diagram below. The car experiences a constant frictional force of 15 N, as it moves up the inclined plane. The speed of the car at the bottom of the inclined plane is 3 $m \cdot s^{-1}$



Use energy principles to calculate the speed of the car after it has travelled 5 m up the inclined plane. (6)

[15]

QUESTION 3

A 850 kg roller-coaster is released from rest at point A on the track shown in the figure below. It travels along the straight decline section A to B and continues along the curved section B to C where the brakes are then applied from point C. The roller-coaster comes to a stop at D, 50 m from C. The coefficient of kinetic friction of the track is 0,42.

Ignore the rotational effects of the roller coaster's wheels.

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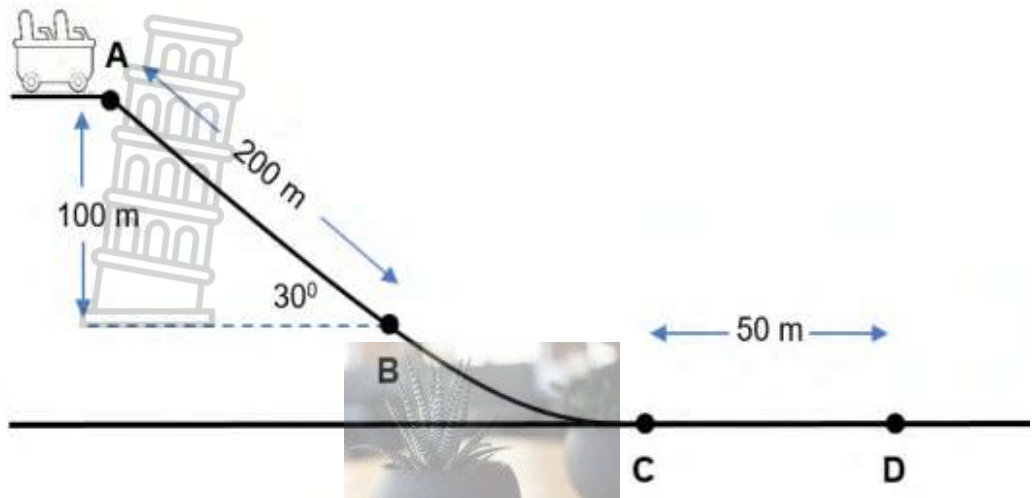

3.1 State the work-energy theorem in words. (2)

3.2 Draw a labelled free body diagram showing all the forces acting on the roller-coaster as it moves from A to B. (3)

3.3 Calculate the net work done on the roller-coaster as it moves from A to B. (5)

3.4 Along the curved section BC, the kinetic energy of the roller-coaster decreases by 108 950 J. The brakes are then applied at point C.
Calculate the magnitude of the average braking force required by the braking system to bring the roller-coaster to a stop at point D. Use ENERGY PRINCIPLES ONLY. (7)

[17]

QUESTION 4

A 5 kg block is released from rest from a height of 5 m and slides down a frictionless incline to point **P** as shown in the diagram below. It then moves along a frictionless horizontal portion **PQ** and finally moves up a second rough inclined plane. It comes to a stop at point **R** which is 3 m above the horizontal.

The frictional force, which is a non-conservative force, between the surface and the block is 18 N.

4.1 Using ENERGY PRINCIPLES only, calculate the speed of the block at point **P**. (4)

4.2 Calculate the angle (θ) of the slope **QR**. (7)

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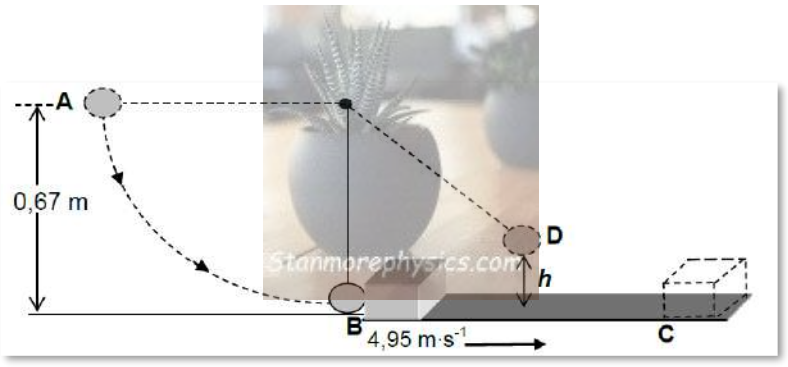
QUESTION 5

5.1 The diagram below shows a steel ball of mass 5 kg, suspended from a string of negligible mass released from rest at point A 0,67 m from its lowest point, B. As the steel ball swings through its lowest position at point B, it collides with a stationary block of mass 2 kg. Immediately after the collision, the block moves to the right with a velocity of 4,95 m·s^{-1} on frictionless track BC. Ignore frictional effects and assume no loss of mechanical energy occurs during the collision.



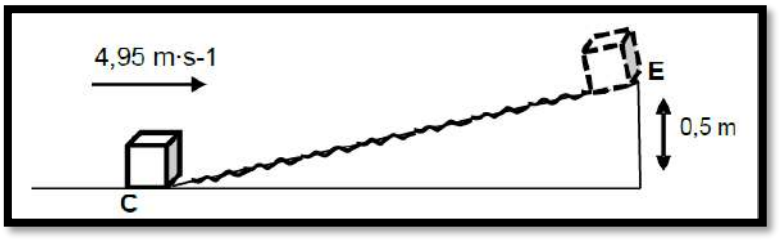
5.1.1 Explain what is meant by *isolated system*. (2)

5.1.2 Calculate the velocity of the steel ball immediately after collision. (7)

5.1.3 Calculate the maximum height, ***h***, the steel ball reached at point **D** after collision. (5)

5.1.4 Give a reason why the ball is NOT reaching its original height of 0,67 m. (2)

5.2 The block moves from point C at a speed of 4,95 m·s^{-1} up a rough inclined plane to point E which is 0,5 m above the horizontal as shown in the diagram below.



5.2.1 State *work-energy theorem* in words. (2)

5.2.2 The block reaches point **E** with a speed of 2 m·s^{-1}. Use energy principles to calculate the work done by the frictional force when the 2 kg block moves from point **C** to point (4)

[22]

QUESTION 6

An electric motor pulls a 20 kg crate from rest at point A up an inclined plane by means of a light inextensible rope. The inclined plane makes an angle of 18° with the horizontal. B, C and D are points

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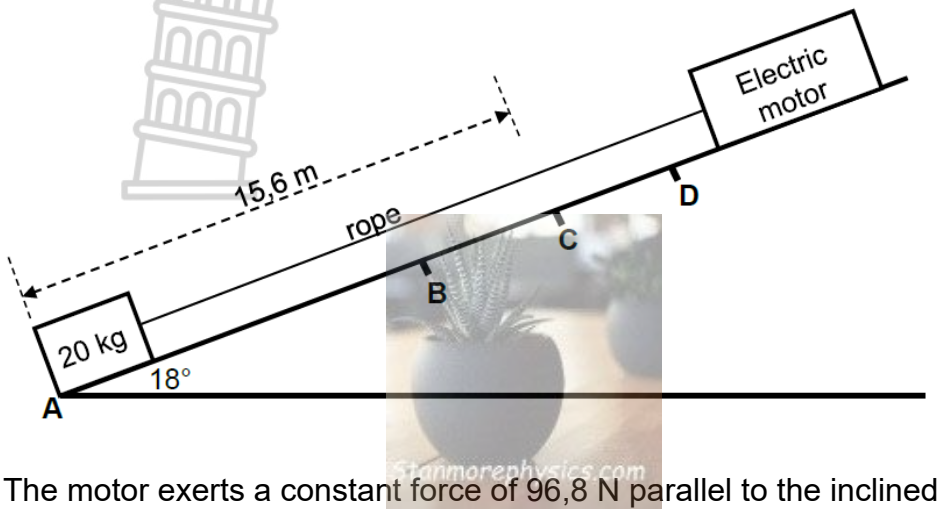
on the inclined plane and the distance between points A and C is 15,6 m, as shown in the diagram below.



The motor exerts a constant force of 96,8 N parallel to the inclined plane on the rope
A constant frictional force of 13,5 N acts on the crate as it moves on the inclined plane.

6.1 Define a non-conservative force. (2)

6.2 Use ENERGY PRINCIPLES to calculate the speed of the crate when it reaches point C. (5)

6.3 Calculate the minimum average power dissipated by the electric motor to pull the crate from point A to point C. (3)

When the crate reaches point C, the rope breaks. The crate continues moving up the inclined plane, comes to a stop at point D, and then slides down the plane past point B.

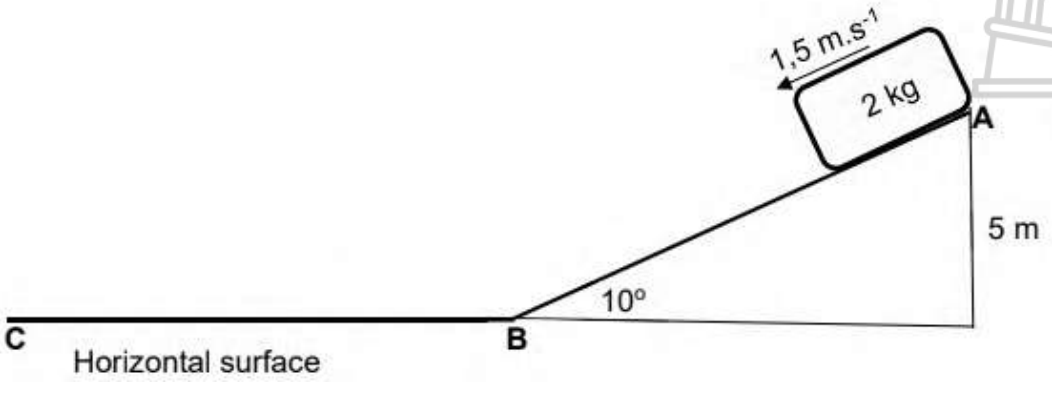
6.4 Draw a labelled free-body diagram for the crate as it slides down the plane past point **B**. (3)

6.5 Draw a velocity-time graph for the entire motion of the crate starting from point **A** until it passes point **B** again on its motion down the inclined plane. (4)

[17]

QUESTION 7

In the diagram below, a small object of mass 2 kg is sliding at velocity of 1,5 m.s^{-1} down a rough plane inclined at 10o to the horizontal surface.



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At the bottom of the plane, the object continues sliding onto the rough horizontal surface and eventually comes to a stop. The frictional force acting on the block while it slides along the inclined surface is 2,5 N.
The coefficient of kinetic friction between the object and the surface is the same for both the inclined surface and the horizontal surface.

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

7.2 Draw a labelled free-body diagram of all the forces acting on the block while it is on the inclined surface. (3)

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

7.4 Use ENERGY PRINCIPLES to calculate the:

7.4.1 Speed of the block at the bottom of the incline at point B (5)

7.2.2 Distance BC that the block moves before it comes to a stop (5)

[17]

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CHEMICAL EQUILIBRIUM

Open System

An open system is the one in which mass or energy can be transferred into or out of the system during a reaction. An open system continuously interacts with its environment.

Figure 1 below shows 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.

Figure 1: open system

Closed System

For equilibrium to be reached, the reaction must be reversible, and the change has to take place in a closed system.
A *closed system* is one in which the system is isolated from its surrounding environment in such a way that there is no mass transferred into or out of the system.

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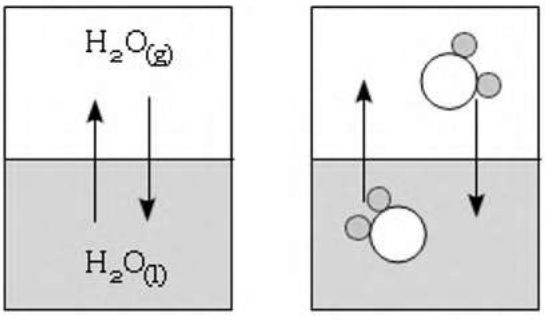

Figure 2: closed system

This means that the container must be sealed if gases are present in the system.
In Figure 2, evaporation takes place. Also, droplets of water form 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:
"⇌" means *reversible reaction***.**

"*Equilibrium***"** means that the rate of forward reaction is EQUAL to the rate of the reverse reaction.

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 increases. 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* level: So small as to be visible only with a microscope

Factors Affecting Equilibrium
Concentration
Temperature
Pressure (gases only)

If any of the above conditions (factors) are changed, the forward or reverse reaction will be favoured until a new equilibrium is established.

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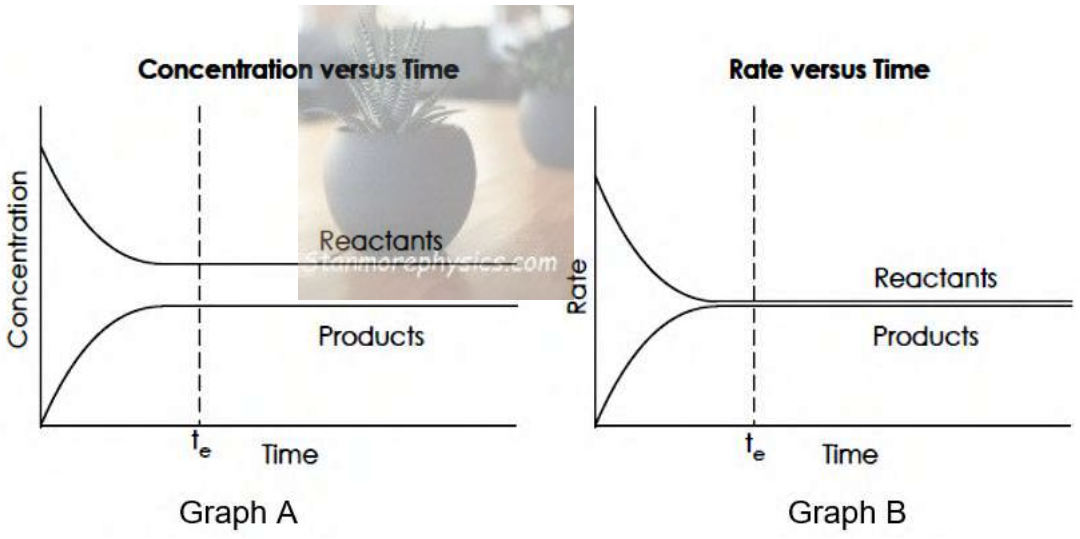
Le Chatelier's Principle: When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.

Graphical Representation

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 (graph A), while the rate of forward and reverse reactions are equal (graph B).

General Application of Le Chatelier's Principle

NB: If a catalyst is added initially, then the equilibrium position is reached much quicker.

Practical Demonstration of the Common-ion Effect

If a compound is added to a system in equilibrium and that compound contains an ion that is already present in the equilibrium system, then the reaction that uses up that ion will be favoured.

$NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$

By adding HCl(l), the concentration of $Cl^-(aq)$ ions 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 Example 1

1. A mixture of 5 moles of H_2 and 6 moles of $I_2(g)$ is placed in a sealed container of $2dm^3$ at a temperature of 458ºC.The balanced chemical equation for this reaction is:

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$H_2(g) + I_2(g)$ $\rightleftharpoons$ 2HI(g)

Equilibrium is reached in a certain time frame. At equilibrium,there are 4 moles of HI(g) in the container.Calculate the concentrations of $H_2(g)$ and $I_2(g)$ at equilibrium.

SOLUTION

$H_2(g)$ + $I_2(g)$ $\rightleftharpoons$ 2HI(g)

Ratio	1	1	2
*n***I**nitial (mol)	5	6	0
n**C**hange (mol)	**(-1a) -2**	**(-1a) -2**	**(+2a)** ✓ **+4**✓
n**E**quilibrium (mol)	3	4 ✓	4
Volume (dm^3)	2	2	2
[equilibrium] mol/dm^3	1,5	2	2✓

Worked example 2

2. The following reaction takes place in a 250 cm^3 container at 400 K

2NO(g) +Br_2 (g) $\rightleftharpoons$ 2NOBr (g)

The reaction initially contains 0.25moles of NO and 0.1 moles Br_2. When equilibrium is reached, it is found that 80% of NO remained at, calculate the concentrations at equilibrium.

SOLUTION

2NO(g) +Br_2 (g) $\rightleftharpoons$ 2NOBr (g)

Ratio	2	1	2
*n***I**nitial (mol)	0.25	0.1	0
n**C**hange (mol)	(-2y) -0.5	(-1y) -0.25	(+2y) +0.5✓
n**E**quilibrium (mol)	0.2✓	0.75	0.5✓
Volume (dm^3)	0.25	0.25	0.25
[equilibrium] mol/dm^3	0.8	0.3	0.2✓

No. of moles at equilibrium

$\frac{80}{100} \times 0.25 = 0.2$ ✓

Worked example 3

3.1 The expression for the equilibrium constant (K_C) of a hypothetical reaction is given as follows:

$$Kc = \frac{[D]^2\,[C]}{[A]^3}$$

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Which ONE of the following equations for a reaction at equilibrium matches the above expression?

A $3A(s) \rightleftharpoons C(g) + 2D(g)$

B $3A(\ell) \rightleftharpoons C(aq) + 2D(aq)$

C $3A(aq) + B(s) \rightleftharpoons C(g) + D_2(g)$

D $3A(aq) + B(s) \rightleftharpoons C(aq) + 2D(aq)$ (2)

3.2 For reaction: $PCl_5\ (g) \rightleftharpoons PCl_3\ (g) + Cl_2\ (g)$

0,375 mol of PCl_5 (g) is heated in a closed 1 dm^3 container. The equilibrium mixture contains 0,125 mol of chlorine.

3.2.1 Calculate the equilibrium constant for the decomposition of PCl_5 at this temperature (6)

3.2.2 What does the Kc value for this forward reaction tell us about the equilibrium (2)

SOLUTION

3.1 D✓✓

3.2.1

$PCl_5\ (g) \rightleftharpoons PCl_3\ (g) + Cl_2\ (g)$

Ratio	1	1	1
*n*Initial (mol)	0.375	0	0
nChange (mol)	(-1x) -0.125	(-1x) -0.125	(+1x) 0.125
nEquilibrium (mol)	0.25	0.125	0.125
Volume (dm^3)	1	1	1
[equilibrium] mol/dm^3	0.250	0.125	0.125

$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$ ✓

$= \frac{(0,125)(0,125)}{(0,25)}$ ✓

$= 6,25 \times 10^{-2}$ ✓ (6)

3.2.2 At equilibrium the concentration of products is lower than the concentration of reactants✓✓ (2)

[10]

Worked example 4

4 The rapidly increasing human population is resulting in an ever-increasing demand for food. To meet this demand, farmers apply fertiliser to the same cultivated land EACH YEAR. Sulphuric acid is an important substance used in the manufacture

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fertilisers. The equation below represents one of the steps in the industrial preparation of sulphuric acid.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$

4.1 Define the term *chemical equilibrium*. (2)

4.2 Is the forward reaction exothermic or endothermic? Give a reason for your answer. (2)

4.3 How will EACH of the following changes affect the number of moles of $SO_3(g)$ at equilibrium?

Choose from INCREASES, DECREASES or REMAINS THE SAME.

4.3.1 The addition of more oxygen. (1)

4.3.2 An increase in temperature

Use Le Chatelier's principle to explain the answer. (4)

4.4 The reaction above, reaches equilibrium at a certain temperature in a 2 dm^3 closed container. On analysis of the equilibrium mixture, it is found that 0,6 mole of $SO_2(g)$, 0,5 mole of $O_2(g)$ and 0,4 mole of $SO_3(g)$ are present in the container.

4.4.1 List THREE changes that can be made to this equilibrium to increase the yield of $SO_3(g)$. (3)

4.4.2 The temperature is NOW increased and the reaction is allowed to reach equilibrium for the second time at the new temperature. On analysis of this new equilibrium mixture, it is found that 0,2 mole of $SO_3(g)$ is present in the container.

Calculate the equilibrium constant for this reaction at the new temperature. (8)

[21]

SOLUTION

4.1 (The stage in a chemical reaction when the) rate of the forward reaction equals the rate of the reverse reaction. ✓✓

OR

(The stage in a chemical reaction when the) concentrations of reactants and products remain constant. ✓✓

4.2 Exothermic ✓

$\Delta H < 0$ **OR** ΔH is negative ✓

4.3.1 Remains the same ✓

4.3.2 Decrease✓

• When the temperature is increased the reaction that will oppose this increase/decrease the temperature will be favoured.

OR

• The forward reaction is exothermic. ✓

• An increase in temperature favours the endothermic reaction. ✓

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• The reverse reaction is favoured. ✓

4.4.1 ANY THREE:

• Decrease temperature ✓
• Increase pressure✓
• Increase concentration of both/any one of reactants. ✓
• Remove SO_3 continuously

4.4.2 **CALCULATIONS USING MOLES**

Mark allocation:

• Change in $n(SO_3)$ = 0,2 (mol)
• Ratio $n(SO_2) : n(O_2) : n(SO_3)$ = 2 : 1: 2
• $n(SO_2)$ at equilibrium = initial + change
• $n(O_2)$ at equilibrium = initial + change
• Divide three equilibrium amounts by 2 (calculation of concentration)
• K_c expression
• Substitution into K_c expression
• Final answer = 0,21

OPTION 1

Amount of SO_3 reacted = 0,2 mol
$n(SO_2$ formed) = 0,2 mol
$n(O_2$ formed) = ½ $n(SO_3$ formed) = 0,1 mol
At equilibrium: $n(SO_2)$ = 0,6 + 0,2 = 0,8 mol
$n(O_2)$ = 0,5 + 0,1 = 0,6 mol

$$\left.\begin{aligned} c(SO_3) &= \frac{n}{V} = \frac{0,2}{2} = 0,1\ mol\cdot dm^{-3} \\ c(SO_2) &= \frac{n}{V} = \frac{0,8}{2} = 0,4\ mol\cdot dm^{-3} \\ c(O_2) &= \frac{n}{V} = \frac{0,6}{2} = 0,3\ mol\cdot dm^{-3} \end{aligned}\right\} ✓\ \text{divide by/}\textit{gedeel deur}\ 2$$

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} ✓ = \frac{(0,1)^2}{(0,4)^2(0,3)} ✓ = 0,21\ ✓\ (0,208)$$

OPTION 2

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	SO_2	O_2	SO_3	
Molar ratio/*Molverhouding*	2	1	2	
Initial quantity (mol) *Aanvanklike hoeveelheid (mol)*	0,6	0,5	0,4	Ratio/*verhouding* ✓
Change (mol)/*Verandering (mol)*	0,2	0,1	0,2 ✓	
Quantity at equilibrium (mol) *Hoeveelheid by ewewig (mol)*	0,8 ✓	0,6 ✓	0,2	
Concentration ($mol \cdot dm^{-3}$) *Konsentrasie ($mol \cdot dm^{-3}$)*	0,4	0,3	0,1	Divide by 2 *Gedeel deur 2* ✓

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} \checkmark = \frac{(0,1)^2}{(0,4)^2(0,3)} \checkmark = 0,21 \checkmark \ (0,208)$$

Equilibrium Constant (K_c)

The equilibrium constant can be defined as being an expression, or ratio, of the concentration of the products over the concentration of the reactants for a reaction that is in equilibrium.

$$K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$$ (K_c is a number without units)

The brackets "[ ]" represent the concentration of the species ($mol.dm^{-3}$).
The equilibrium constant (K_c) indicates the yield of a reaction. A large K_c value indicates a large yield, i.e. at equilibrium there is a relatively small amount of reactants compared to the products.

A small K_c indicates a low yield, i.e. at equilibrium there is a relatively small amount of products compared to the reactants.
The equilibrium constant (K_c) is temperature dependent.
When writing the K_c expression, first balance the equation and then IGNORE all solids and pure liquids since their concentrations are constant.

Consider the following chemical reaction that reached equilibrium at 90 ^{0}C.
$2A(g) + 3B(g) \rightleftharpoons 3C(g) + D(g)$

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.

$$\frac{[C]^3[D]}{[A]^2[B]^3} = K_C$$

Consider the following chemical reactions:

REACTION 1: $N_2(g)+3H_2(g) \rightleftharpoons 2NH_3(g)$

$$K_c = \frac{[NH3]^2}{[N2][H2]^3}$$

This is an example of a homogeneous equilibrium because all the substances in the system are in the same phase.
REACTION 2: $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

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$K_c = [CO_2]$

NB: The concentrations of all the solids are constant and taken as 1, it will not change the Kc value

REACTION 3: $HCl(aq) + H_2O_{(l)} \rightleftharpoons Cl^-(aq) + H_3O^+(aq)$

$K_C = \frac{[Cl^-][H_3O^+]}{[HCl]}$

NB: Solvents of dilute solutions remain constant and are taken as 1; $[H_2O]$ remains constant and as a rule does not appear in the K_c expression.

If substances of different phases occur in the system, we say it is a heterogeneous equilibrium.

IMPORTANT:
The K_c value indicates to what extent reactants have changed into products by the time equilibrium is reached.
This is of particular importance in the high K_c evaluation of the efficiency of industrial processes:
A high K_c value (K_c >1) indicates that there is a lot of product has been formed and there is higher concentration of products than reactants (the equilibrium lies to the right).
A low K_c value (K_c <1) indicates that there is a higher concentration of reactants than products are present (the equilibrium lies to the left).
K_c = 1 indicates equal concentrations of reactants and products.

Increase in Temperature
Endothermic reaction is favoured
Forward reaction is endothermic
[Products] > [Reactants]
K_c value Increases

Decrease in Temperature
Exothermic reaction is favoured
Reverse reaction is exothermic
[Products] < [Reactants]
K_c value decreases

Graphs for Chemical Equilibrium

1. Changing the Concentration of Reactants or Products
Increasing concentration of a reactant will favour 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.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

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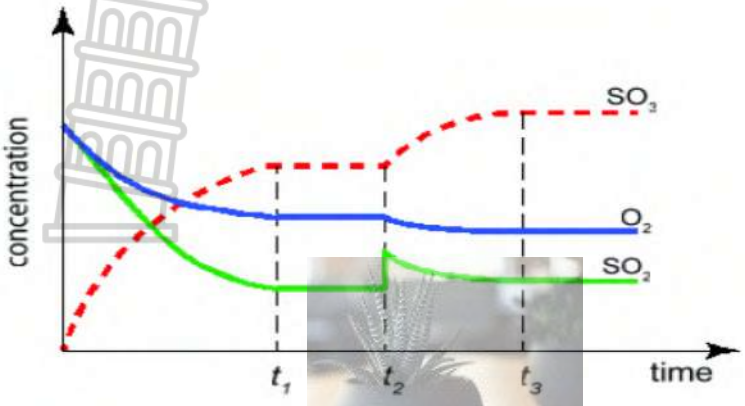
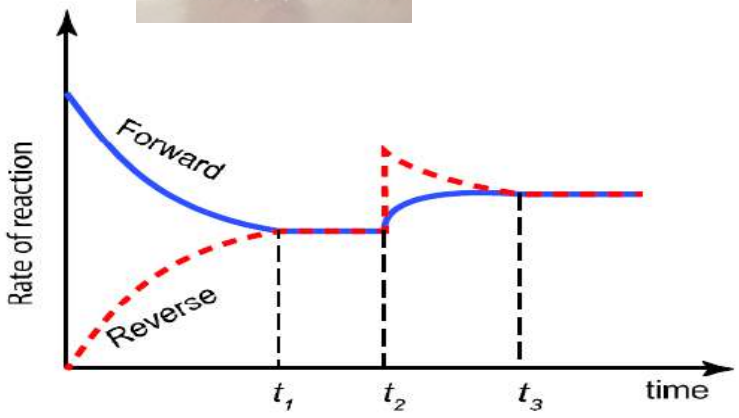
At time t_2, the concentration of SO_2 is increased



Forward reaction will be favoured to re-establish the new equilibrium at a higher rate.



NB: "Notice that an increase in a concentration looks like and NOT like

Also, a decrease in concentration looks like and **NOT li**ke

2. 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 re-establish 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. Consider the following reaction:

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)\ \Delta H < 0$

At time t_2, the temperature of the container is increased. Increasing the temperature favours the endothermic reaction, therefore the reverse reaction is favoured, concentration of the reactants will increase and that of products will decrease.

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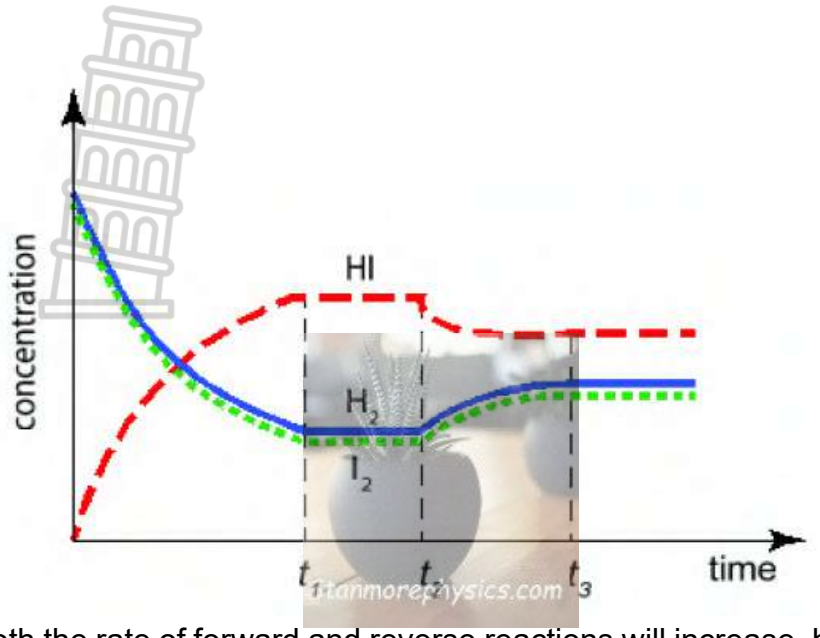
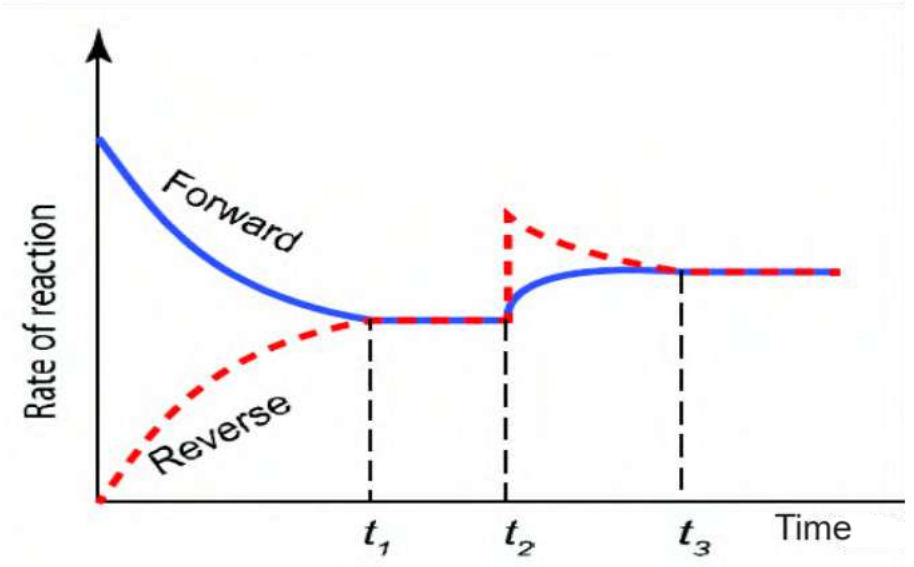


Both the rate of forward and reverse reactions will increase, but the rate of reverse reaction will be the most favoured, the new equilibrium will be at a higher rate (increase in temperature favours the endothermic reaction



3. 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 least moles will be favoured to re-establish the new equilibrium.

If the *pressure is decreased* by increasing the volume, concentrations of both the reactants and products are decreased. The reaction with the highest moles will be favoured to re-establish the new equilibrium. Pressure is applicable to gases only.

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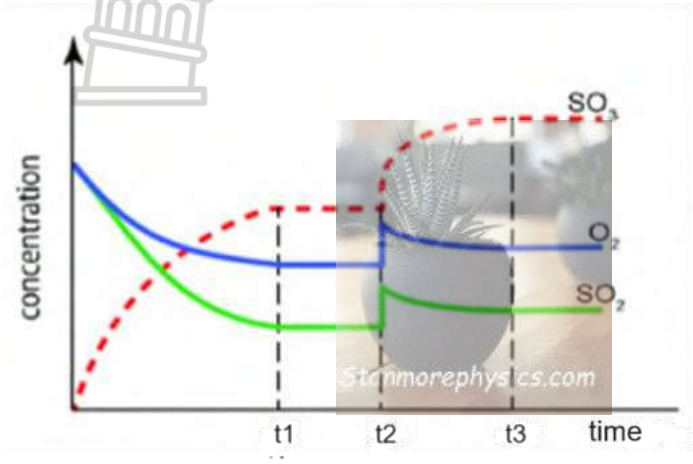
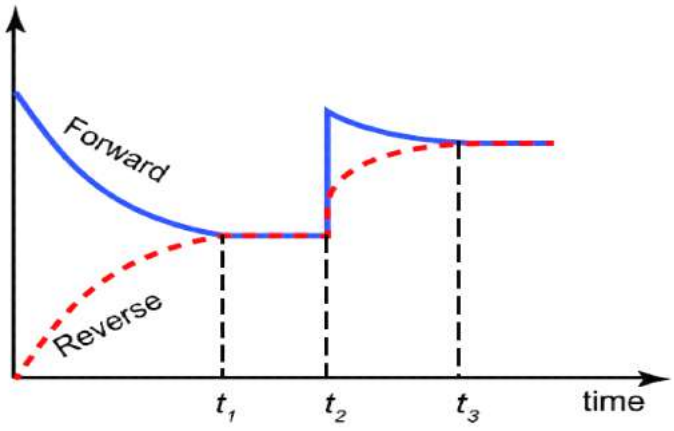
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

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 mostly favoured, the new equilibrium will be at a higher rate.



4. Use of a Catalyst

A catalyst increases the rate of both the forward and the reverse reactions equally so that the equilibrium position will not be changed. The reaction will take place at a higher rate. No change in the concentration.

ACTIVITIES

QUESTION 1: MULTIPLE CHOICE QUESTIONS

1.1 Adding a catalyst to a reaction in equilibrium will speed up …

A the forward and reverse reactions equally and increase the yield.

B the forward and reverse reactions equally, and not affect the yield.

C the forward reaction more than the reverse reaction and increase the yield.

D the forward reaction more than the reverse reaction, and not affect the yield. (2)

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1.2 Ethene can be oxidised to form epoxyethane, C_2H_4O.

$$2C_2H_4(g) + O_2(g) \rightleftharpoons 2C_2H_4O(g) \qquad \Delta H = -107\ kJ{\cdot}mol^{-1}$$

Which set of conditions will give the greatest yield of epoxyethane at equilibrium?

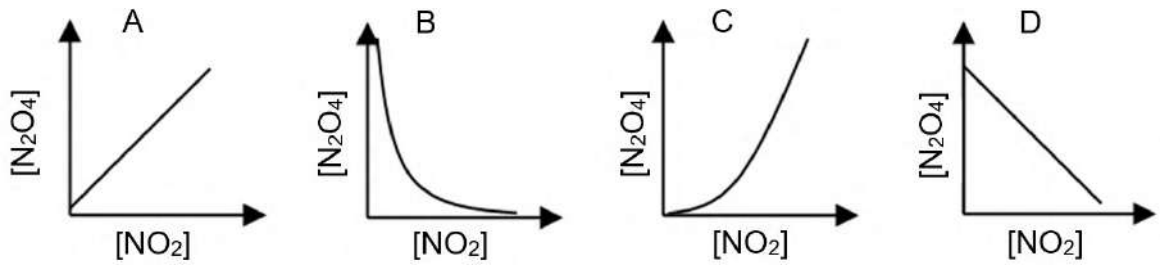
	Pressure	**Temperature (ºC)**
A	Low	100
B	High	200
C	High	100
D	Low	200

(2)

1.3 $NO_2(g)$ and $N_2O_4(g)$ are in equilibrium in a closed system:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

Which graph represents the mathematical relationship between the concentrations of the gases once a new equilibrium has been established at a constant temperature? Make use of the K_c expression for the reaction.



(2)

1.4 Consider the following equation:

$CaO(s) + SO_3(g) \rightleftharpoons CaSO_4(s)$

If the equilibrium concentration of $SO_3(g)$ at 298K is equal to x mol.dm^3, then the value of the equilibrium constant at this temperature will be equal to:

A x

B $\frac{1}{x^2}$

C x^2

D $\frac{1}{x}$

(2)

1.5 Consider the following equilibrium constants for the same reaction at two different temperatures:

298 K : $k_c = 0{,}03$

318K : $k_c = 0{,}005$

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Which ONE of the following is CORRECT?

	HEAT OF REACTION	YIELD OF PRODUCTS AS THE TEMPERATURE INCREASES
A	$\Delta H > 0$	Increases
B	$\Delta H < 0$	Decreases
C	$\Delta H > 0$	Decreases
D	$\Delta H < 0$	Remains the same

(2)

1.6 Ammonia gas NH_3 (g) and oxygen gas (O_2), reacts in a closed container at a constant temperature according to the following equation below.

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $(\Delta H < 0)$

Which ONE of the combinations of pressure and temperature will result in an increase in the yield of nitrogen monoxide NO(g)?

	Pressure	Temperature
A	Decreases	Decreases
B	Decreases	Increases
C	Increases	Increases
D	increases	Decreases

1.7 The balanced equation below represents a reaction at equilibrium.

$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-} + H_2O(l)$ $\Delta H < 0$

Which ONE of the following changes to the equilibrium will favour the forward reaction?

	TEMPERATURE	pH
A	Decreases	Increases
B	Decreases	Decreases
C	Increases	Increases
D	increases	Decreases

(2)

1.8 Two gases are added into each of four empty containers at the same temperature. The diagrams below show the molecules of the gases and the volumes of the containers at the start of the reation

In which ONE of the following containers is the initial reaction rate the highest?

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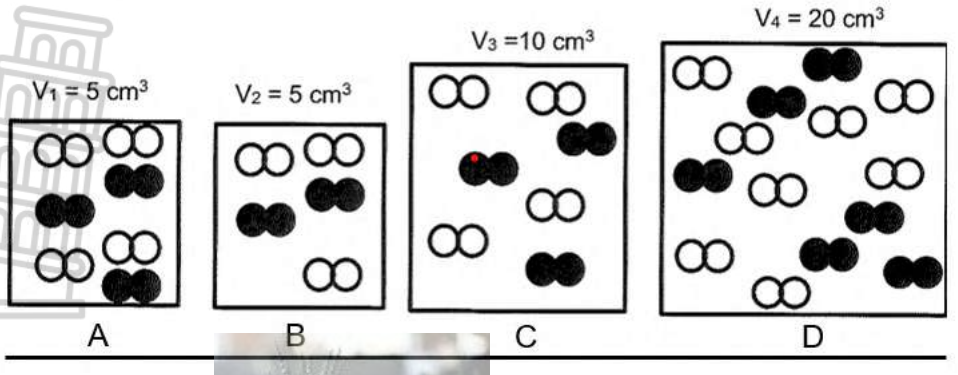

(2)

1.9 Which of the statements is TRUE for the effect of the catalyst on the reaction at equilibrium?

A. The equilibrium constant increases.
B. The rate of the reverse reaction increases.
C. The activation energy for the reverse reaction increases.
D. The enthalpy change, ΔH, for the forward reaction decreases. (2)

1.10 A reaction is at equilibrium in a closed container according to the following balanced equation:

$4CuO(s) \rightleftharpoons 2Cu_2O(s) + O_2(g)$

The volume of the container is now increased while the temperature remains constant. A new equilibrium is reached.

Which ONE of the following combinations is CORRECT for the new equilibrium?

	CONCENTRATION OF O_2	NUMBER of MOLES OF O_2	EQUILIBRIUM CONSTANT (K_c)
A	Decreases	Remains the same	Increases
B	Remains the same	Decreases	Remains the same
C	Remains the same	Increases	Remains the same
D	Decreases	Increases	Remains the same

(2)
[20]

STRUCTURED QUESTIONS
QUESTION 2
The equilibrium reaction between hydrogen gas and iodine gas is investigated at 200 °C. The equation for the reaction is as follows:

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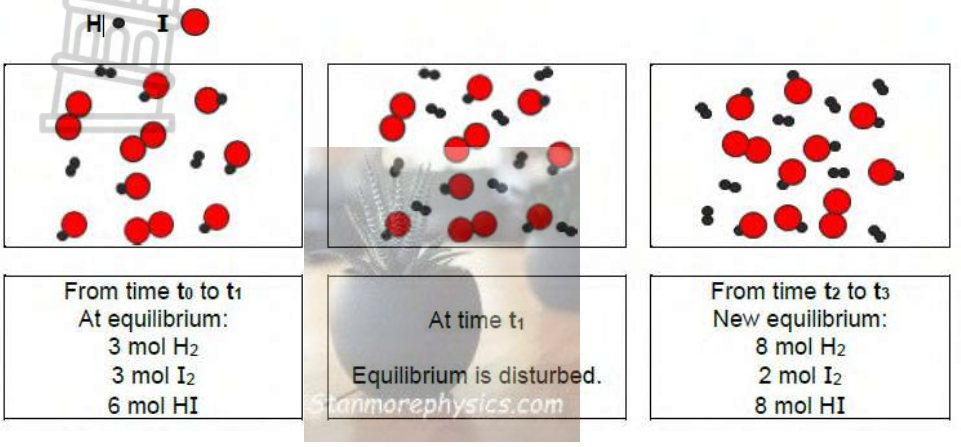
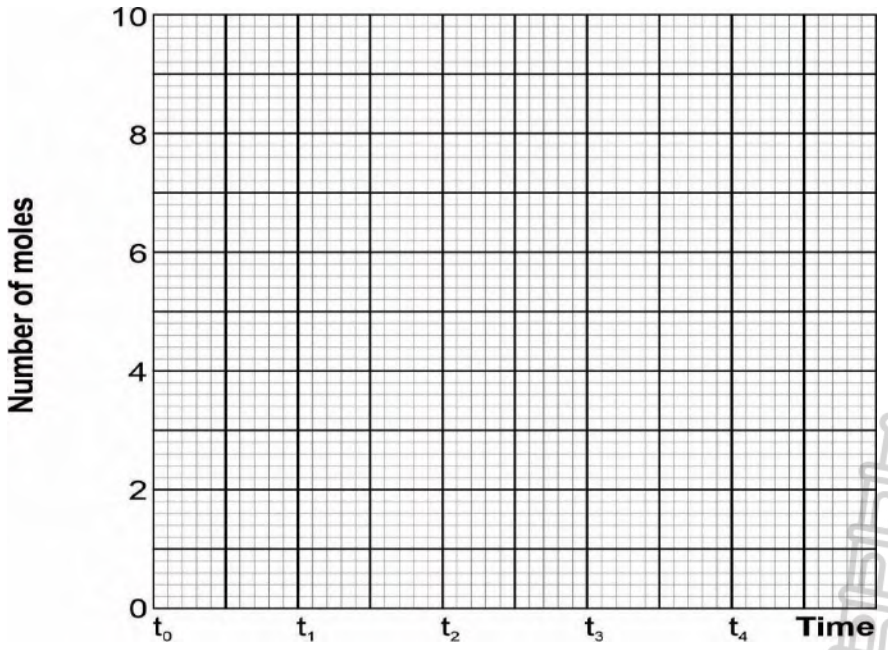
$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

The number of moles of each substance present in a sealed 2 dm^3 container at various times is represented below. Each molecule represents a mole of that substance.



2.1 Identify the disturbance that occurred at time t_1. (2)

2.2 Plot the number of moles of H_2, I_2 and HI on the axes below, **from t_0 to t_3 only**. Label each of the three lines clearly. (6)



2.3 Explain the change in the number of moles of each substance from time **t_1** to time **t_2** by applying Le Châtelier's principle. (4)

2.4 Calculate K_c before and after the disturbance at **t_1** and hence explain why the disturbance could not have been a temperature change. (5)

2.5 At time **t_3**, the volume of the container is doubled. Explain any changes to the graphs in QUESTION 2.2 that occur as a result of the disturbance at **t_3**. (2)

2.6 On the axes below, sketch the graphs of rate versus time for the forward and reverse reactions, from **t_0** to **t_4**.

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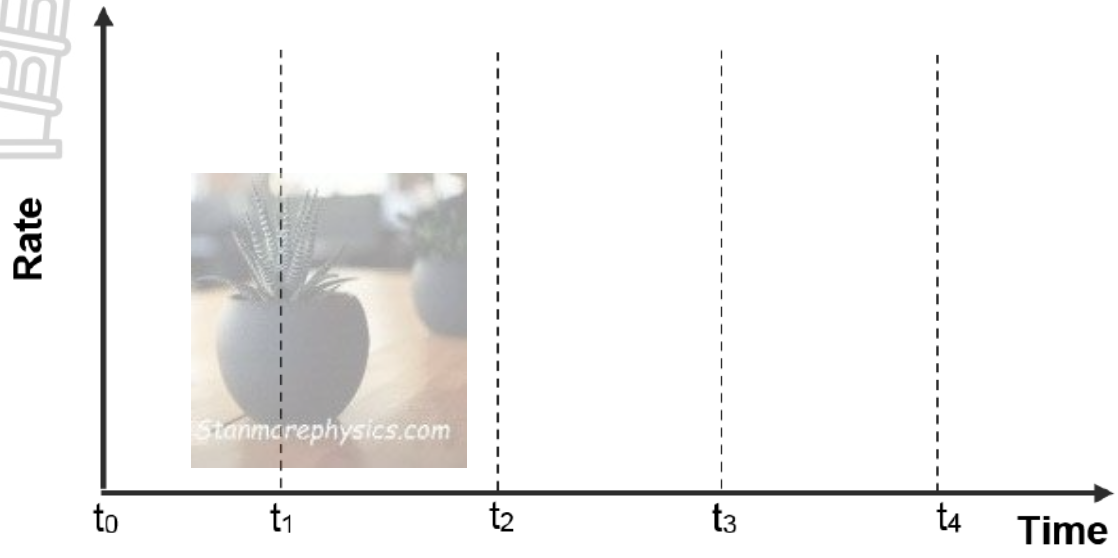
- Use a solid line _____ to represent the rate of the forward reaction.
- Use a dashed line ---------- to represent the rate of the reverse reaction.



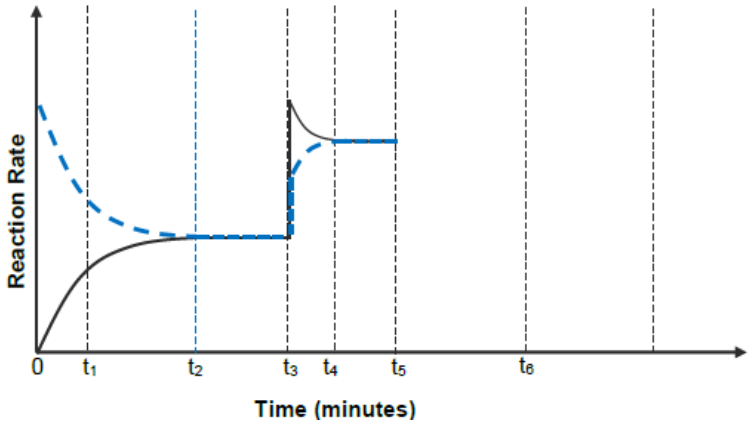
(5)
[25]

QUESTION 3

Gas AB decomposes according to the following equation

$$2AB(g) \rightleftharpoons 2A(g) + B_2(g)$$

A certain amount of AB is sealed in a container and allowed to decompose. The graph of the reaction rate vs time is shown below.



3.1 Is the statement below TRUE or FALSE? (1)
'At t_1 the graph indicates that the concentration of AB is greater than the concentrations of A and B_2.'

3.2 What is represented by the dashed line (---------) on the graph? (2)

3.3 Between t_2 and t_3, comment on the concentrations of AB, A and B_2.
Choose from EQUAL TO EACH OTHER, CONSTANT, or CHANGING. (1)

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3.4 The temperature of the system was increased at time **t_3.**
Is the forward reaction EXOTHERMIC or ENDOTHERMIC?
Explain by applying Le Châtelier's principle. (3)

3.5 At **t_5**, the volume of the container was increased at constant temperature, resulting in a decrease in the pressure.
3.5.1 Explain the effect of this change by applying Le Châtelier's principle. (3)
3.5.2 Complete the above graph of reaction rate vs time from **t_5** until after equilibrium is re-established at **t_6**. (3)

3.6 Gas AB was pumped into an evacuated container until the concentration was **X** mol·dm^{-3}. The container was sealed. Once equilibrium was established at 25 °C, the concentration of gas B_2 was 0,025 mol·dm^{-3}.

The reaction equation is re-written below:
$2AB(g) \rightleftharpoons 2A(g) + B_2(g)$
3.6.1 Write the equilibrium constant expression, Kc, for the reaction. (2)

The value of K_c for the reaction at 25 °C is $1,56 \times 10^{-3}$.
3.6.2 Show that the equilibrium concentration of gas AB is 0,2 mol·dm^{-3}. (2)
3.6.3 Hence, calculate **X**, the initial concentration of gas AB in the container (3)
[20]

QUESTION 4
The oxygen and nitrogen present in air can react in an internal combustion engine at 1 200 °C as follows:
$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H > 0$
The equilibrium constant for this reaction at 1 200 °C is $1,1 \times 10^{-5}$.

4.1 What does the magnitude of the equilibrium constant for this reaction indicate? (2)
4.2 Fully explain the effect of the high temperature on the YIELD of nitrogen monoxide. (4)
4.3 What is the effect of high pressure on the amount of nitrogen monoxide formed? State only INCREASES, DECREASES, or REMAINS THE SAME. (2)
4.4 If oxygen-rich air (air with a higher concentration of oxygen) entered the combustion chamber, how would this affect the amount of nitrogen monoxide formed? State only INCREASE, DECREASE, or REMAIN THE SAME. (2)
4.5 $4,5 \times 10^{-3}$ mol each of N_2 and O_2 are added to an empty 0,2 dm^3 container at 1 200 °C, which is then sealed.
4.5.1 Write the expression for the equilibrium constant for this reaction. (1)
4.5.2 Determine the concentration of nitrogen monoxide gas that is present at (6)
When the colourless nitrogen monoxide gas leaves the engine in the exhaust, it reacts reversibly with the oxygen in the air to form the brown gas, NO_2, which is a major contributor to air pollution and smog.
4.6 Write a balanced chemical equation for this reaction. (3)
4.7 Use Le Châtelier's principle to explain the effect of decreasing the pressure of an equilibrium system of nitrogen monoxide, oxygen and nitrogen dioxide. State also any observation that will be made. (4)
[24]

QUESTION 5

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Hydrogen gas is prepared by the reaction of methane and steam, as shown in the following balanced chemical equation:

$$CH_4(g) + H_2O(g) + \rightleftharpoons CO(g) + 3H_2(g) \quad \Delta H = +206\ kJ.mol^{-1}$$

The methane (CH_4) and steam (H_2O) are sealed in a 2 dm^3 container to react and allowed to reach equilibrium at temperature T.

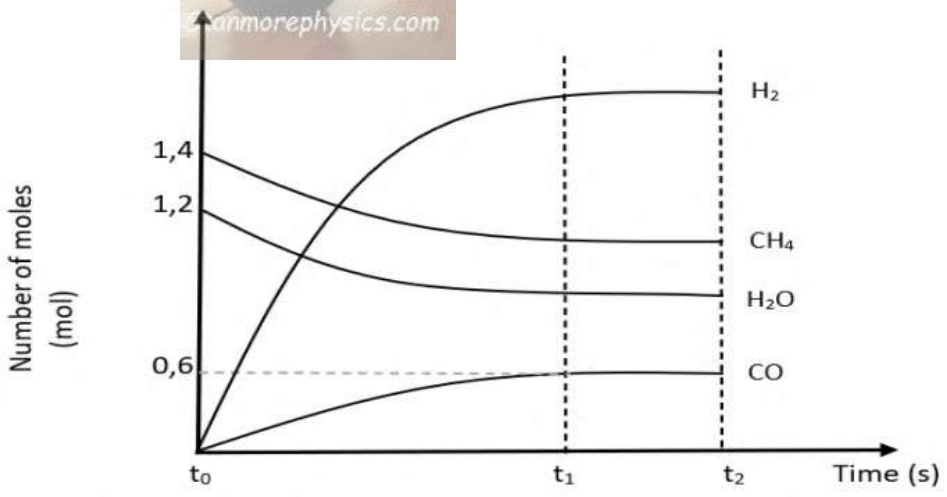
5.1 State Le Chatelier's principle (2)

5.2 Use Le Chatelier's principle to explain how the following changes will affect the yield of $H_2(g)$:

5.2.1 Adding more CH_4 (3)

5.2.2 A decrease in the volume of the container (3)

5.3 The sketch below shows the changes in the number of moles of methane, steam and carbon monoxide as the reaction proceeds for the preparation of H_2 gas in the 2dm^3 container.



5.3.1 Write down a reason why is no change in the number of moles of each of gases between times **t_1** and **t_2.** (1)

5.3.2 Use the information on the graph and calculate the equilibrium constant (K_c), for this reaction at temperature T. (7)

[17]

QUESTION 6

Hydrogen iodide (HI) is allowed to decompose in a 5 dm^3 closed container at a temperature of 300k, according to the following balanced equation:

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

When the mixture reaches equilibrium at 300k, it is found that 0.02 mol of H_2 is present in the container. The equilibrium for this reaction at 300k is 0.016.

6.1 Define the term *closed system*. (2)

6.2 Calculate the initial number of moles of HI in the container. (8)

6.3 How will EACH of the following changes affect the number of moles of $H_2(g)$ Produced?

Choose from INCREASES, DECREASES or REMAINS THE SAME.

6.3.1 More $I_2(g)$ is added at 300K. (1)

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6.3.2 The pressure is increased (1)

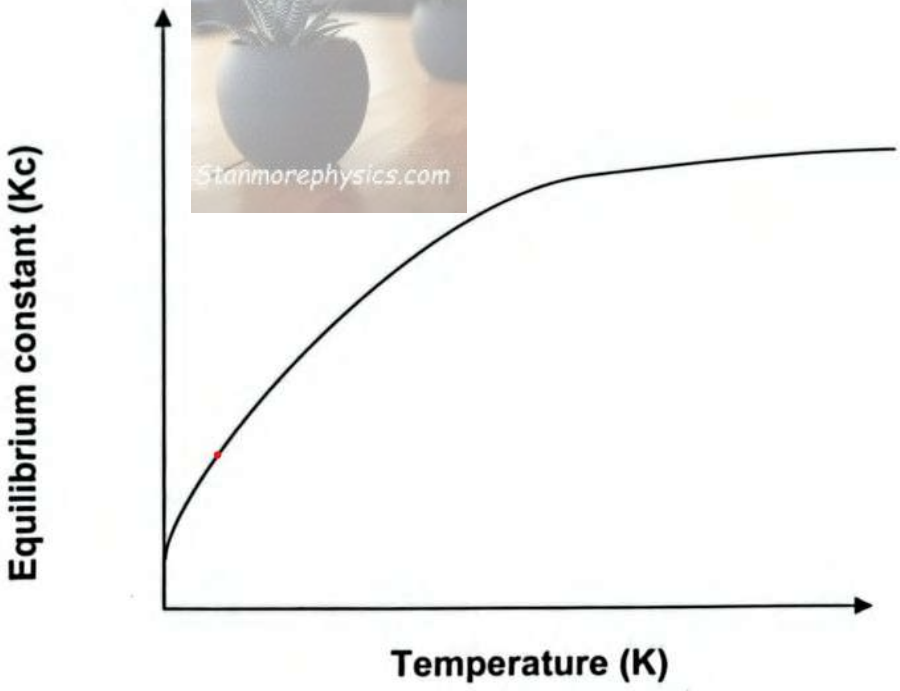
6.4 At 300k, the equilibrium constant (k_c) for the reaction above is 0.014. is the reaction EXOTHERMIC or ENDOTHERMIC? Fully explain the answer. (4)

[16]

QUESTION 7

7.1 The graph below shows the effect of the temperature of the value of K_c for the following reaction:

N_2O_4 (g) ⇌ $2NO_2$(g)



7.1.1 Write down the effect of increasing temperature on the amount of NO_2 (1)

7.1.2 Which reaction was favoured due to an increase in temperature? Write down FORWARD or REVERSE? (1)

7.1.3 Is the above an example of a homogeneous or heterogeneous equilibrium? (2)
Give reason for your answer.

7.1.4 Is the forward reaction ENDOTHERMIC or EXOTHERMIC? Explain the answer. (4)

7.1.5 Write down TWO changes, that can be introduced to decrease the rate of the forward reaction (2)

7.2 1 mol SO_2(g) and ***x*** mol O_2 is initially placed in an empty 2 dm^3 container and sealed at a specific temperature. At equilibrium 6 mole SO_3(g) was present in the container. If the value for the following equilibrium constant at this temperature is 9 calculate ***x***, the initial quantity of O_2 that was present in the container (6)

[16]

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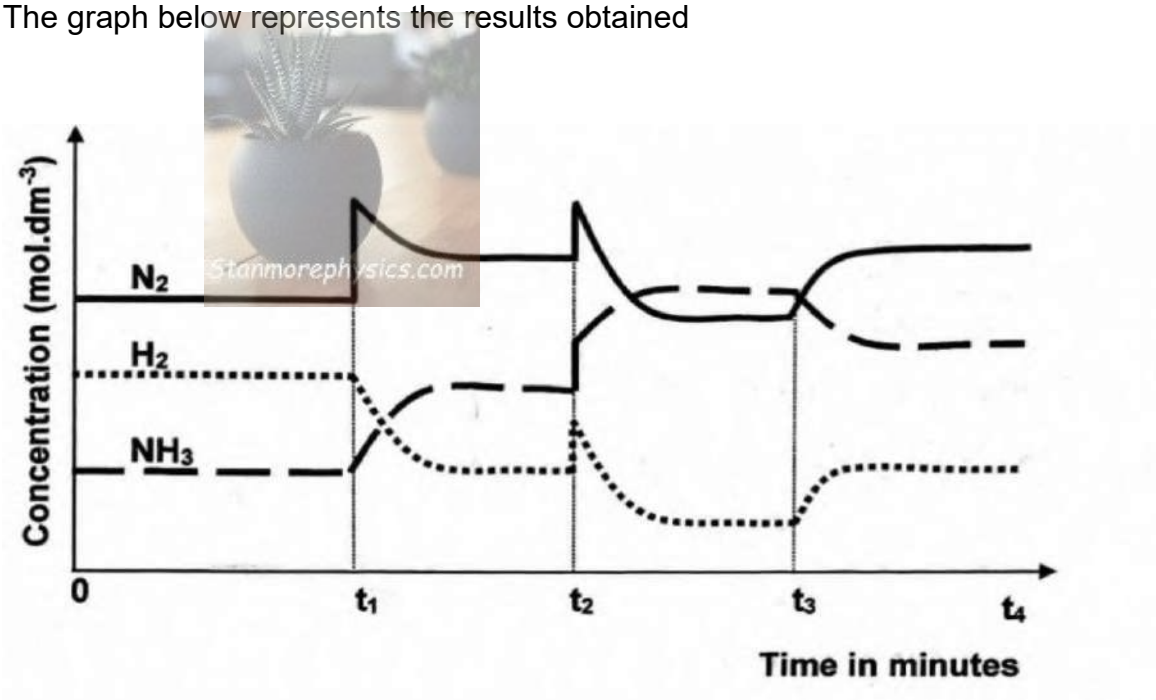
QUESTION 8

8.1 An investigation is performed to determine the effect of TEMPERATURE, PRESSURE and CONCENTRATION on the equilibrium in the production of ammonia in a sealed container. The volume of the container is kept constant

The balanced equation below represents the reaction that takes place in the sealed container

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H < 0$

The graph below represents the results obtained



8.1.1 What information about the reaction does the graph provide between 0 and t_1? (2)

8.1.2 Will the Kc value for this reaction between 0 and t_1 be GREATER THAN 1, EQUAL TO 1 OR LESS THAN 1? (1)

8.1.3 At which time t_1, t_2 or t_3 was the concentration of the reactant increased? Give reason for your answer. (2)

8.1.4 State Le Chartelier's principle (2)

8.1.5 Which ONE of the factors TEMPERATURE, PRESSURE or CONCENTRATION was changed at t_3. (1)

8.1.6 Was the factor identified in QUESTION 5.1.5 INCREASED OR DECREASED?
Explain the answer by referring to Le Chartelier's principle (4)

8.1.7 A partial graph of reaction rate versus time is drawn below. The dotted line represents the reverse reaction.

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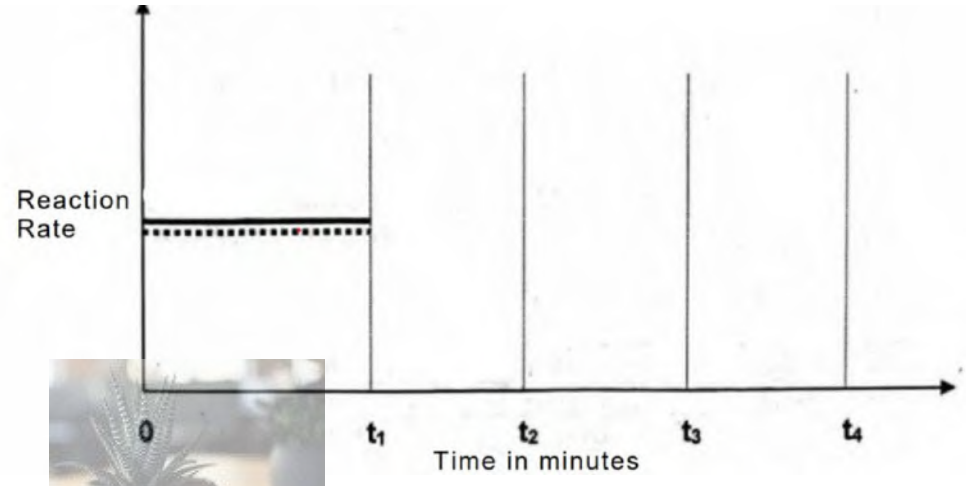

Copy the above graph in your answer book. Complete the graph for of the time periods till t_4. Use the solid line for the forward reaction rate and the dotted line for the reverse reaction rate. (5)

8.2 An equilibrium reaction for the decomposition of a reddish-brown substance AO_2 is given below. Both products are colorless.

$4AO_2(g) \rightleftharpoons 2A_2O_3(g) + O_2(g)$

Brown Colourless

Initially 2.0 mol.dm^{-3} of AO_2 are present in a 1.0 dm^3 container. Only 10.0% of the AO_2 decomposes at equilibrium. Calculate the equilibrium concentration of each species. (6)

[23]

QUESTION 9

The equation below represents a hypothetical reaction that reaches equilibrium in a closed container after 2 minutes at room temperature. The letters **x**, **y z** represent the number of moles in the balanced equation

$$\mathbf{x}A(aq) + \mathbf{y}B(aq) \rightleftharpoons \mathbf{z}C(aq)$$

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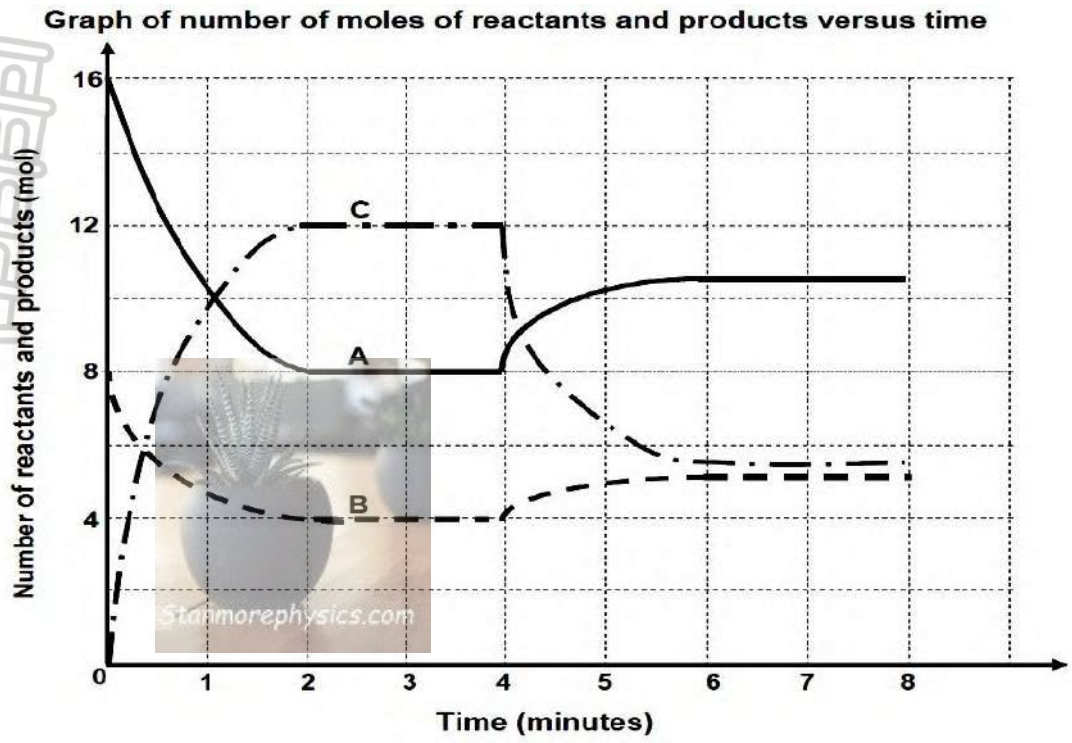

9.1 Define a dynamic equilibrium (2)

9.2 Use the information in the graph and write down the value of:

9.2.1 x (1)

9.2.2 y (1)

9.2.3 z (1)

9.3 Calculate the equilibrium constant, K_c, for this hypothetical reaction at room temperature if the volume of the closed container. is 3 dm^3 (7)

9.4 At t = 4 minutes, the temperature of the system was increased to 60 °C. Is the REVERSE reaction EXOTHERMIC or ENDOTHERMIC? Explain how you arrived at the answer. (3)

[15]

QUESTION 10

The reaction between powdered carbon, C(s), and carbon dioxide gas, $CO_2(g)$, takes place in a closed 3 dm^3 container according to the balanced equation below.

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g) \quad \Delta H < 0$$

Equilibrium is reached at temperature T °C.

The graph below, not drawn to scale, shows the curves for the mass of the reactants in the container against time.

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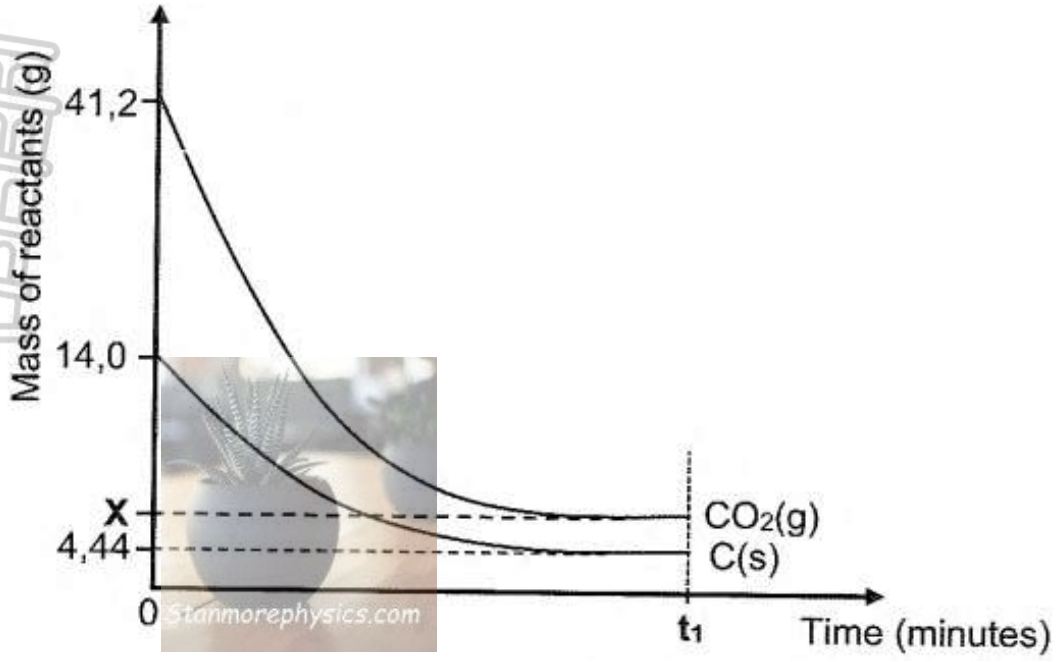

10.1 How will EACH of the following changes affect the number of moles of $CO_2(g)$ at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME.

10.1.1 A catalyst is added (1)
10.1.2 The volume of the container is increased at a constant temperature. (1)
10.1.3 More powdered carbon is added (1)

10.2 Explain the answer to QUESTION 10.1.2 by referring to Le Chatelier's principle. (2)
10.3 Calculate the value of X shown on the graph. (6)
10.4 Calculate the equilibrium constant, Kc, at T °C. (5)

10.5 The graph below shows the equilibrium number of moles of CO(g), C(s) and $CO_2(g)$ in the flask at time t_1.

At t_2, some CO(g) is added to the flask and the reaction is allowed to reach equilibrium. Curve Z correctly shows the change in the amount of CO(g) between t_2 and t_3.

A learner draws corresponding curves, labelled X and Y, for C(s) and $CO_2(g)$ respectively.

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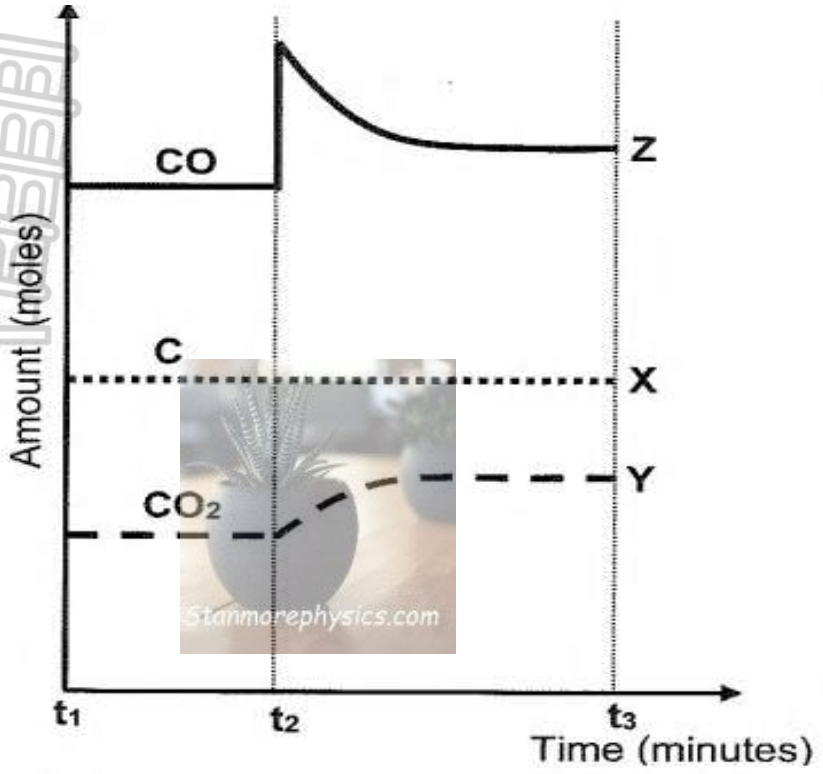

Which of these curves is the CORRECT representation for these changes?
Choose from:
X or
Y or
X and Y. (2)

10.6 What effect will the addition of CO(g) have on the equilibrium constant, Kc? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[19]

QUESTION 11

Consider the balanced equation for a hypothetical reaction that takes place in 2 dm³ sealed containers

$P_2Q(g) + 3Q(s) \rightleftharpoons 2PQ_2(g)$

The graphs below, not drawn to scale, are obtained for the same reaction at two different temperatures.

Graph **A** is obtained at 298 K and graph **B** at 398 K.

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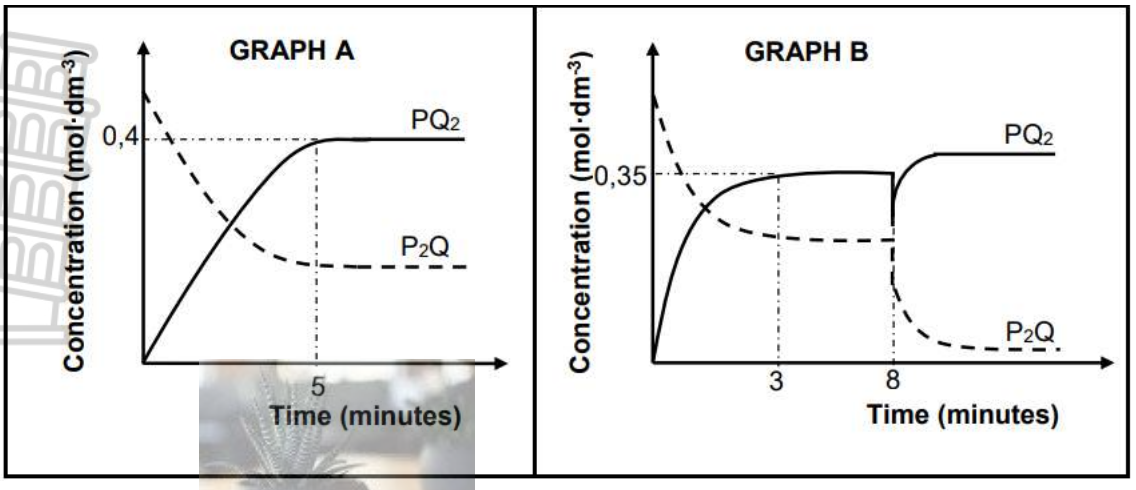

11.1 State Le Chatelier's principle. (2)

11.2 What do the parallel lines after t = 5 minutes in graph A represent? (1)

11.3 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? (1)

11.4 Explain the answer to QUESTION 11.3. (2)

11.5 How does the value of the equilibrium constant, Kc, for the reaction in graph B compare to that in graph A? Choose from GREATER THAN, LESS THAN or EQUAL TO. (1)

11.6 The equilibrium constant, Kc, is 0,49 at 398 K (**graph B**) (8)

11.7 Describe the change made to the equilibrium system at t = 8 minutes, as shown in graph B, at a constant temperature. (1)

11.8 Explain by using Le Chatelier's principle how the system reacts to the change in QUESTION 11.7. (2)

[18]

QUESTION 12

12.1 The reaction of carbon monoxide gas, CO(g), with oxygen gas, $O_2(g)$, is investigated. The reaction reaches equilibrium in a closed container at constant temperature T °C, according to the balanced equation:

$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$ $\Delta H < 0$

Changes to the conditions of equilibrium are made at different times. The graph shows the results obtained. **X**, **Y** and **Z** represent the gases in the above reaction.

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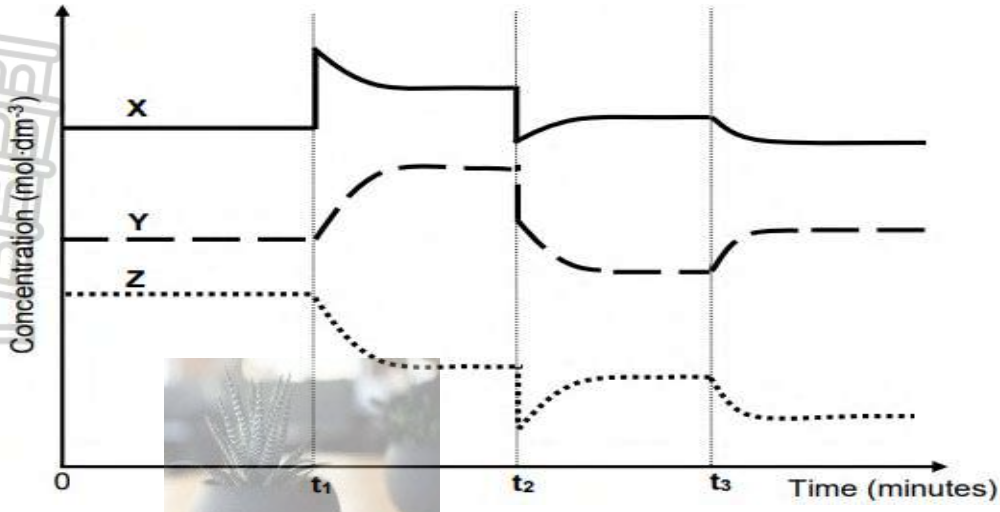

12.1.1 Define the term *chemical equilibrium*. (2)

Use the graph to answer the questions below.

12.1.2 At t_1, oxygen, $O_2(g)$, was added to the container. Write down the letter that represents $O_2(g)$. Choose from **X**, **Y** or **Z** (1)

12.1.3 At t_2, the pressure is adjusted by changing the volume of the container. Was the pressure INCREASED or DECREASED? (1)

12.1.4 Give a reason for the answer to QUESTION 12.1.3 (1)

12.1.5 Write down the NAME or FORMULA of the gas that is represented by the letter **Z** (1)

12.1.6 Give a reason for the answer to QUESTION 12.1.5 (1)

12.1.7 What change in temperature is made at t_3? Choose between INCREASED or DECREASED. (1)

12.1.8 Use Le Chatelier's principle to explain the answer to QUESTION 12.1.7 (3)

12.2 Carbon monoxide gas, CO(g), reacts with water vapour, $H_2O(g)$, at T °C. The reaction reaches chemical equilibrium according to the balanced equation:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

Initially, 0,6 moles of CO(g), 0,6 moles of $H_2O(g)$, 0,1 moles of carbon dioxide gas, $CO_2(g)$, and 0,1 moles of hydrogen gas, $H_2(g)$, were mixed and sealed in a 2 dm³ flask.

If the equilibrium constant, Kc, for this reaction at T °C is 4, calculate the mass of CO(g) present in the flask at equilibrium. (9)

[20]

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ELECTROCHEMICAL REACTIONS

REDOX REACTION

A redox reaction is a chemical reaction that involves a transfer of electrons.

A redox reaction involves the change in oxidation numbers.

Oxidation number:

A number assigned to each element in a chemical compound in order to monitor the movement of electrons.

In terms of electron transfer	*In terms of oxidation number).*
Oxidation:	**Oxidation:** An increase in oxidation number.
The loss of electrons.	
Reduction:	**Reduction:**
The gain of electrons.	A decrease in oxidation number.
Oxidising agent:	**Oxidising agent:**
A substance that is reduced by gaining electrons.	A substance whose oxidation number decreases.
Reducing agent:	**Reducing agent:**
A substance that is oxidised by losing electrons.	A substance whose oxidation number increases.

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GALVANIC CELLS

A galvanic cell is an electrochemical cell that converts chemical energy into electrical energy.

Electrolyte:

A substance that dissolves in water to give a solution that conducts electricity.

Cathode:

The electrode where reduction takes place.

Anode:

The electrode where oxidation takes place.

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Properties of a galvanic cell.

Chemical reactions are spontaneous.

Chemical reactions are exothermic.

Galvanic cells are made of two different electrolytes. There are two half-cells.

The anode is negative and the cathode positive.

Electrons move from the anode to the cathode in the external circuit.

Galvanic cells possess a salt bridge.

The cell potential is positive.

Standard conditions

Standard conditions under which cells operate are:

Temperature = 25^0C / 298K.

Concentration = 1mol.dm^{-3}.

Pressure = 1atm/101,3kPa.

Salt bridge

The functions of the salt bridge are:

To maintains electrical neutrality of the electrolytes.

To complete the circuit.

During operation, the cations from the salt bridge move towards the cathode half-cell and the anions move towards the anode half-cell.

Cell notation

A cell notation is a symbolic description of the components of a galvanic cell.

It is written as:

With active electrodes:

reducing agent | oxidised species || oxidising agent | reduced species

With inert electrodes (usually Pt or C):

Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt

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Cell potential

The cell potential is calculated using the formula:

$$\mathbf{E^{\theta}_{Cell} = E^{\theta}_{Cathode} - E^{\theta}_{Anode}}$$

Or

$$\mathbf{E^{\theta}_{Cell} = E^{\theta}_{Reduction} - E^{\theta}_{Oxidation}}$$

Or

$$\mathbf{E^{\theta}_{Cell} = E^{\theta}_{Oxidising\ agent} - E^{\theta}_{reducing\ agent}}$$

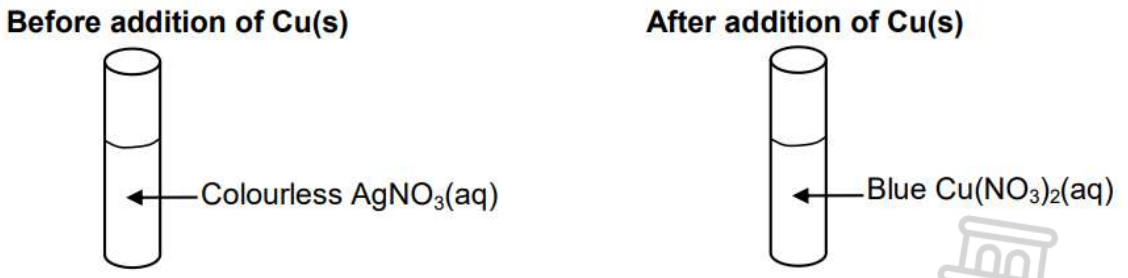
WORKED EXAMPLES

QUESTION 1

A learner conducts two experiments to investigate the reaction between copper (Cu) and a silver nitrate solution, $AgNO_3(aq)$.

EXPERIMENT 1

The learner adds a small amount of copper (Cu) powder to a test tube containing silver nitrate solution, $AgNO_3(aq)$. The solution changes from colourless to blue after a while.



1.1 Define the term oxidising agent. (2)

1.2 Explain why the solution turns blue by referring to the relative strength of oxidising agents. (4)

EXPERIMENT 2

The learner now sets up a galvanic cell as shown below. The cell functions under standard conditions.

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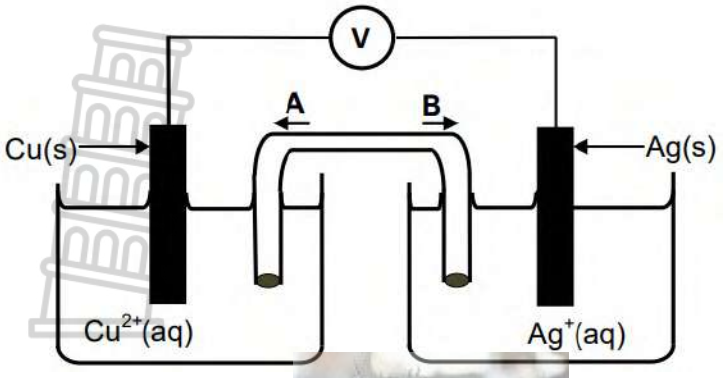

1.3 Write down the energy conversion that takes place in this cell. (1)

1.4 In which direction (A or B) will ANIONS move in the salt bridge? (1)

1.5 Calculate the emf of the above cell under standard conditions. (4)

1.6 Write down the balanced equation for the net cell reaction that takes place in this cell. (3)

1.7 How will the addition of 100 cm^3 of a 1 $mol.dm^{-3}$ silver nitrate solution to the silver half-cell influence the initial emf of this cell? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]

SOLUTIONS

1.1 A substance that is being reduced. ✓✓

OR

A substance that gains/accepts electrons.

OR (2)

A substance whose oxidation number decreases.

1.2 Ag^+ is a stronger oxidising agent ✓ than Cu^{2+} ✓ and will oxidise Cu ✓ to (blue) Cu^{2+} ions. ✓

OR

Cu^{2+} is a weaker oxidising agent ✓ than Ag^+ ✓ and Cu will be oxidised ✓ to Cu^{2+} ions. ✓ (4)

1.3 Chemical energy to electrical energy. ✓ (1)

1.4 A ✓ (1)

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1.5 $E^{\ominus}_{Cell} = E^{\ominus}_{cathode} - E^{\ominus}_{anode}$ ✓

$= 0,80$ ✓ $- 0,34$ ✓ (4)

$= +0,46$ V ✓

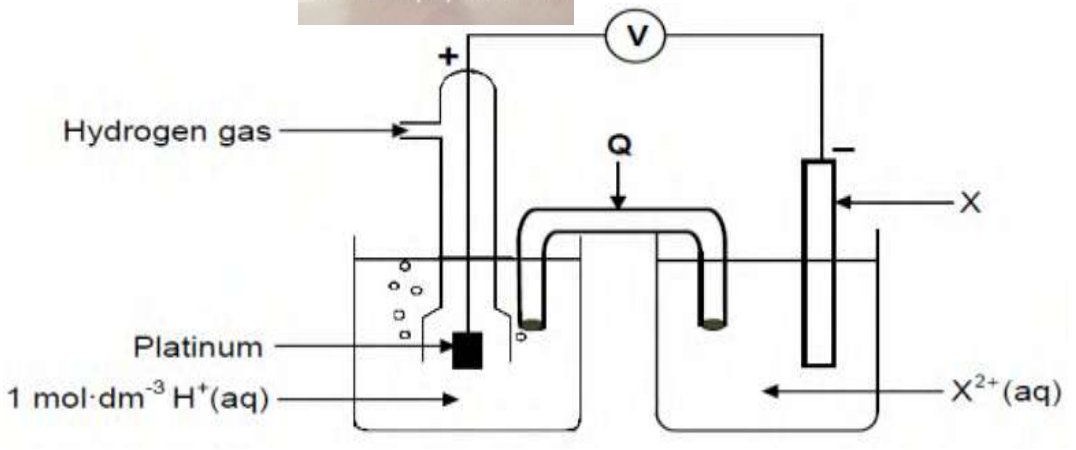
1.6 $Cu + 2Ag^{+}(aq)$ ✓ $\rightarrow Cu^{2+}(aq) + 2Ag(s)$ ✓ Balancing ✓ (3)

1.7 Remains the same. ✓ (1)

[16]

QUESTION 2

A standard electrochemical cell is set up using a standard hydrogen half-cell and a standard **X**I**X²⁺** half-cell, as shown below. A voltmeter connected across the cell, initially registers 0,31 V.



2.1 Besides concentration, write down TWO conditions needed for the Hydrogen half-cell to function under standard conditions. (2)

2.2 Give TWO reasons, besides being a solid, why Platinum is suitable to be used as an electrode in the above cell. (2)

2.3 Write down the:

2.3.1 Name of component **Q** (1)

2.3.2 Standard reduction potential of the XIX^{2+} half-cell. (1)

2.3.3 Half-reaction that takes place at the cathode of this cell. (2)

2.4 The Hydrogen half-cell is now replaced by a **M**I**M²⁺** half-cell. The cell notation of this cell is:

M(s) **I M²⁺** (aq) II X^{2+}I X (s)

The initial reading on the voltmeter is now 2, 05 V.

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2.4.1 Identify metal **M**. Show how you arrived at the answer. (5)

2.4.2 Is the cell reaction EXOTHERMIC or ENDOTHERMIC? (1)

2.5 The reading on the voltmeter becomes zero after using the cell for several hours. Give a reason for this reading by referring to the cell reaction. (1)

[15]

SOLUTIONS

2.1 Temperature: 25 °C ✓ or 298 K

Pressure: 101,3 kPa ✓ or 1,013 x 105 Pa / 1 atm ✓ (2)

2.2 - Good conductor of electricity. ✓

- Unreactive (Inert). ✓ (2)

2.3.1 Salt bridge. ✓ (1)

2.3.2 – 0, 31 V ✓ (1)

2.3.3 $2H^+ (aq) + 2e^-$ ✓ $\rightarrow H_2 (g)$ ✓ (2)

2.4.1 $E^{\ominus}_{Cell} = E^{\ominus}_{cathode} - E^{\ominus}_{anode}$ ✓

2, 05 ✓ = – 0, 31 ✓ – x

x = – 2, 36 V ✓

M is Magnesium (Mg) ✓ (5)

2.4.2 Exothermic. ✓ (1)

2.5 The cell reaction has reached equilibrium. ✓ (1)

[15]

ACTIVITIES

QUESTION 1: MULTIPLE CHOICE QUESTIONS

1.1 A galvanic cell consists of the following half–cells:

$Pt(s) \mid Cl_2(g) \mid Cl^- (aq)$ and $Zn^{2+} (aq) \mid Zn (s)$

Which ONE of the following substances is the reducing agent?

A Pt (s)

B Cl_2 (g)

C $Cl^-(aq)$

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D Zn (s) (2)

1.2 Which ONE of the following is a SPONTANEOUS redox reaction?

A $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(s)$

B $Fe(s) + CuCl_2(aq) \rightarrow FeCl_2(aq) + Cu\ (s)$

C $2Ag(s) + Mn\ (NO_3)_2\ (aq) \rightarrow 2AgNO_3\ (aq) + Mn(s)$

D $3Ni(s) + 2Al\ (NO_3)_3\ (aq) \rightarrow 3Ni\ (NO_3)_2\ (aq) + 2Al(s)$ (2)

1.3 In a galvanic (voltaic) cell, electrons move from the ...

A anode to the cathode through the salt bridge.

B cathode to the anode through the salt bridge.

C anode to the cathode in the external circuit.

D cathode to the anode in the external circuit. (2)

1.4 Consider the cell notation for a galvanic cell.

$Pt\ |\ H_2(g)\ |\ OH^-(aq)\ |\ H_2O\ (\ell)\ ||\ Ag^+(aq)\ |\ Ag(s)$

Which ONE of the following equations represents the half-reaction taking place at the positive electrode? (2)

A $Ag^+(aq) + e^- \rightarrow Ag(s)$

B $Ag(s) \rightarrow Ag^+(aq) + e^-$

C $2H_2O\ (\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

D $H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(\ell) + 2e^-$ (2)

1.5 A copper rod is dipped into a zinc sulphate solution. Which of the following will be observed? (2)

A The copper rod turns a silver colour

B The zinc solution turns blue

C The copper rod becomes eroded

D No observation is made (2)

[10]

QUESTION 2

The following cell is set up in a laboratory by a group of learners:

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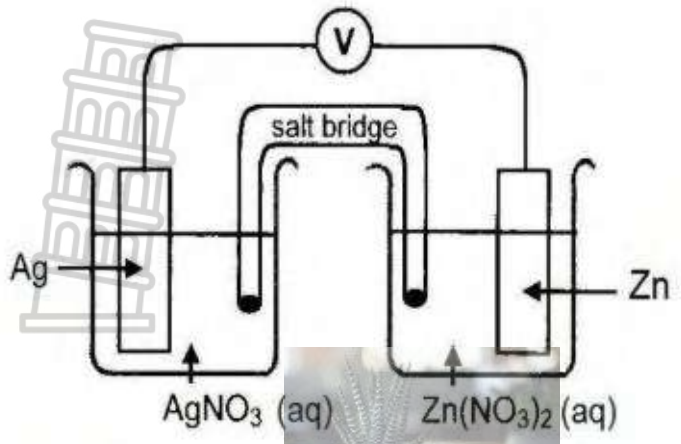


The cell operates under standard conditions.

2.1 State the energy conversion that takes place when this cell is in operation. (1)

2.2 Write down the cell notation for this cell. (3)

2.3 Define the term Anode. (2)

2.4 Write down the NAME of the oxidising agent. (1)

2.5 Write down the balanced overall cell reaction. (3)

2.6 State TWO standard conditions applicable to this cell. (2)

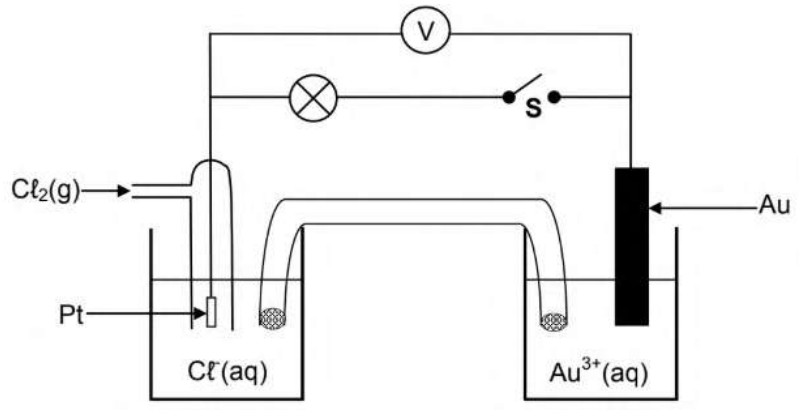
2.7 Calculate the initial emf of this cell. (4)

[16]

QUESTION 3

The diagram below shows a galvanic cell operating under standard conditions. The cell reaction taking place when the cell is functioning is:

$6Cl^-(aq) + 2Au^{3+}(aq) \rightarrow 3Cl_2(g) + 2Au(s)$



With switch S OPEN, the initial reading on the voltmeter is 0,14 V.

3.1 Write down the:

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3.1.1 NAME or FORMULA of the oxidising agent. (1)

3.1.2 Half-reaction that takes place at the anode. (2)

3.1.3 Cell notation for this cell (3)

3.2 Calculate the standard reduction potential of Au. (4)

Switch S is now closed and the bulb lights up.

3.3 How will the reading on the voltmeter now compare to the INITIAL reading of 0,14 V?

Write down only LARGER THAN, SMALLER THAN or EQUAL TO.

Give a reason for the answer. (2)

[12]

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QUESTION 4

Learners are given the following two unknown half-cells:

Half-cell 1: Q^{2+} (aq) | Q(s)

Half-cell 2: Pt | R_2(g) | R^-(aq)

During an investigation to identify the two half-cells, the learners connect each half-cell alternately to a Cd^{2+}(aq) | Cd(s) half-cell under standard conditions.

For each combination of two half-cells, they write down the net cell reaction and measure the cell potential. The results obtained for the two half-cell combinations are given in the table below.

COMBINATION	NET CELL REACTION	CELL POTENTIAL
I	$Q^{2+}(aq) + Cd(s) \rightarrow Cd^{2+}(aq) + Q(s)$	0, 13 V
II	$R_2(g) + Cd(s) \rightarrow Cd^{2+}(aq) + 2R^-(aq)$	1, 76 V

4.1 Write down THREE conditions needed for these cells to function as standard cells. (3)

4.2 For Combination I, identify:

4.2.1 The anode of the cell. (1)

4.2.2 **Q** by using a calculation. (5)

4.3 For Combination II, write down the:

4.3.1 Oxidation half-reaction (2)

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4.3.2 NAME or FORMULA of the metal used in the cathode compartment (1)

4.4 Arrange the following species in order of INCREASING oxidising ability:

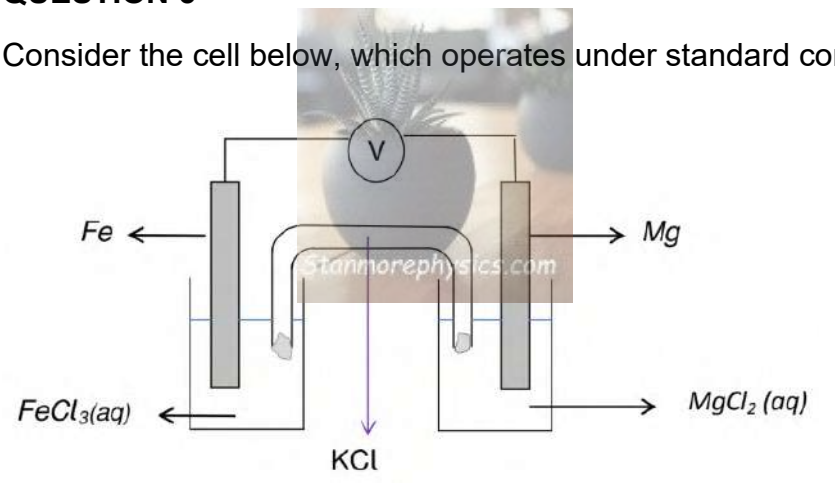
Q^{2+}; R_2; Cd^{2+}

Explain fully how you arrived at the answer. A calculation is NOT required. (4)

[16]

QUESTION 5

Consider the cell below, which operates under standard conditions:



The net cell reaction for this cell is:

$2\ Fe^{3+} + 3\ Mg\ (s) \rightarrow 2\ Fe\ (s) + 3\ Mg^{2+}$

5.1 What energy conversion takes place in this cell? (1)

5.2 State the standard conditions that will apply to this cell. (2)

5.3 Which electrode is the ANODE: Fe or Mg? (1)

5.4 Write down the oxidation half-reaction for this cell. (2)

5.5 After the cell had been operating for a while, it was determined that the mass of the Magnesium plate had changed by 0,96g.

Calculate the change in mass of the iron electrode over the same period of time. (5)

5.6 A light bulb is marked "2 V". Calculate the emf of the cell and state whether or not the light bulb will burn if used in this circuit. Ignore internal resistance. (5)

5.7 How will the concentration of Mg^{2+} ions change while the cell is in operation?

Write down only INCREASE, DECREASE or REMAIN THE SAME. (1)

5.8 What effect, if any, will this change in Question 5.7 have on the voltmeter reading over a period of time? Give a reason for your answer. (2)

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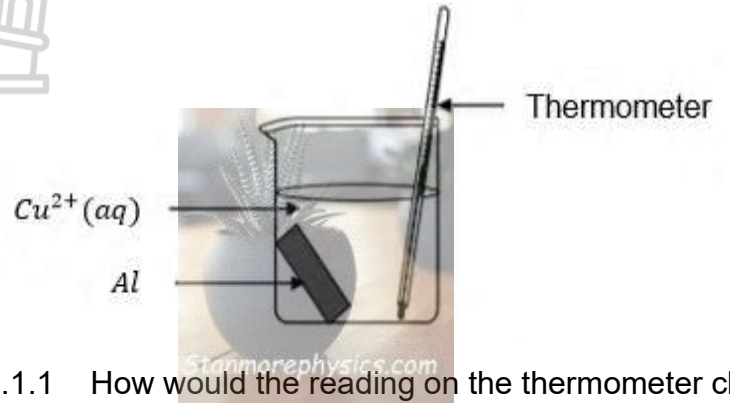
[19]

QUESTION 6

6.1 A strip of aluminium is placed in a beaker containing a blue solution of a copper (II) salt. After a while the solution becomes colourless.

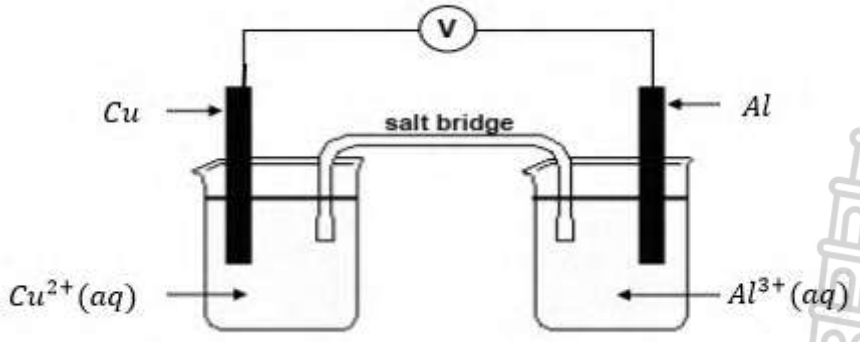


6.1.1 How would the reading on the thermometer change as the reaction proceeds? Write down INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

6.1.2 Refer to the reducing ability of aluminium to explain why the solution becomes colourless (3)

6.1.3 Write down the balanced net IONIC equation for the reaction that takes place (3)

6.2 The electrochemical cell shown below functions at standard conditions.



6.2.1 Which electrode (Cu or Al) is the anode? (1)

6.2.2 Write down the cell notation for this cell. (3)

6.2.3 Calculate the emf of this cell (4)

The salt bridge is removed.

6.2.4 What will the reading on the voltmeter be? Give a reason for your answer? (2)

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[18]

ELECTROLYTIC CELLS

An electrolytic cell is a chemical cell that converts electrical energy into chemical energy.

Electrolysis

A process during which electrical energy is converted into chemical energy.

Properties of an electrolytic cell.

Chemical reactions are non-spontaneous.

Chemical reactions are endothermic.

Electrolytic cells are made of a single electrolyte.

The anode is positive and the cathode negative.

Cations move towards the cathode and anions towards the anode.

There is no salt bridge in electrolytic cells.

Electrolyte

An electrolyte conducts electricity through the movement of free ions.

Electrolytes are present as molten substances or solutions, in order to have free ions.

Practical applications of Electrolytic cells.

Some of the applications of electrolytic cells include;

Electrolysis of concentrated solution of Sodium chloride (Brine).

Decomposition of copper II chloride.

Electroplating.

Purification (Electro-refining) of copper.

WORKED EXAMPLES

QUESTION 1

An attractive silver appearance can be created by electroplating artefacts made from cheaper metals, such as nickel, with silver.

The simplified diagram below represents an arrangement that can be used to electroplate a nickel artefact with silver.

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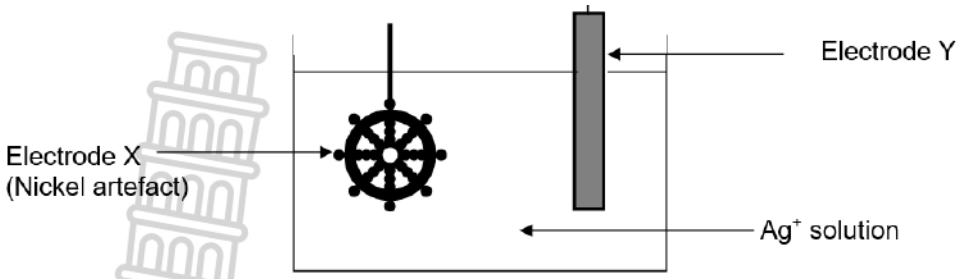

1.1 Which electrode (cathode/anode) will the nickel artefact represent? (1)

1.2 Name the metal represented by electrode Y. (1)

1.3 Write down the half-reaction responsible for the change that occurs at the surface of the artefact. (2)

1.4 Give a reason why the concentration of the electrolyte remains constant during electroplating. (2)

1.5 In industry, some plastic articles are sometimes electroplated. Explain why plastic must be coated with graphite before electroplating. (2)

1.6 Give a reason why, from a business point of view, it is not advisable to plate platinum with silver. (1)

[9]

SOLUTIONS

1.1 Cathode. ✓ (1)

1.2 Silver. ✓ (1)

1.3 $Ag^+ + e^- \rightarrow Ag$ ✓✓ (2)

1.4 The rate of oxidation of silver at the anode is equal to the rate of reduction of silver ions at the cathode. ✓✓ (2)

1.5 Plastic is a non-conductor✓ Graphite is a conductor. ✓ (2)

1.6 Platinum is expensive/more durable than other metals. ✓ (1)

[9]

QUESTION 2

The sketch below shows a cell used in the purification of copper.

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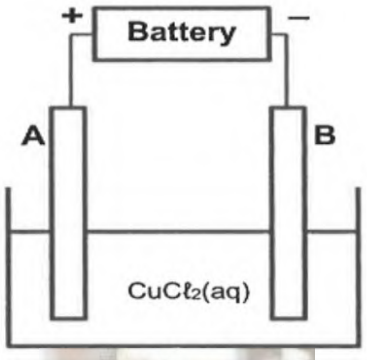

2.1 Define the term electrolysis (2)

2.2 Which electrode **A** or **B** represented the impure copper? (1)

2.3 Which electrode **A** or **B** will increase in mass? (1)

2.4 Write down the equation for the reaction that takes place at the cathode. (2)

2.5 "The colour of the electrolyte remains unchanged" when the cell is in operation. Is this statement TRUE or FALSE? Explain the answer. (2)

The two electrodes **A** or **B** are now replaced with carbon rods.

2.6 Write down TWO reasons why carbon rod is used as electrodes. (2)

2.7 At which electrode (**A** or **B)** will chlorine gas form when the cell is in operation?

Write down a half-reaction to show the formation of chlorine gas. (3)

2.8 State whether the concentration of the electrolyte will INCREASE, DECREASE or REMAIN THE SAME when carbon rods are used. (1)

[14]

SOLUTIONS

2.1 The chemical process in which electrical energy is converted to chemical energy. ✓✓ (2)

2.2 A ✓ (1)

2.3 B ✓ (1)

2.4 $Cu^{2+} + 2e^- \rightarrow Cu$ ✓✓ (2)

2.5 True ✓

Rate of oxidation of Cu is equal to the rate of reduction of Cu^{2+}. ✓ (2)

2.6 Carbon is unreactive ✓ and can conduct electricity. ✓ (Carbon is a solid) (2)

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2.7 A ✓

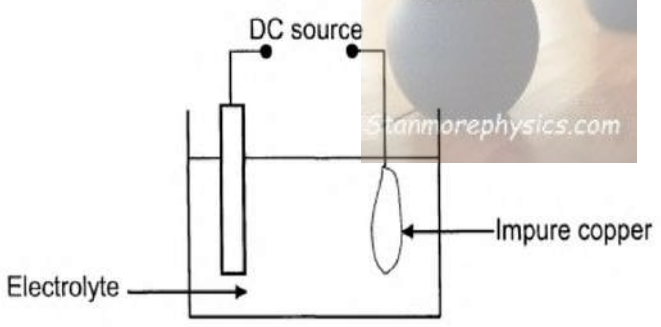
$2Cl^- \rightarrow Cl_2 + 2e^-$ ✓✓ (3)

2.8 Decrease ✓ (1)

[14]

QUESTION 3

The simplified diagram below represents an electrochemical cell used for the purification of copper. The impure copper contains small amounts of silver (Ag) and zinc (Zn) as the only impurities.



3.1 Define the term electrolysis (2)

3.2 Write down the NAME or FORMULA of TWO positive ions present in the electrolyte. (2)

3.3 Write down the half-reaction that takes place at the cathode. (2)

3.4 Refer to the Table of Standard Reduction Potentials and explain why the purified copper will NOT contain any zinc. (3)

3.5 Calculate the maximum mass of Cu formed if 0.6 moles of electrons are transferred. (3)

[12]

SOLUTION

3.1 The chemical process in which electrical energy is converted to chemical energy. ✓✓ (2)

3.2 Copper (II) ions / Cu^{2+} ✓

Zinc (II) ions / Zn^{2+} ✓ (2)

3.3 Cu^{2+} (aq) + $2e^- \rightarrow$ Cu (s) ✓✓ (2)

3.4 Zn^{2+} is a weaker oxidising agent ✓ than Cu^{2+} ✓ and will not be reduced to Zn (2)

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3.5 n(Cu) = $^1/_2$ n electrons

= $^1/_2$ (0.6) ✓

= 0.3 mol

m= n x M

= 0.3 x 63.5 ✓

= 19.05 g ✓ (3)

[12]

ACTIVITIES

Question 1: MULTIPLE CHOICE QUESTIONS

1.1 An electrochemical cell is used to electroplate an iron spoon with silver. The half-reaction that takes place at the negative electrodes of this cell is

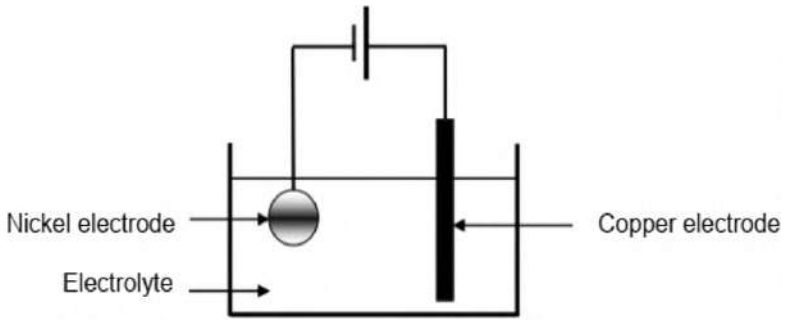
$Ag^+(aq) + e^- \rightarrow Ag|(s)$

$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

$Ag(s) \rightarrow Ag^+(aq) + 2e^-$

$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$ (2)

1.2 The simplified diagram below represents an electrolytic cell used to electroplate a nickel (Ni) coin with copper (Cu).



Which ONE of the following reactions takes place at the anode?

$Ni^{2+} + 2e^- \rightarrow Ni$

$Ni \rightarrow Ni^{2+} + 2e^-$

$Cu^{2+} + 2e^- \rightarrow Cu$ (2)

$Cu \rightarrow Cu^{2+} + 2e^-$

1.3 The simplified diagram below represents an electrochemical cell used for the PURIFICATION of copper.

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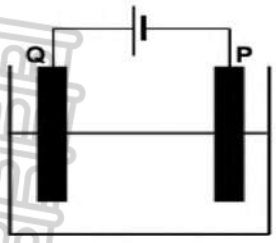

Consider the following statements regarding this cell.

Electrode P is the cathode.

Cu^{2+} is reduced to Cu at electrode Q.

The mass of electrode Q decreases.

Which of the above statements is / are correct?

I only

I and II only

I and III only

I , II and III (2)

1.4 Which of the following half-reactions occurs at the cathode during the electrolysis of a solution of concentrated NaCl?

$2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$

$Na^+ + e^- \rightarrow Na$ (2)

$2Cl^- \rightarrow Cl_2 + 2e^-$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

1.5 During the electrolysis of a concentrated sodium chloride solution, water is reduced and not sodium ions because…

Na^+ is a stronger oxidising agent than H_2O.

H_2O is a stronger reducing agent than Na^+.

H_2O is a stronger oxidizing agent than Na^+. (2)

Na^+ is a stronger reducing agent than H_2O.

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1.6 Which ONE of the following correctly describes the electrode in an electrolytic cell and its polarity the best?

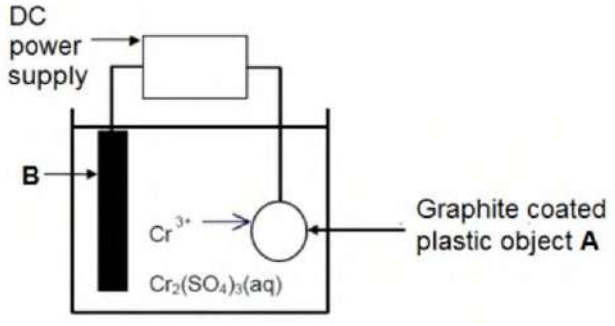
	ELECTRODE	POLARITY	TYPE OF HALF-REACTION
A	Anode	Positive	Reduction
B	Anode	Negative	Oxidation
C	Cathode	Negative	Reduction
D	Cathode	Positive	Oxidation

(2)

[12]

QUESTION 2

Chromium metal can be plated onto a plastic object from an acidic solution of chromium ions. The plastic object must be coated with a layer of graphite paste. This process is indicated by the simplified electrochemical cell diagram below. The chromium electrode used in this cell is oxidized.



2.1 Define the term oxidation in terms of electrons (2)

2.2 Which electrode A or B is connected to the negative terminal of the DC power supply? Give a reason for your answer. (2)

2.3 Write down the balanced equation half-reaction for the electrochemical cell. (2)

2.4 Use the concept of reducing agent to explain why it is possible to electroplate a thin layer of silver onto a chrome object. Consider the reaction to occur spontaneously. (2)

[8]

QUESTION 3

The diagram below shows the apparatus used during the electrolysis of a concentrated sodium chloride solution at 25^0C using carbon electrodes.

The balanced equation for the net (overall) cell reaction is:

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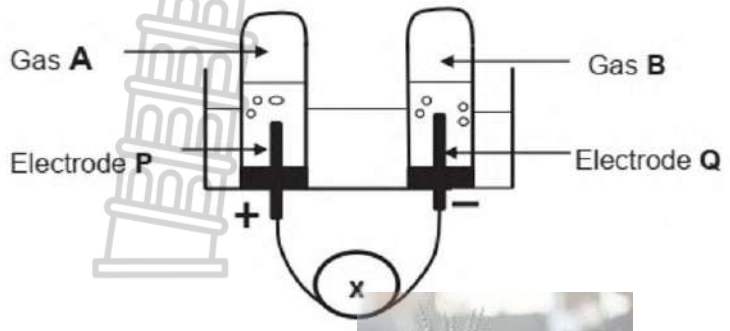
$2NaCl\ (aq) + 2H_2O(l) \rightarrow Cl_2\ (g) + H_2\ (g) + 2NaOH(aq)$



3.1 Write down the :

3.1.1 NAME of component X (1)

3.1.2 NAME or FORMULA of gas **A** (1)

3.1.3 Half-reaction taking place at electrode **Q** (2)

3.1.4 FORMULA of the reducing agent (1)

3.2 Which ONE of the following CORRECTLY describes the concentration of hydronium ions $[H_3O^+]$ in $mol.dm^{-3}$, in the electrolyte after the cell reaction has run to completion?

$[H_3O^+] < 1x10^{-7}$	**$[H_3O^+] > 1x10^{-7}$**	**$[H_3O^+] = 1x10^{-7}$**

(2)

Explain the answer.

3.3 The electrolyte (NaCl) is replaced with a $CuCl_2$ solution.

The following observation is made about the products formed at electrode **Q.**

When $CuCl_2$ solution is used, a metallic products formed at Q but there is NO metallic products at Q when NaCl solution is used.

Explain this observation in terms of the strengths of oxidizing agents involved. (3)

[10]

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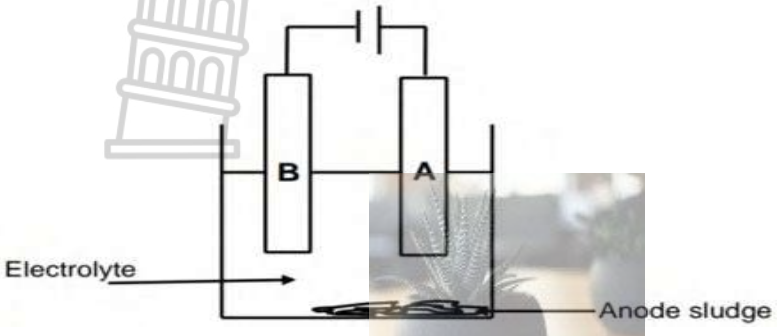
QUESTION 4

High purity of copper is obtained by electrolysis using the electrolytic cell in the diagram below



4.1 Define electrolytic cell. (2)

When a constant current flows for 1 hour, 32g of pure copper is deposited at one of the electrodes.

4.2 At which electrode would pure copper be deposited? (2)

4.3 Calculate :

4.3.1 The number of moles of copper deposited. (2)

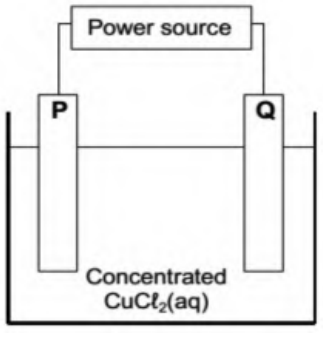
4.3.2 The average current required to deposit 32g of copper (6)

4.4 The purity of the copper obtained is not influenced by the Zn^{2+} ions present in the impure copper. Refer to the relative strength of the OXIDISING AGENTS to explain this observation. (3)

[14]

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)

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5.2 When an electric current passes through the $CuCl_2$ (aq), the mass of electrode **P** increases. Is electrode P the **cathode** or the **anode**? (3)

Write down the relevant half-reaction to support your answer.

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? (2)

Choose from increases, decreases or remains the same.

[11]

ELECTRODYNAMICS

The learner must know the following:

Faraday's law of Electromagnetic induction (Grade 11)
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).

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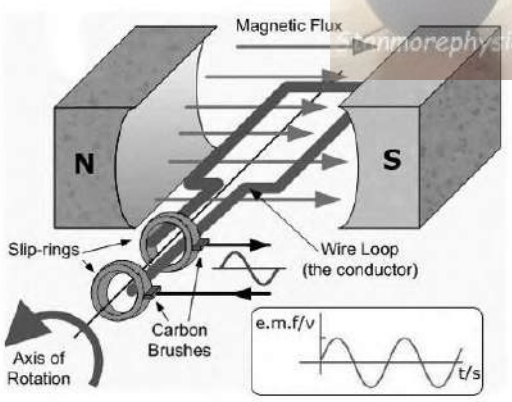
1 GENERATORS

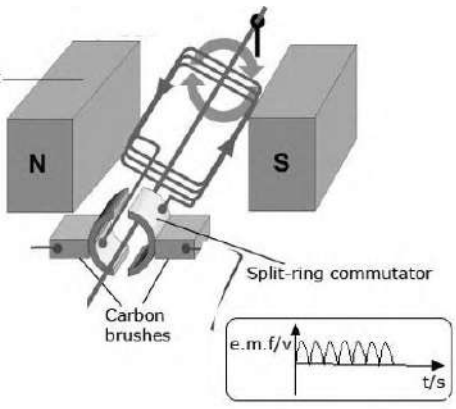
Energy conversion: Mechanical energy to electrical energy.
Principle: electromagnetic induction.
Electromagnetic induction: A changing magnetic field induces a current in a conductor.
Faraday's law: The induced emf is equal to the rate of change of magnetic flux.

TYPES OF GENERATORS

AC GENERATOR



DC GENERATOR



Components and functions

Slip rings
Allows the continuous rotation of the coil

Allows the induced current to change direction every half rotation of the coil.

Carbon brushes
Maintain electrical contact with slip rings.

Allows connection to the external circuit.

Armature coil
Allows current to be induced through it as it rotates in the magnetic field.

Magnet
Provides the magnetic field.

Components and functions

Split ring commutator
Allows the continuous rotation of the coil

Allows the induced current to flow in one direction as the coil rotates.

Carbon brushes
Maintain electrical contact with the split ring commutator.

Allows connection to external circuit.

Armature coil
Allows current to be induced through it as it rotates in the magnetic field.

Magnet
Provides the magnetic field.

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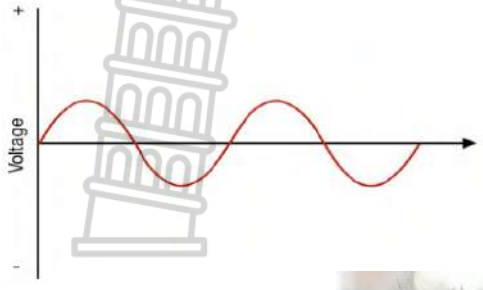
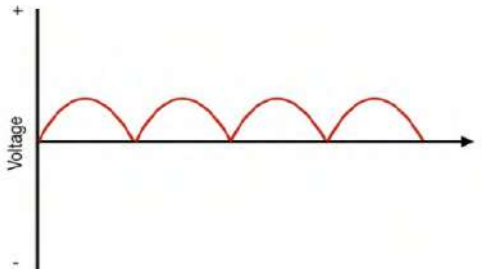
AC generators produce an Alternating current.



DC generators produce a Direct current.



How to increase the output voltage of a generator:

Increase the speed of rotation of the coil
Use a stronger magnet
Increase the number of conductors in the coil

How to determine the direction of the induced current in the coil?:

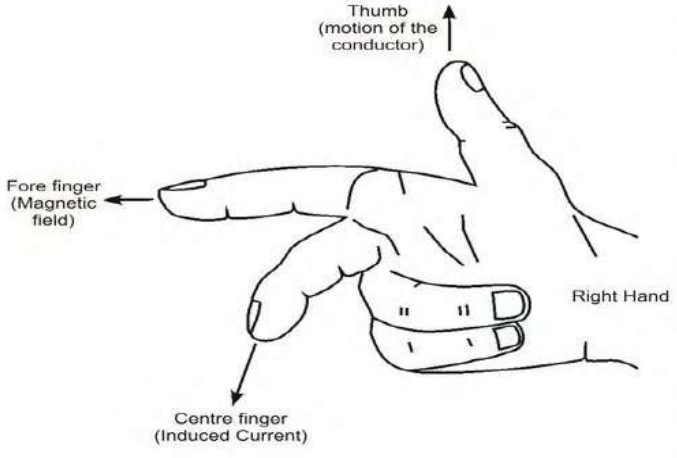
Fleming's Right-hand rule:

Three fingers (Thumb, Index and middle finger) placed at 90° with each other, representing the following directions:

Thumb: Motion

Index: Magnetic field

Middle finger: Current



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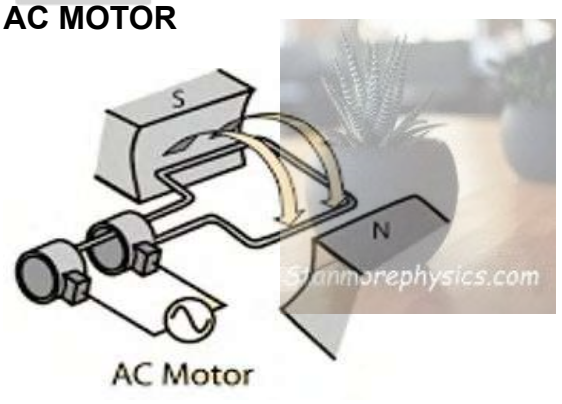
2 MOTORS

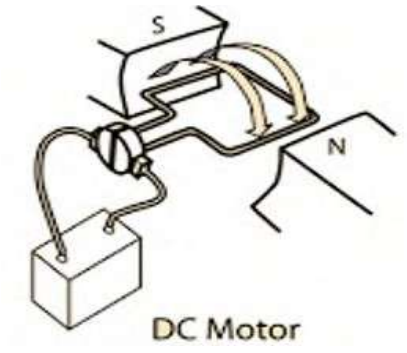
Energy conversion: Electrical energy to mechanical energy.
Principle: Motor effect.
Motor effect: A current carrying conductor placed in a magnetic field experiences a force.

Types of motors

AC MOTOR



DC MOTOR



Generators and motors (AC and DC) have the same components except that motors have a source of electrical energy such as an alternator (for AC) or battery (for DC).

How to increase the rotational speed of a motor:

Increase the input current (voltage)
Use a stronger magnet
Increasing the number of conductors in the coil
How to determine the direction of motion of the coil:

Fleming Left-hand rule:

Three fingers (Thumb, Index and middle finger) placed at 90° with each other, representing the following directions:

Thumb: Motion

Index: Magnetic field

Middle finger: Current

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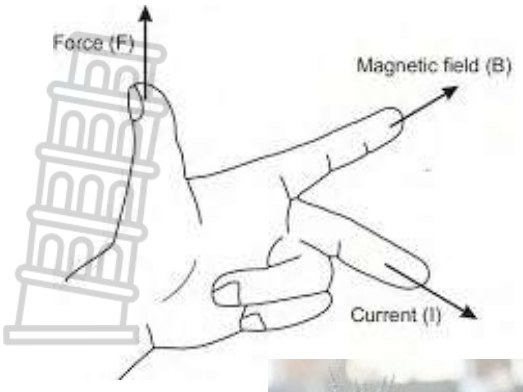

Differences between AC and DC machines

AC machines have slip rings

DC machines have a split ring commutator

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ALTERNATING CURRENT

Alternating current means current that changes direction over time. The polarity changes every half of a rotation.

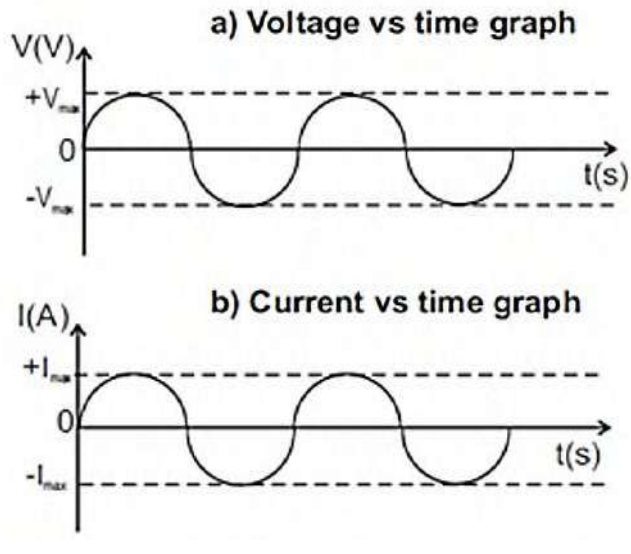
Advantages of alternating current over direct current

AC can be stepped up or stepped down by using transformers.

Allows electrical energy to be transmitted in electric cables over long distances without much energy loss.

Cheaper to convert AC to DC

AC Graphs



Root mean square (rms)

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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).

Applicable formulae

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

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

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

$P_{ave} = I^2_{rms} \times R$

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

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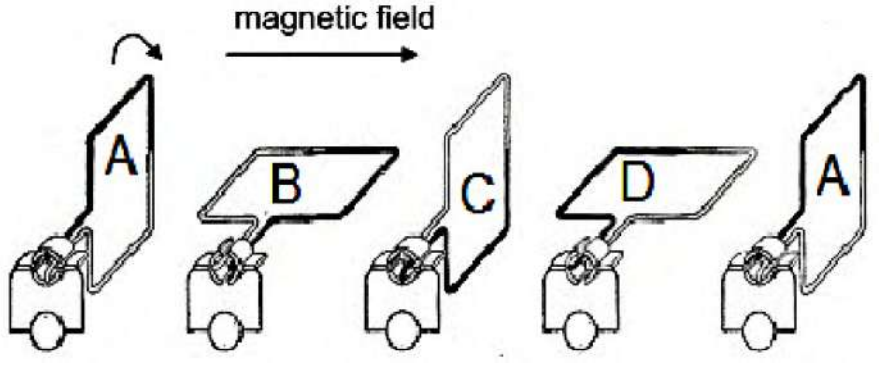
WORKED EXAMPLE 1

1.



1.1 The diagram shows different positions (**ABCDA**) of the coil in a DC generator for a complete revolution. The coil is rotated clockwise at a constant speed in a uniform magnetic field. The direction of the magnetic field is shown in the diagram.

1.1.1 Write down the energy conversion that takes place during the operation of the DC generator (1)

1.1.2 Sketch a graph to show how the induced emf of the generator varies with time. Clearly indicate positions A, B, C, D and A on the graph. (2)

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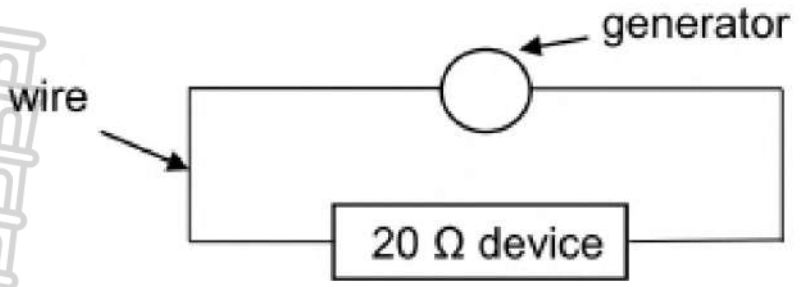
1.2



A small AC generator, providing an rms voltage of 25 V, is connected across a device with a resistance of 20 Ω. The wires connecting the generator to the device have a total resistance of 0,5 Ω. Refer to the diagram.

1.2.1 Write down the total resistance of the circuit. (1)

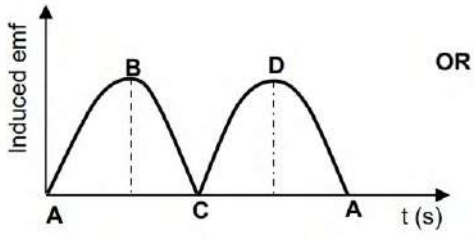
1.2.2 Calculate the average power delivered to the device. (5)

SOLUTIONS

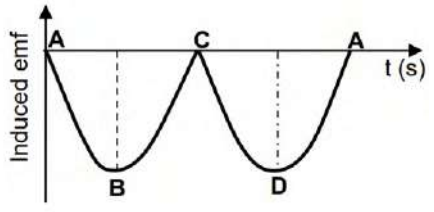
1.1

1.1.1 Mechanical to electrical √ (1)

1.1.2



OR



Criteria for graph	
Correct DC shape, starting from zero	✓
Positions ABCDA correctly indicated on the graph	✓

1.2 1.2.1 20,5 Ω ✓

1.2.2 (5)

<u>OPTION 1</u>

$I_{rms} = \frac{V_{rms}}{R}$ ✓

$= \frac{25}{20.5}$ ✓

$= 1.22\ A$

$P_{av} = I_{rms}^2 R$ ✓ $= (1.22)^2(20)$✓	$W = I_{rms}^2 R\Delta t$ $= (1.22)^2 0.5(1)$ $= 0.74J$	$P_{av} = I_{rms}^2 R$ $= (1.22)^2(0.5)$ $= 0.74W$

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$= 29.77W$ ✓	$P_{av} = \frac{V_{rms}^2}{R}$ ✓ $= \frac{(25)^2}{20.5}$ ✓ $= 30{,}49W$ *Actual energy delivered per second (power)* $(30.49 - 0.74)$ $= 29.75W$ ✓	$P_{av} = \frac{V_{rms}^2}{R}$ ✓ $= \frac{(25)^2}{20.5}$ ✓ $= 30{,}49W$ *Actual energy delivered per second (power)* $= (30.49 - 0.74)$ $= 29.75W$ ✓

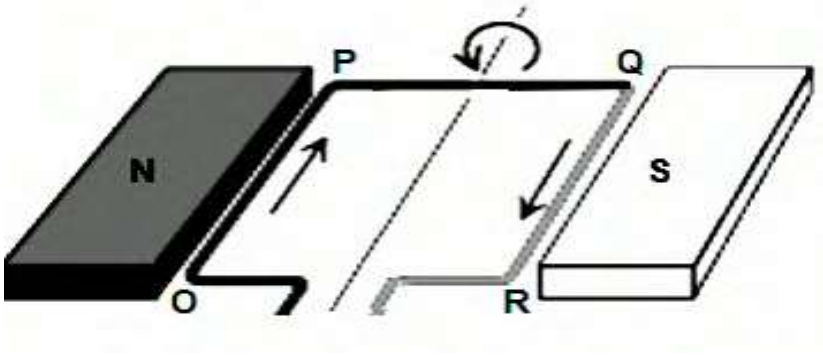
OPTION 2

$V_{rms} = \frac{20}{20.5} \times 25$ ✓ $= 24{,}39V$

$P_{av} = \frac{V_{rms}^2}{R}$ ✓ $= \frac{(24.39)^2}{20}$ ✓ $= 29.74W$ ✓

QUESTION 1 (Multiple choice questions)

1.1 A DC current passes through a rectangular wire loop OPQR placed between two pole pieces of a magnet, as shown below.



Which TWO segments of the loop will experience an electromagnetic force when the loop is in the position above?

A OP and PQ

B QR and RO

C OP and QR

D RO and OP (2)

1.2 In a DC generator, the current to the external circuit is delivered through the …

A Coils

B Battery

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C Slip rings

D Split ring commutator (2)

1.3 The Speed of rotation of the coils in an AC generator is increased.

Which one of the following combinations of frequency and output voltage for the generator will occur as a result of the change?

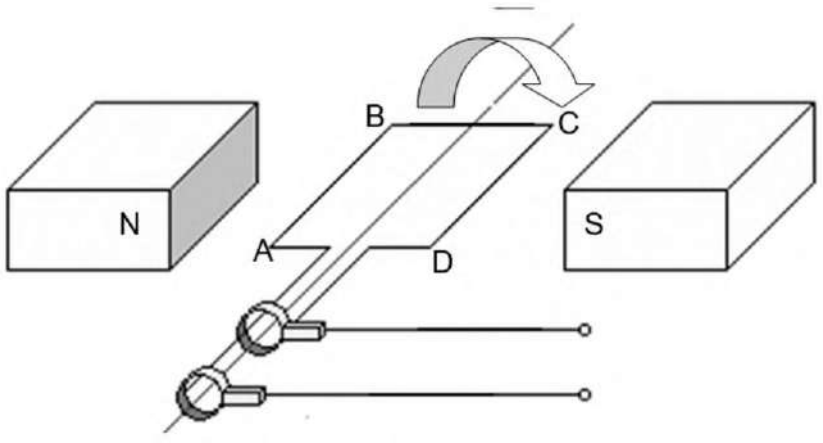
	FREQUENCY	OUTPUT VOLTAGE
A	Increases	Increases
B	No change	Increases
C	Decreases	Decreases
D	Increases	No change (2)

[6]

LONG QUESTIONS

QUESTION 1

A simplified diagram of an electric machine is shown below.



1.1 Is this electric machine a generator or an electric motor? Give a reason for the answer. (2)

1.2 Write down the names of the components labelled A, B, C and D. (1)

1.3 Give a reason why carbon is preferred over iron for the brushes in electric machines. (1)

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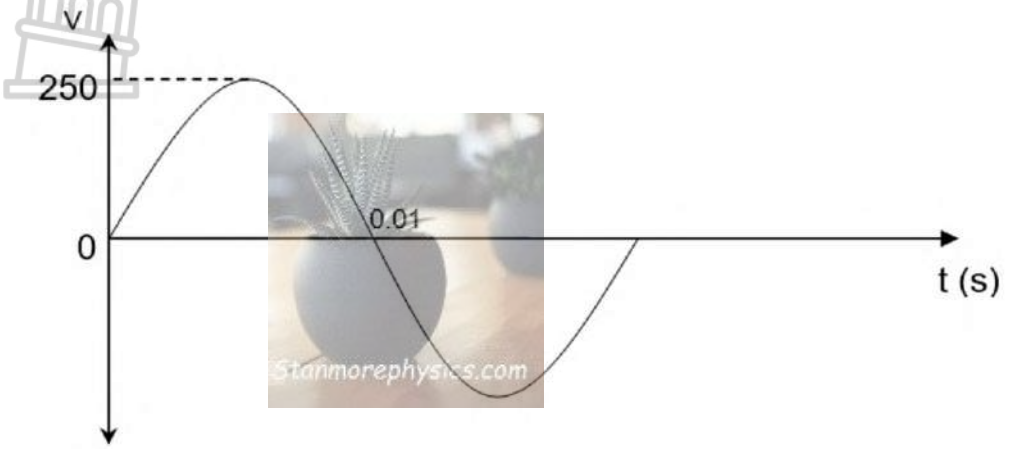
1.4 In which direction is the current flowing? (2)

Choose from A to B or B to A.

1.5 The graph below of voltage vs time was obtained from an alternating current generator.

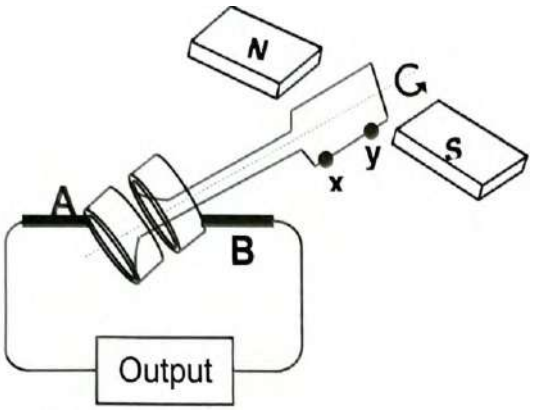


1.5.1 Calculate the frequency of this voltage. (2)

1.5.2 Calculate the average power generated if the generator produces a maximum current of 2 A. (5)

[13]

QUESTION 2



2.1 Does the diagram represent an AC or a DC generator? Suggest a reason for the answer. (2)

2.2 State the energy conversion that takes place in this generator. (1)

2.3 For the parts labelled **A** and **B** in the diagram, write down:

2.3.1 Their name (1)

2.3.2 Their function (1)

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2.4 The part XY of the coil is about to move upwards. As soon as it moves upwards, will the induced current flow from X to Y or from Y to X? (1)

2.5 The peak voltage supplied by this generator is 120 V.

2.5.1 In the position that the coil is shown, is the output voltage 0V, 85 V or 120 V? (1)

The rms value of the current supplied to the external circuit is 1,2 A.

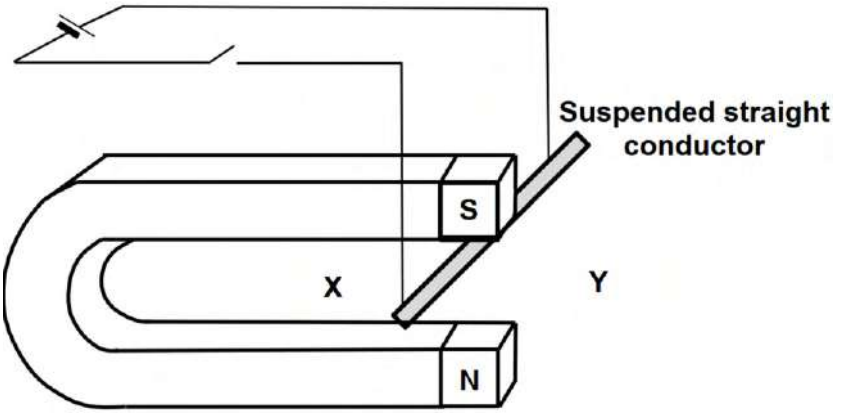
2.5.2 Define the term rms for an alternating current. (2)

2.5.3 Calculate the average power output of the generator. (4)

[13]

QUESTION3

3.1 The diagram below shows a straight conductor connected to a battery and suspended between the poles of a permanent magnet so that it is perpendicular to the magnet. The conductor is free to move.



3.1.1 The switch is closed. Will the conductor move towards X or Y? (1)

3.1.2 Write down ONE change that could be made to the set-up, so that the conductor will move in the opposite direction. (1)

3.1.3 Identify TWO changes that could be made to increase the emf through the conductor. (2)

3.2 An AC generator, producing a maximum voltage of 460 V, is connected to a heater of resistance 40 Ω.

3.2.1 Define the root mean square potential difference. (2)

3.2.2 Write down the TWO structural differences between the AC generator and the DC generator. (2)

3.2.3 Calculate the root mean square value of the voltage. (3)

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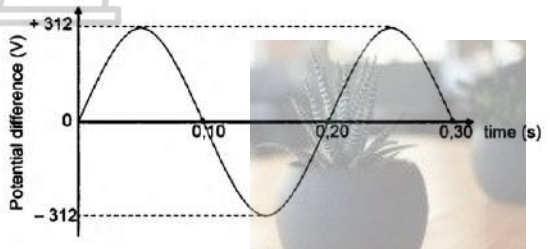
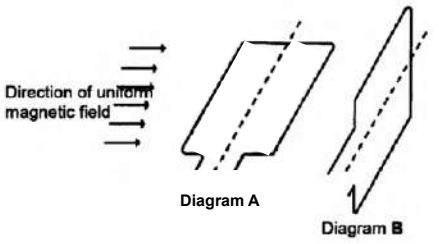
3.2.4 Calculate the root mean square value of the current in the heater. (4)

[4]

QUESTION 4

The graph shows the voltage output of a generator. Diagrams A and B show the position of the generator at different times.





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

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

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

4.4 A device with a resistance of 40 Ω is connected to this generator. Calculate the:

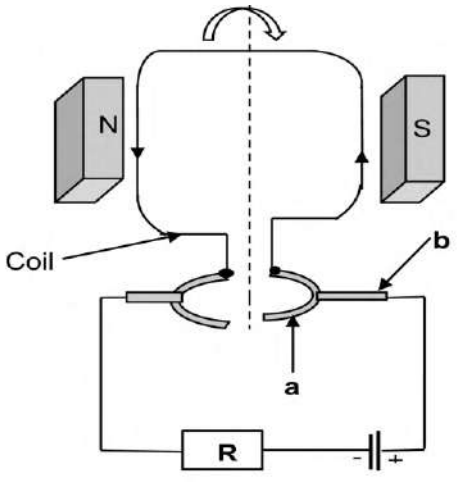
4.4.1 Average power delivered by the generator to the device (3)

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

[12]

QUESTION 5

A diagram below shows a simplified electric motor.



5.1.1 Write down the energy conversion which takes place in an electric motor. (1)

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5.1.2 Is this an AC or DC electric motor? Give a reason for the answer. (2)

5.1.3 Name the component b. (1)

5.1.4 Write down the function of component a. (1)

5.1.5 The resistance R is now decreased. What is the effect of this change on the speed of the motor? Choose from INCREASES, DECREASES or STAYS THE SAME. Give a reason for the answer. (2)

5.2 A municipality experiences a temporary power shortage. During this period the root mean square (rms) voltage reduced from 220 V to 200 V.

5.2.1 Define the term rms voltage. (2)

5.2.2 Calculate the maximum (peak) voltage during the power shortage. (3)

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PHOTOELECTRIC EFFECT

ELECTROMAGNETIC RADIATION

Dual (particle/wave) nature of electromagnetic radiation

Explain that some aspects of the behaviour of electromagnetic radiation can best be explained using a wave model and some aspects can best be explained using a particle model.

Nature of electromagnetic radiation

Describe the source of electromagnetic waves as an accelerating charge.

Describe how an electromagnetic wave propagates when an electric field oscillating in one plane produces a magnetic field oscillating in a plane at right angles to it, which produces an oscillating electric field, and so on.

State that these mutually regenerating fields travel through space at a constant speed of 3×10^8 $m \cdot s^{-1}$, represented by c.

List properties of electromagnetic waves:

Originate from accelerating electric charges

Propagate as electric and magnetic fields that are perpendicular to each other

Can travel through a vacuum

Have a speed of 3×10^8 $m \cdot s^{-1}$

Electromagnetic spectrum

Given a list of different types of electromagnetic radiation, arrange them in order of frequency or wavelength.

Given the wavelength of electromagnetic waves, calculate the frequency and vice versa, using the equation $c = f\lambda$.

Give an example of the use of each type of electromagnetic radiation, i.e. gamma rays, X-rays, ultraviolet light, visible light, infrared, microwave and radio and TV waves.

Nature of electromagnetic as particle

Define a photon as a packet of energy found in light.

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Relate the energy of a photon to the frequency and wavelength of the light.

Calculate the energy of a photon using: $E = hf = \frac{hc}{\lambda}$ where $h = 6{,}63 \times 10^{-34}$ J·s is Planck's constant, $c = 3 \times 10^{8}$ m·s^{-1} is the speed of light in a vacuum and **λ** is the wavelength.

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

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

Work function, W_o, is the minimum energy that an electron in the metal needs to be emitted from the metal surface.

Perform calculations using the photoelectric equation:

$E = W_o + E_{k(max)}$, where $E = hf$ and $W_o = hf_o$ and $E_{k(max)} = ½ mv^2_{max}$

Where: E= energy of light (J)

h= Planck's constant ($6{,}63 \times 10^{-34}$ J.s^{-1})

f = frequency (Hz)

W_o= work function (J)

$E_{k(max)}$= maximum kinetic energy (J)

v_{max}= maximum velocity (m.s^{-1})

m= mass of an electron ($9{,}11 \times 10^{-31}$ kg)

The **frequency** of the incident light is increased while its intensity (brightness) remains constant:

Number of photoelectrons emitted remain the same

Kinetic energy of photoelectrons increases

the speed at which the photoelectrons move away from the metal increases

The **intensity** (brightness) of the incident light is increased while its frequency remains constant:

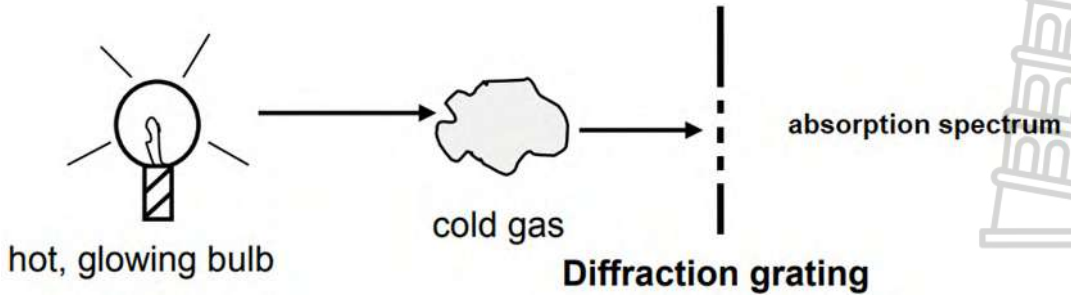
The kinetic energy and speed of the emitted photoelectrons remains constant

More photons strike the metal surface per unit time.

More photoelectrons are emitted from the metal surface per unit time.

The current (ammeter reading) increases.

Atomic absorption spectrum is formed when certain frequencies of electromagnetic radiation passing through a substance is absorbed.



Atomic 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

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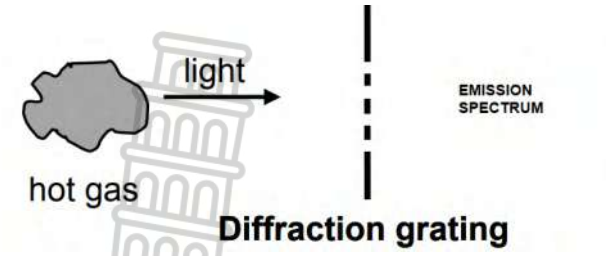
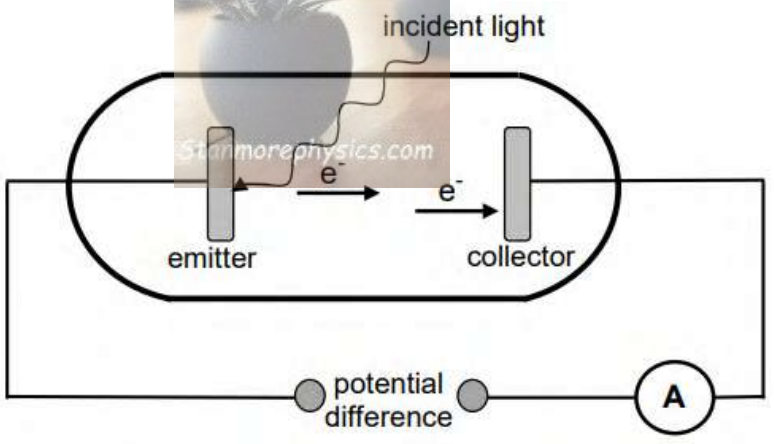


WORKED EXAMPLE 1

In the simplified diagram below, light is incident on the emitter of a photocell. The emitted photoelectrons move towards the collector and the ammeter registers a reading.



1.1 Name the phenomenon illustrated above. (1)

1.2 The work function of the metal used as emitter is 8,0 x 10^{-19} J. The incident light has a wavelength of 200 nm.
Calculate the maximum speed at which an electron can be emitted. (5)

1.3 Incident light of a higher frequency is now used.
How will this change affect the maximum kinetic energy of the electron emitted in QUESTION 1.2? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

1.4 The intensity of the incident light is now increased.
How will this change affect the speed of the electron calculated in QUESTION 1.2? Write down INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

1.5 A metal worker places two iron rods, A and B, in a furnace. After a while he observes that A glows deep red while B glows orange.
Which ONE of the rods (A or B) radiates more energy? Give a reason for the answer. (2)

1.6 Neon signs illuminate many buildings. What type of spectrum is produced by neon signs? (1)

[12]

SOLUTIONS

1.1 Photo-electric effect (1)

1.2 $E = W_0 + E_{K(MAX)}$ ✓ (5)

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$\frac{(6.63\times10^{-34})(3\times10^{8})}{(200\times10^{-9})} = 8\times10^{-19} + \frac{1}{2}(9{,}11\times10^{-31})v^{2}{}_{max}$✓✓✓

$v_{max} = 6{,}53\times10^{5} m.s^{-1}$✓

1.3 Increases✓ (1)

1.4 Remains the same ✓

Intensity only affects number of photoelectrons emitted per second. ✓ (2)

1.5 B ✓

Orange light has a higher frequency than red light. ✓ (2)

1.6 Line emission✓

[12]

<u>WORKED EXAMPLE 2</u>

During an investigation, light of different frequencies is shone onto the metal cathode of a photocell. The kinetic energy of the emitted photoelectrons is measured. The graph below shows the results obtained.

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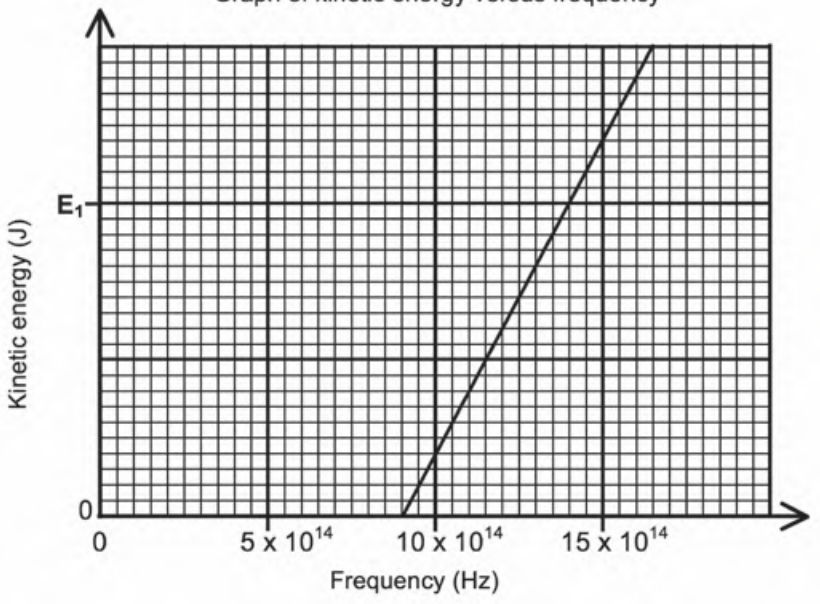
Graph of kinetic energy versus frequency



2.1 For this investigation, write down the following:

2.1.1 Dependent variable (1)

2.1.2 independent variable (1)

2.1.3 Controlled variable (1)

2.2 Define the term threshold frequency. (2)

2.3 Use the graph to obtain the threshold frequency of the metal used as cathode in the photocell. (1)

2.4 Calculate the kinetic energy at E_1 shown on the graph. (4)

2.5 How would the kinetic energy calculated in QUESTION 4 be affected if light of higher intensity is used? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[11]

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SOLUTIONS

2.1.1 Kinetic energy ✓ (1)

2.1.2 Frequency ✓ (1)

2.1.3 Type of metal ✓ (1)

2.2 The minimum frequency needed to emit electrons from the surface of a metal. ✓✓ (2)

2.3 9×10^{14} Hz ✓ (1)

2.4 $E = W_0 + E_{k(max)}$ ✓

$(6{,}63 \times 10^{-34})(14 \times 10^{14})$ ✓ $= (6{,}63 \times 10^{-34})(9 \times 10^{14}) + E_{k(max)}$ ✓

$E_{k(max)} = 3{,}32 \times 10^{-19}$ J ✓ (4)

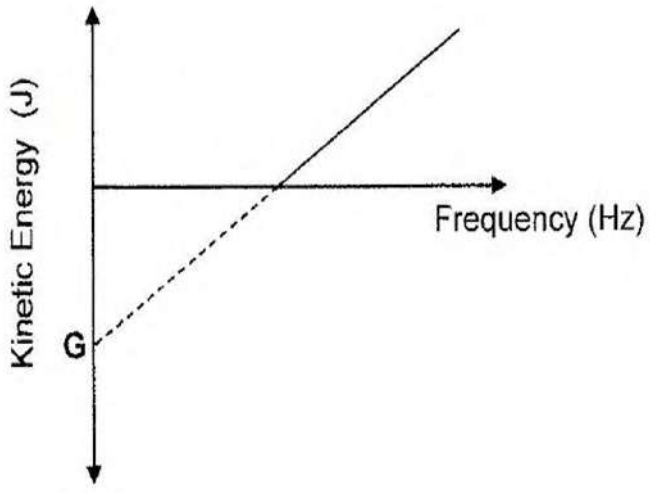
2.5 Remains the same ✓ (1)

[11]

QUESTION 1(MCQ)

Various options are provided as possible answers to the following questions. Choose the answer and write only the letter (A–D) next to the question numbers.

1.1 The graph below shows the relationship between maximum kinetic energy $E_{k(max)}$ of the photoelectrons and frequency of the incident photons during an experiment on the photoelectric effect.



The point labelled G on the graph represent the…

A Threshold wavelength.

B Maximum frequency.

C Threshold frequency.

D Work function. (2)

1.2 Which ONE of the following statements CORRECTLY describes the photoelectric effect?

A An electron absorbs the energy of a photon and emits light.

B An electron emits a photon when it collides with another electron

C An electron absorbs the energy of a photon and is ejected from the surface of a metal.

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D A photon is emitted when an electron moves from a lower energy level to a higher energy level. (2)

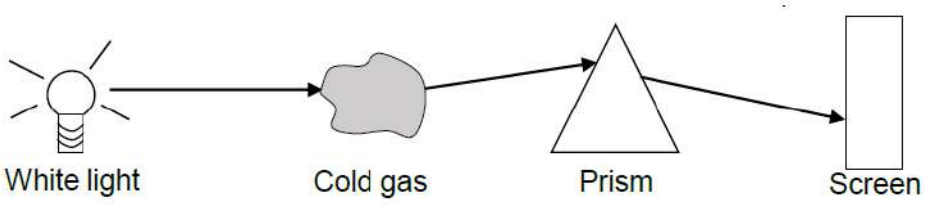
1.3 Which of the following statements is/are TRUE for the photoelectric effect?
The photoelectric effect demonstrates that:
(i) Light has a wave nature
(ii) light has a particle nature
(iii) light energy is quantised

A only
B only
C and (iii) only
D and (iii) only (2)

1.4 The work function of zinc is greater than that of magnesium.
Which ONE of the following statements about the threshold frequencies of the metals is CORRECT?

A The threshold frequency of zinc is greater than that of magnesium.
B The threshold frequency of zinc is smaller than that of magnesium.
C Both zinc and magnesium have the same threshold frequency.
D The threshold frequencies of zinc and magnesium are independent of their work functions (2)

1.5 White light is passed through a cold gas and then through a prism, as shown below. A line spectrum is observed on the screen.



Which ONE of the following correctly describes the ENERGY TRANSITION of the atoms of the gas and the TYPE OF LINE SPECTRUM observed on the screen?

	ENERGY TRANSITION	TYPE OF LINE SPECTRUM
A	Higher to lower energy level	Emission
B	Lower to higher energy level	Emission
C	Higher to lower energy level	Absorption
D	Lower to higher energy level	Absorption (2)

1.6 The graph below is obtained from an experiment on the photoelectric effect.

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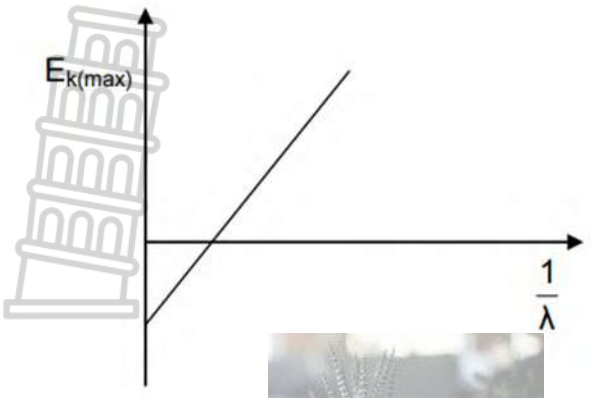


Which ONE of the following represents the gradient of the graph?

A hc

B h

C $\frac{E_{K(MAX)}}{\lambda}$

D W_0 (2)

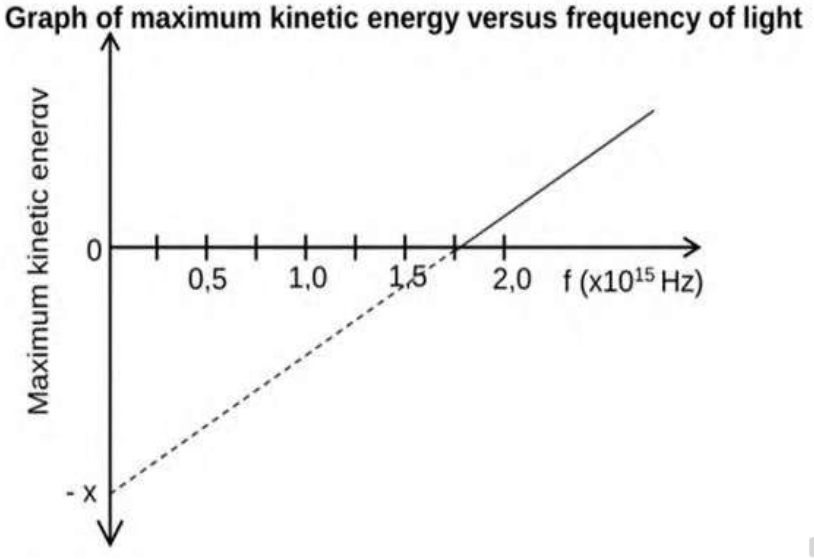
[12]

LONG QUESTIONS (PHOTOELECTRIC EFFECT)

QUESTION 2

An experiment is conducted to investigate the relationship between the frequency of the light incident on a metal cathode and the maximum kinetic energy of the emitted electrons from the surface of a metal cathode of a photocell.

The graph represents the results obtained.



2.1 For this investigation, write down the following

2.1.1 Controlled variable (1)

2.1.2 Dependent variable (1)

2.2 Name the phenomenon on which this experiment is based. (1)

2.3 Define the term work function in words. (2)

2.4 Calculate the:

2.4.1 Value of x as shown on the graph (3)

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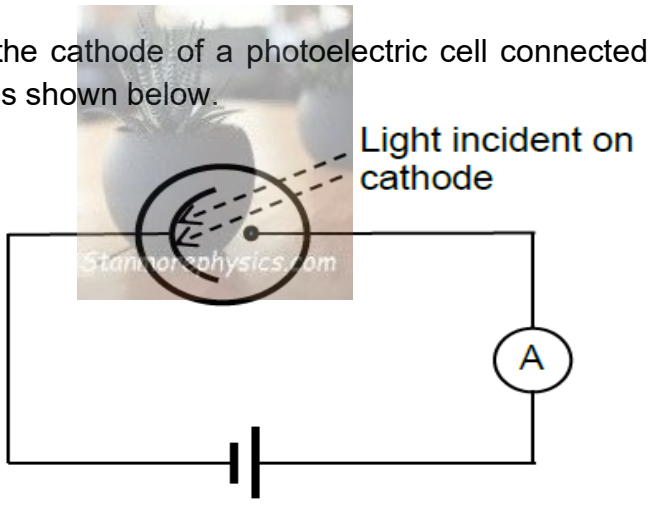
2.4.2 Frequency of the incident light that will emit electrons from the surface with a maximum speed of $5{,}23 \times 10^5 m.s^{-1}$ (4)

2.5 The intensity of the light is now increased. State how this change affects the current in the photocell.
Choose from INCREASES, DECREASES or REMAIN THE SAME.
Explain your answer. (3)

[15]

QUESTION 3

Light is incident on the cathode of a photoelectric cell connected to a battery and a sensitive ammeter, as shown below.



3.1 What conclusive evidence about the nature of light is provided by the photoelectric effect? (1)

The cathode has a work function of $3{,}42 \times 10^{-19}$ J.

3.2 Define the term work function. (2)

Light of frequency $5{,}96 \times 10^{14}$ Hz is shone onto the cathode.

3.3 Calculate the maximum kinetic energy of an electron ejected from the cathode. (4)

3.4 The ammeter registers a constant current of 0,012 A.
Calculate the minimum number of photons of light that strike the cathode in a 10 s period. (4)

3.5 The intensity of the incident light is now INCREASED. How will this change affect the reading on the ammeter?
Choose from INCREASES, DECREASES or REMAINS THE SAME. Explain the answer. (3)

[14]

QUESTION 4

Light of different frequencies is incident on a metal plate. The sketch graph below shows the relationship between the maximum kinetic energy, $E_{k(max)}$, of the photoelectrons and the energy of the incident photons.

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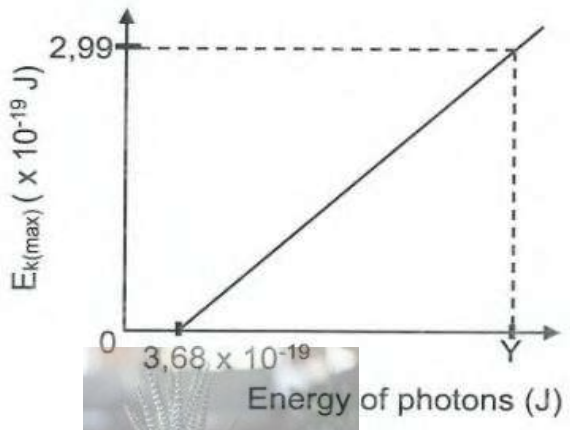

4.1 Define the term work function of the metal. (2)

4.2 Write down the numerical value of the gradient of the above graph. (2)

4.3 Calculate the:

4.3.1 Maximum speed of the electrons when photons with energy Y, as shown on the graph, strike the metal plate (3)

4.3.2 Value of Y (4)

4.4 Photon with energy 4,02 x 10^{-19}J strike the metal plate and photoelectron are emitted.

The number of photons with energy 4,02 x 10^{-19} J that strike the metal plate per second has increased.

How will the maximum kinetic energy of the photoelectrons be affected?

Choose from INCREASES, DECREASES or REMAIN THE SAME (2)

[13]

QUESTION 5

Work function of two metals are listed in the table below.

METAL	Work function (J)
Sodium	2,46 x 10^{-19}
Platinum	6,35 x 10^{-19}

5.1 Define work function. (2)

The sodium surface is illuminated with light having a wavelength of 400 x 10^{-9} m

5.2 Calculate the energy of the photon. (3)

5.3 Calculate the maximum speed of the ejected electrons. (4)

5.4 The same light is now incident on a platinum metal.

Will the electrons be ejected from the platinum metal?

Choose from: YES or NO

Write down a reason for your answer. (2)

[11]

QUESTION 6

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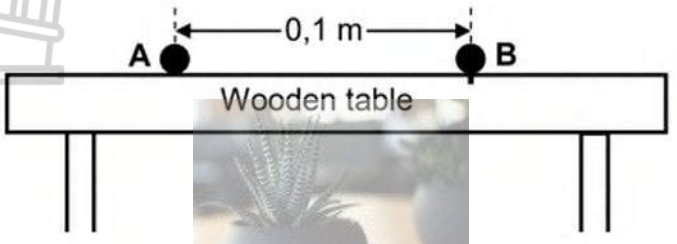
High-intensity ultraviolet light of frequency 2,8 x10^{16} Hz is now shone continuously onto sphere **B.** The work function of zinc is 6,63x10^{-19}J

6.1 Two small spheres, A and B made up of pure zinc are at rest 0,1m apart on a wooden table. Sphere A is negatively charged and is free to move on the table, while sphere B is uncharged and fixed to the table, as shown in the diagram below:



6.1.1 Explain, using a suitable calculation, why the ultraviolet light shone on sphere B will eject electrons from its surface. (4)

6.1.2 Sphere A carried a charge of -5,4 x 10^{-6}C and requires a minimum force of 0,027 N to move from rest.
Calculate the minimum number of photons of ultraviolet light that must strike sphere B which will cause sphere A to move from its rest position. (6)

6.2 A beam of white light is shone through a cold gas. The emerging light is dispersed and a line spectrum is observed on a screen.

6.2.1 Name the type of line spectrum observed. (1)

6.2.2 Describe the spectrum referred to in QUESTION 6.2.1. (2)

6.2.3 The diagrams below indicate some possible energy transitions made by atoms.
Which ONE of the diagrams could result in the type of spectrum observed in QUESTION 6.2.1? choose from DIAGRAM A or DIAGRAM B.

DIAGRAM A

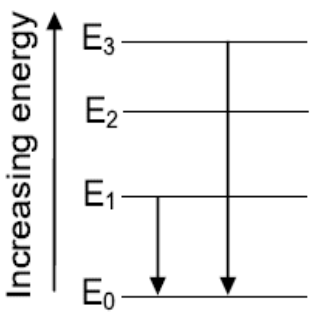
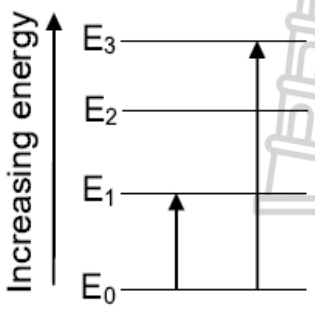


DIAGRAM B



(1)

[14]

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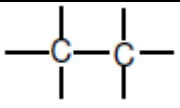
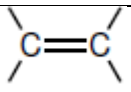
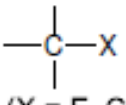
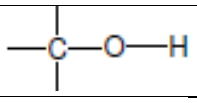
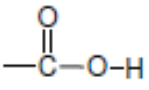
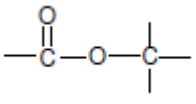
MATTER AND MATERIALS
ORGANIC MOLECULES

Hydrocarbon: Organic compounds that consist of hydrogen and carbon only.
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 (triple/double) bonds between C atoms.
Molecular formula: A chemical formula that indicates the type of atoms and the correct number of each in a molecule.
Structural formula: A structural formula of a compound shows which atoms are attached to which within the molecule.
Condensed structural formula: This notation shows the way in which atoms are bonded together in the molecule, but DOES NOT SHOW ALL bond lines.
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 CH_2 group.
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	FUNCTIONAL GROUP	NAME OF FUNCTIONAL GROUP	GENERAL FORMULA	SUFFIX IN NAMING
Alkanes		Single bond between carbon atoms	C_nH_{2n+2}	-ane
Alkenes		Double bond between carbon atoms	C_nH_{2n}	-ene
Alkynes		Triple bond between carbon atoms	C_nH_{2n-2}	-yne
Haloalkanes/ Alkyl halides	 (X = F, Cℓ, Br, I)	Halogen atom bonded to C atom in an alkane	$C_nH_{2n+1}X$	Chloro-ane, bromo-ane
Alcohols		Hydroxyl group	$C_nH_{2n+1}OH$	-anol
Carboxylic Acids		Carboxyl group	$C_nH_{2n+1}COOH$	--anoic acid
Esters		-	RCOOR	-yl -anoate

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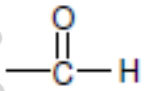
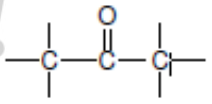
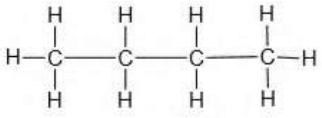
Aldehydes		Formyl group	RCHO	-anal
Ketones		Carbonyl group bonded to C-atoms	RCOR'	-anoate

Structural isomer: Organic molecules with the same molecular formula, but different structural formulae

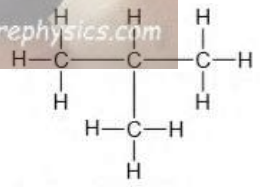
Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.

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.

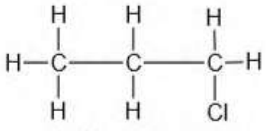


butane

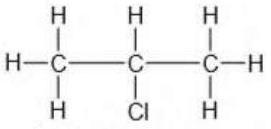


2-methylpropane

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

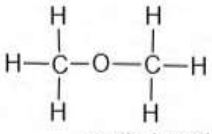


1-chromopropane

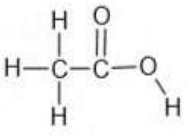


2-chromopropane

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.

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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

Factors that influence the physical property will always be the independent variable and the physical property (Boiling Point, Melting Point, Vapour Pressure) will always be the dependent variable being tested in an investigation)

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
(CAKAEHAAA)

The stronger the intermolecular force the higher the boiling point and melting point, lower vapour pressure.

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WEAK INTERMOLECULAR FORCE	WEAK INTERMOLECULAR FORCE
London Forces Alkanes, alkenes and alkynes Dipole-dipole Aldehydes, ketones, haloalkanes and esters Shorter C-Chains Smaller molecular mass Branched C-Chains	Hydrogen Bonds Alcohols Carboxylic Acids ***Carboxylic acids stronger intermolecular forces than alcohols because it has 2 sites available for H-bonding, alcohols have only 1 site.*** Longer C-Chains Greater molecular mass Straight C-Chains
Less energy required to overcome intermolecular forces – Low Boiling Point/ Melting Point, High Vapour Pressure	More energy required to overcome intermolecular forces – High Boiling Point/ Melting Point, Low Vapour Pressure

Guideline for answering questions

State homologous series and type of intermolecular force

Compare the strength of intermolecular forces

Energy required

Conclusion

ORGANIC 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.

Dehydration: The elimination of water from an alcohol.

Cracking of alkanes: (1) Thermal or (2) Catalytic

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.

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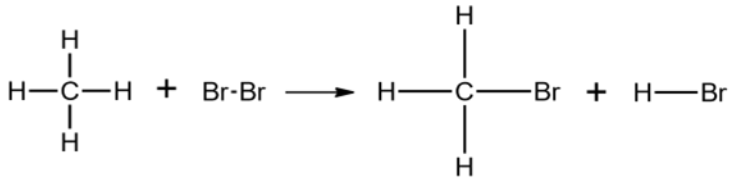
REACTIONS OF ALKANES

SUBSTITUTION
Alkane → haloalkane

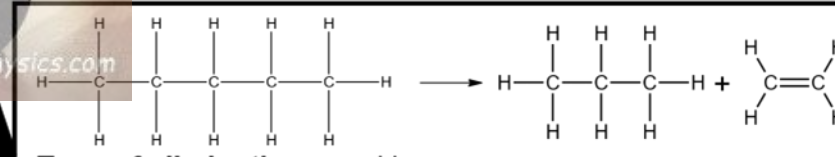


Type of substitution: halogenation
Reaction conditions: heat OR sunlight
Reactants: alkane + X_2 (F, Cℓ, Br, I)
Products: haloalkane + HX

OXIDATION (COMBUSTION)

$2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$
Alkane + oxygen → carbon dioxide + water + **energy**
Reaction conditions: Burns in EXCESS oxygen

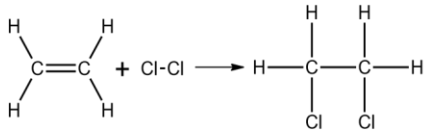
ELIMINATION
Alkane → alkene(s) + alkane with shorter chain



Type of elimination: cracking
Reaction conditions: heat + high pressure OR catalyst
Reactant: alkane
Products: alkene(s) + alkane / alkene + H_2

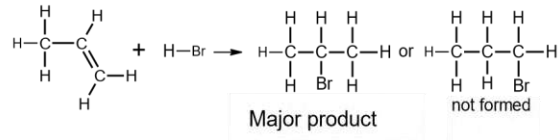
REACTIONS OF ALKENES

ADDITION



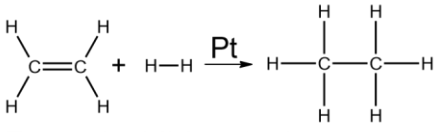
Type of addition: halogenation
Reaction conditions: unreactive solvent
Reactants: alkene + X_2 (X = Cℓ, Br)
Product: haloalkane

ADDITION



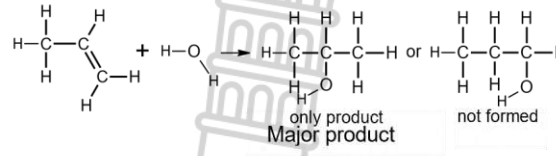
Type of addition: hydrohalogenation
Reaction conditions: no water; unreactive solvent
Reactants: alkene + HX (X = I, Br, Cℓ)
Product(s): haloalkane(s)
Major product: H atom bonds to the C atom already having the greater number of H atoms.

ADDITION



Type of addition: hydrogenation
Reaction conditions: Pt, Pd or Ni as catalyst
Reactants: alkene + H_2
Product: alkane

ADDITION



Type of addition: hydration
Reaction conditions: excess H_2O; small amount of acid (H_2SO_4) as catalyst
Reactants: alkene + H_2O
Product: alcohol(s)
Major product: H atom bonds to the C atom already having the greater number of H atoms.

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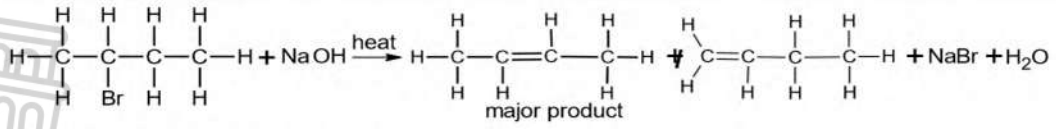
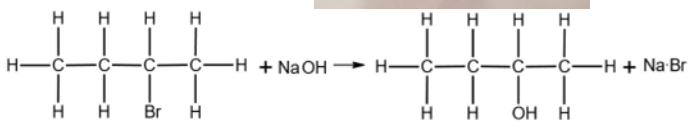


Type of elimination: dehydrohalogenation
Conditions: concentrated strong base (NaOH, KOH, LiOH) in ethanol + heat
Reactants: haloalkane + concentrated strong base **Products:** alkene + NaBr + H_2O
Major product: The one where the H atom is removed from the C atom with the least number of H atoms (most substituted double bond forms i.e. double bond with most alkyl groups)

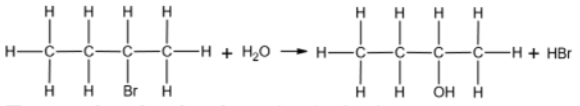
ELIMINATION

REACTIONS OF HALOALKANES

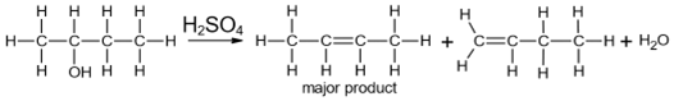
SUBSTITUTION



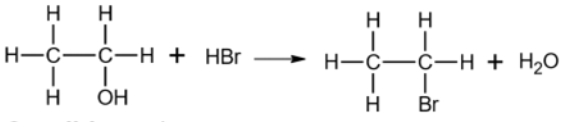
Type of substitution: hydrolysis
Conditions: dilute strong base (NaOH/KOH/LiOH) + mild heat
Reactants: haloalkane + dilute strong base
Products: alcohol + NaBr/KBr/LiBr



Type of substitution: hydrolysis
Conditions: excess H_2O + mild heat
Reactants: haloalkane + H_2O
Products: alcohol + HBr



Type of elimination: dehydration
Conditions: dehydrating agent (H_2SO_4/H_3PO_4) + heat
Reactants: alcohol + H_2SO_4
Products: alkene(s) + H_2O
Major product: The one where the H atom is removed from the C atom with the least number of H atoms



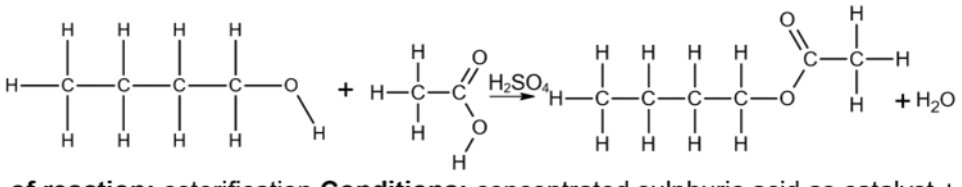
Conditions: heat
Reactants needed: alcohol + HX
Primary & secondary alcohols:
NaBr + H_2SO_4 used to make HBr in reaction flask
Tertiary alcohols: water free HBr (or HCℓ)
Products: haloalkane + H_2O

ELIMINATION
Alcohol → alkene

SUBSTITUTION

REACTIONS OF ALCOHOLS

ESTERIFICATION



Type of reaction: esterification **Conditions:** concentrated sulphuric acid as catalyst + heat
Reactants: alcohol + carboxylic acid **Products:** ester + water

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MULTIPLE CHOICE QUESTIONS

1 1.1. Which ONE of the compounds below is an aldehyde? **(Identify the molecular formula of functional group of an aldehyde)** (2)

A CH_3CHO
B CH_3COCH_3
C CH_3COOH
D CH_3OH

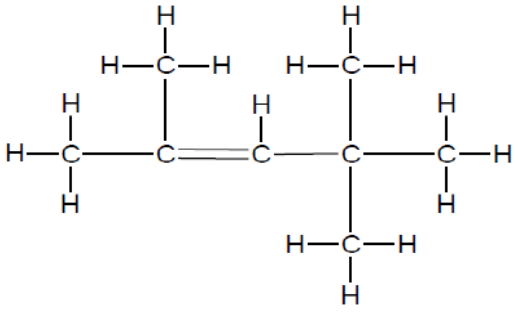
1.2. The reaction represented by the equation below takes place in the presence of a catalyst. (2)

$C_{13}H_{28}$ (l) ⟶ C_2H_4 (g) + C_3H_6 (g) + C_8H_{18} (l)

This reaction is an example of **… (Use knowledge of the different type of organic reactions**)

A addition.
B cracking.
C substitution.
D oxidation

1.3. Consider the structural formula of an organic compound below. (2)



Which ONE of the following is the correct IUPAC name of this compound? **(Review rules for IUPAC Nomenclature. Remember: Functional group takes preference over branches/ substituents)**

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

1.4. Which ONE of the following statements is CORRECT? (2)

Alkenes … **(Review chemical properties of 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.

1.5. When 2-chlorobutane is strongly heated in the presence of concentrated sodium hydroxide, the major product formed is … **(Identify reaction as a type of elimination reaction that will form a major product by applying Zaitsev's rule.)** (2)

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A but-1-ene
B but-2-ene
C butan-1-ol
D butan-2-ol

1.6. Which ONE of the following compounds is an ester? **(Identify the naming suffix of organic molecules.)** (2)

A Pentanal
B Pentan-2-ol
C Pentan-2-one
D Ethyl propanoate

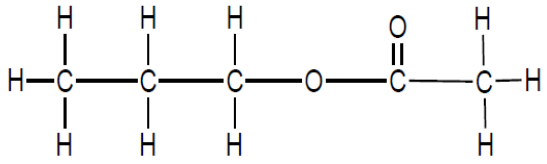
1.7. Consider the reaction represented by the equation below: (2)

$CH_3CHCH_2 + H_2 \longrightarrow CH_3CH_2CH_3$

This reaction is an example of … **(Identify type of organic reaction.)**

A hydration.
B dehydration.
C substitution.
D hydrogenation.

1.8. Consider the structural formula of a compound below. (2)



Which ONE of the following pairs of reactants can be used to prepare this compound in the laboratory? **(Recall of esterification reactions.)**

A Propanoic acid and ethanol
B Propanoic acid and methanol
C Ethanoic acid and propan-1-ol
D Methanoic acid and propan-1-ol

1.9. Which ONE of the following compounds has dipole-dipole forces between its molecules? **(Review intermolecular forces of different organic molecules.)** (2)

A Ethanal
B Ethane
C Ethene
D Ethyne

1.10. Which ONE of the following is a product formed during the hydrolysis of bromoethane? **(Recall the type of substitution reactions and their specific products.)** (2)

A Water
B Ethene
C Ethanol
D Bromine

[20]

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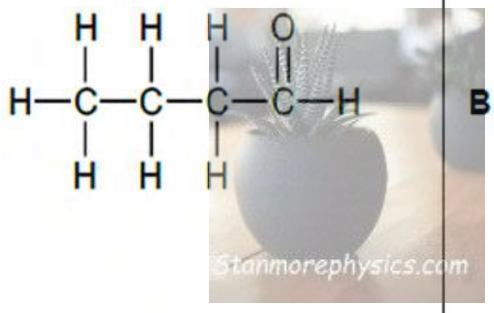
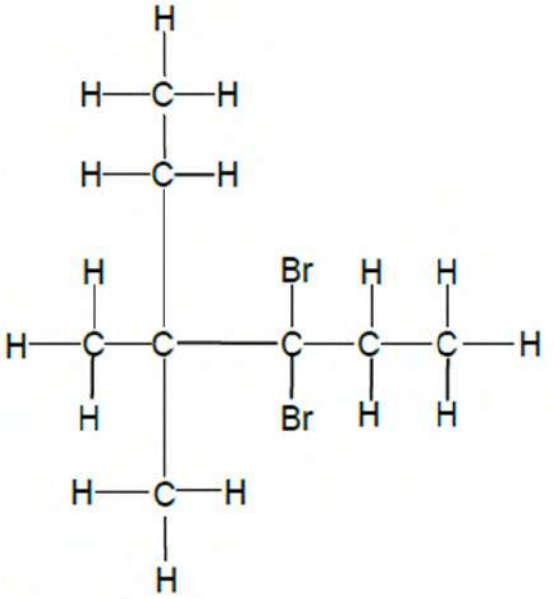
LONG QUESTIONS
QUESTION 1

The letters A to H in the table below represent organic compounds.

A		**B**	
C	Butanone	**D**	$C_4H_{10}O$
E	$CH_3C(CH_3)_2CCCH_3$	**F**	$CH_3COO(CH_2)_2CH_3$
G	$C_4H_8O_2$	**H**	$CH_3C(CH_3)_2CH_2CH_3$

Use the information in the table to answer the questions that follow.

1.1. Write down the LETTER that represents EACH of the following:
- 1.1.1 An alcohol (1)
- 1.1.2 A compound with a formyl group (1)
- 1.1.3 An unsaturated compound (1)

1.2. Write down the IUPAC name of compound:
- 1.2.1 A (2)
- 1.2.2 E (3)

1.3. Two different compounds in the above table are functional isomers.
- 1.3.1 Define the term functional isomer. (2)
- 1.3.2 Write down the LETTERS that represent these functional isomers. (1)

1.4. Compound F is formed when a carboxylic acid reacts with another organic compound, X, in the presence of a catalyst.
Write down the:
- 1.4.1 NAME or FORMULA of the catalyst (1)
- 1.4.2 Type of reaction (1)
- 1.4.3 STRUCTURAL FORMULA of compound F (2)
- 1.4.4 IUPAC name of compound X (2)

[17]

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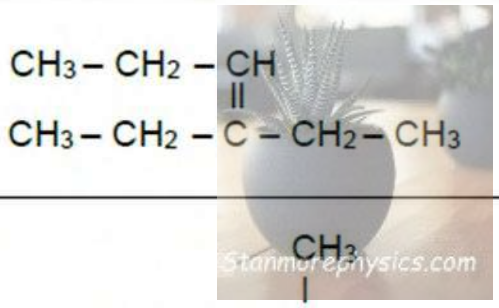
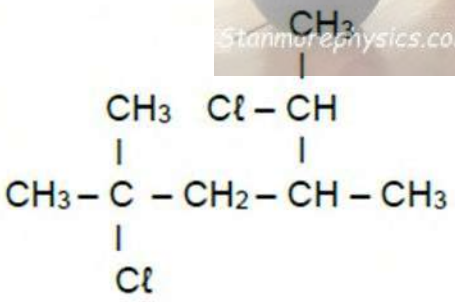
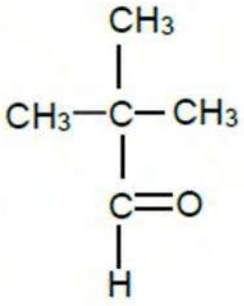
QUESTION 2

The letters A to F in the table below represent eight organic compounds.

A	Butan-2-ol	**B**	$CH_3C(CH_3)_2(CH_2)_2CH_3$
C	3-ethylpent-1-yne	**D**	$CH_3CH_2CH_2CH_2CHO$
E		**F**	Butan-1-ol
G		**H**	

2.1. Define the term hydrocarbon (2)

2.2. Write down the letter(s) for:

2.2.1 TWO compounds that are UNSATURATED hydrocarbons (1)

2.2.2 TWO compounds that are CHAIN ISOMERS of each other (2)

2.2.3 A secondary alcohol (1)

2.3. Write down the:

2.3.1 STRUCTURAL formula of the FUNCTIONAL ISOMER of compound D (2)

2.3.2 General formula of the homologous series to which compound B belongs (1)

2.3.3 STRUCTURAL formula of compound C (2)

2.4. Write down the IUPAC name of compound

2.4.1 E (3)

2.4.2 G (3)

2.4.3 H (2)

2.5 Compound B undergoes complete combustion. Using MOLECULAR FORMULAE, write down the balanced equation for this reaction. (3)

[22]

QUESTION 3

Study the table below and answer the questions that follow

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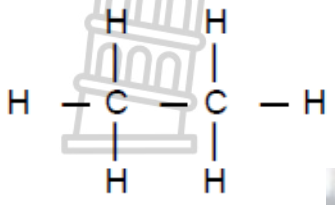
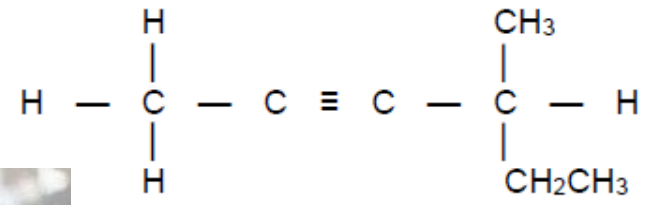
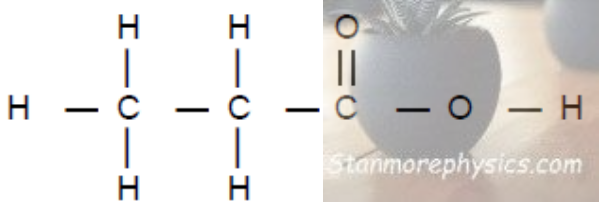
A 3-methylbutanone	**B** $C_3H_7C\ell$
C 	**D** 
E 	

3.1 Define the term *functional group*. (2)

3.2 Write down the LETTER of a compound that:

3.2.1 Contains a carboxyl group (1)

3.2.2 Has the general formula $C_nH_{2n}O$ (1)

3.2.3 Has an empirical formula of CH_3 (1)

3.3 How will the molecular mass of compound E compare to ethyl methanoate?
Choose from GREATER THAN, SMALLER THAN or EQUAL TO.
Give a reason for the answer. (3)

3.4 Write down the:

3.4.1 STRUCTURAL FORMULA of compound A (2)

3.4.2 IUPAC name of compound E (2)

3.4.3 IUPAC name of compound D (3)

3.5 Compound B is a secondary haloalkane.
Draw the STRUCTURAL FORMULA of compound B (2)

3.6 Using the MOLECULAR FORMULAE, write down the balanced equation for the complete combustion of compound D (3)

[20]

QUESTION 4

Study the table below and answer the questions that follow

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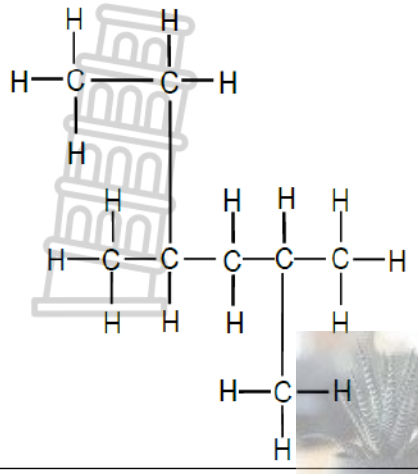
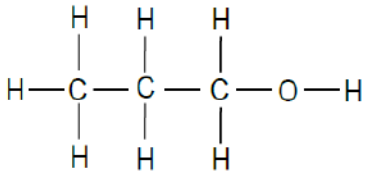
A		**B**	
C	C_4H_8O	**D**	$CH_3(CH_2)_4CHCH_2$
E	$C_XH_YO_Z$		

4.1 Define the term *unsaturated* hydrocarbon. (2)

4.2 Write down the:

4.2.1 Letter that represents an UNSATURATED hydrocarbon (1)

4.2.2 IUPAC name of compound A (3)

4.2.3 IUPAC name of the positional isomer of compound B. (2)

4.2.4 IUPAC name of compound D. (2)

4.2.5 Balanced equation, using MOLECULAR FORMULAE, for the complete combustion of compound A. (3)

4.3 The formula C_4H_8O represents two compounds that are functional isomers of each other.

4.3.1 Define the term *functional isomer.* (2)

4.3.2 Write down the STRUCTURAL FORMULAE of each of these two FUNCTIONAL isomers. (4)

4.4 A 2 g sample of compound E contains 1,09 g carbon and 0,18 g hydrogen. The molecular mass of compound E is 88 g.mol-1.

Determine the molecular formula of compound E by means of a calculation. (6)

[25]

QUESTION 5

The vapour pressures of different organic compounds are determined at 20 °C. The vapour pressures of compounds A, B and C are NOT shown in the table.

COMPOUND	IUPAC NAME	MOLAR MASS ($g \cdot mol^{-1}$)	VAPOUR PRESSURE (kPa) AT 20 °C
A	Pentane	72	
B	2-methylbutane	72	
C	2,2-dimethylpropane	72	
D	Propanoic acid	74	0,32
E	Butanal	72	12,2

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5.1 Define the term *vapour pressure* (2)

5.2 The vapour pressures of compounds A, B and C are given in random order below.

79 kPa	146 kPa	58 kPa

5.2.1 Write down the vapour pressure of compound C (1)

5.2.2 Fully explain your answer to QUESTION 5.2.1. (3)

5.3 Compounds D and E are compared.

5.3.1 Which compound has the lower boiling point? (1)

5.3.2 Fully explain the difference in the vapour pressures between compounds D and E. (4)

[11]

QUESTION 6

The boiling points of some organic compounds are shown in the table below. The atmospheric pressure is 101,3 kPa.

	ORGANIC COMPOUND	BOILING POINT (°C)
A	$CH_3CH_2CH_2CH_2C\ell$	78
B	$CH_3CH(CH_3)CH_2C\ell$	46
C	$CH_3CH_2CH_2CH_2OH$	118
D	$CH_3CH_2CH_2CHO$	X

6.1. Define the term boiling point. (2)

6.2. Which ONE of compounds A, B or C is mainly in the liquid phase at 100 °C? (1)

6.3. Explain the difference in the boiling points of compounds A and B. (3)

6.4. Consider the boiling points below.

75 °C	120 °C	126 °C

6.4.1 Which ONE of these values represents X, the boiling point of compound D? (2)

6.4.2 Fully explain the answer to QUESTION 6.4.1. (2)

6.5 The atmospheric pressure is now changed to 83 kPa.
How will the boiling points of these organic compounds be affected? Choose from INCREASE, DECREASE or REMAIN THE SAME. (1)

[10]

QUESTION 7

7.1 The relationship between boiling point and the number of carbons in STRAIGHT CHAIN PRIMARY ALCOHOLS is investigated. The following curve is obtained:

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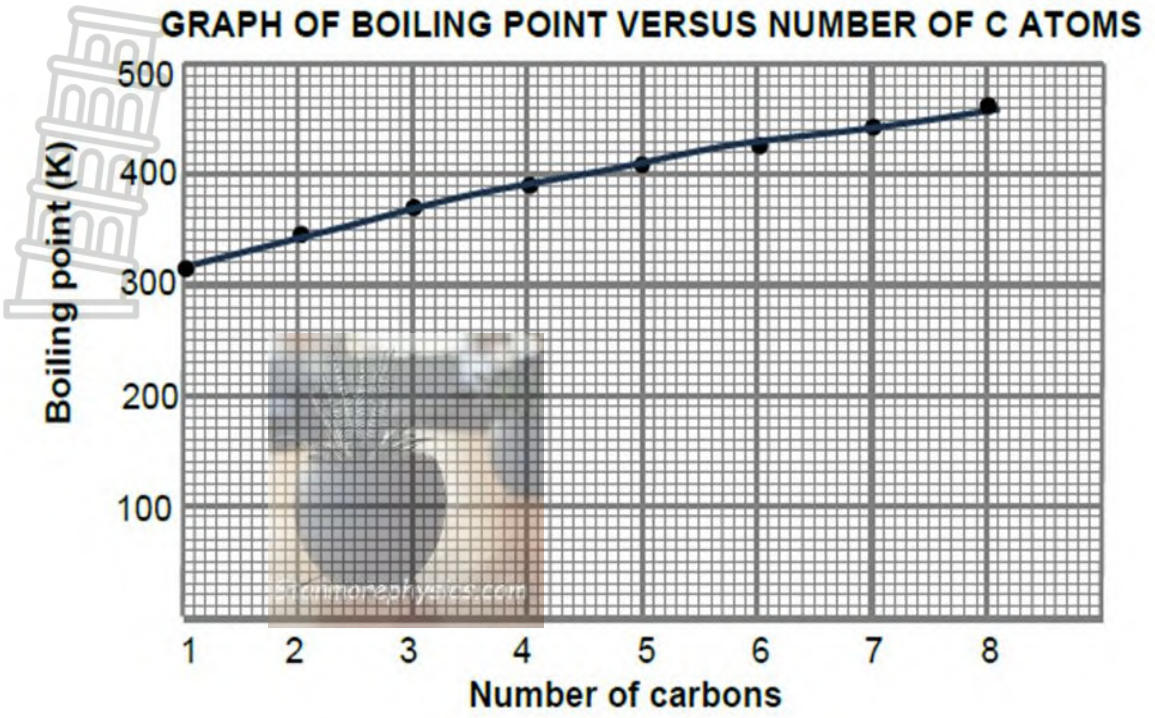

7.1.1 Define boiling point. (2)

7.1.2 What is the structural similarity between the alcohols that make this a fair investigation? (1)

7.1.3 Which van der Waals force is responsible for the trend observed in this curve? (1)

7.1.4 Write down the IUPAC name of the alcohol with a boiling point of approximately 410 K. (2)

7.2 Another investigation is carried out to determine the effect of structural differences on the boiling point. The table below shows the different compounds and their respective molar mass that was used in this investigation.

COMPOUND		MOLAR MASS ($g \cdot mol^{-1}$)
A	Butanone	72
B	Butan-1-ol	74
C	Propanoic acid	74

7.2.1 Which compound A, B or C will have the highest boiling point? (1)

7.2.2 Fully explain the answer to QUESTION 7.2.1. (5)

[12]

QUESTION 8

Compounds A to C are used to investigate a factor that influences boiling point of organic compounds. The table below shows the results obtained.

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	Compound	Boiling point (˚C)
A	Propan-1-ol	97
B	Butan-1-ol	117,7
C	Pentan-1-ol	138

8.1. Define the term boiling point. (2)

8.2. For this investigation, write down the:

8.2.1 Independent variable (1)

8.2.2 Controlled variable (1)

8.3 Name the intermolecular force that is responsible for the observed trend in boiling points. (1)

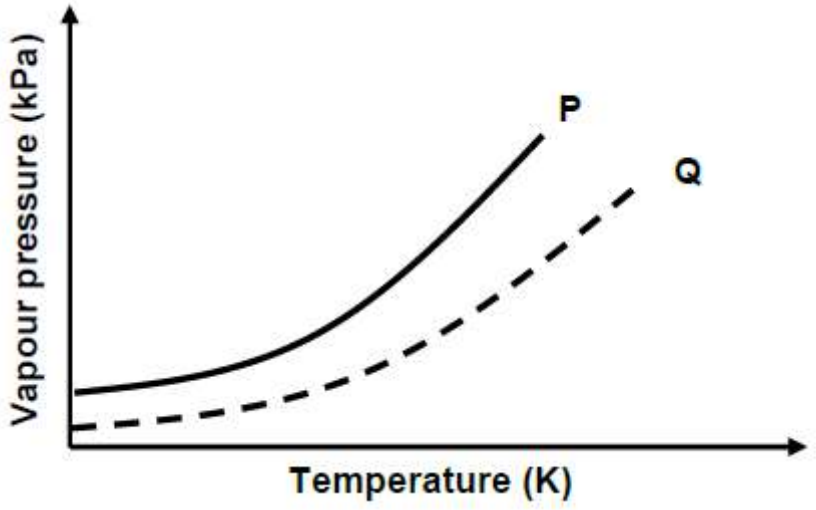
8.4 The boiling points of three branched alcohols are given below.

108 ˚C	129 ˚C	149 ˚C

Which ONE of the three temperatures is most likely to be the boiling point of 2-methylbutan-1-ol? (1)

8.5 Fully explain your answer to QUESTION 8.4. (4)

8.6 The graphs below represent the relationship between vapour pressure and temperature for propan-1-ol and propanal.



8.6.1 Define vapour pressure. (2)

8.6.2 Which curve, P or Q, represents the graph for propan-1-ol? (1)

8.6.3 Explain your answer to QUESTION 8.6.2 by referring to the TYPE of intermolecular forces. (4)

[17]

QUESTION 9

Study the flow diagram below. Reaction I is a CRACKING REACTION forming two organic compounds, W and T, as the ONLY products.

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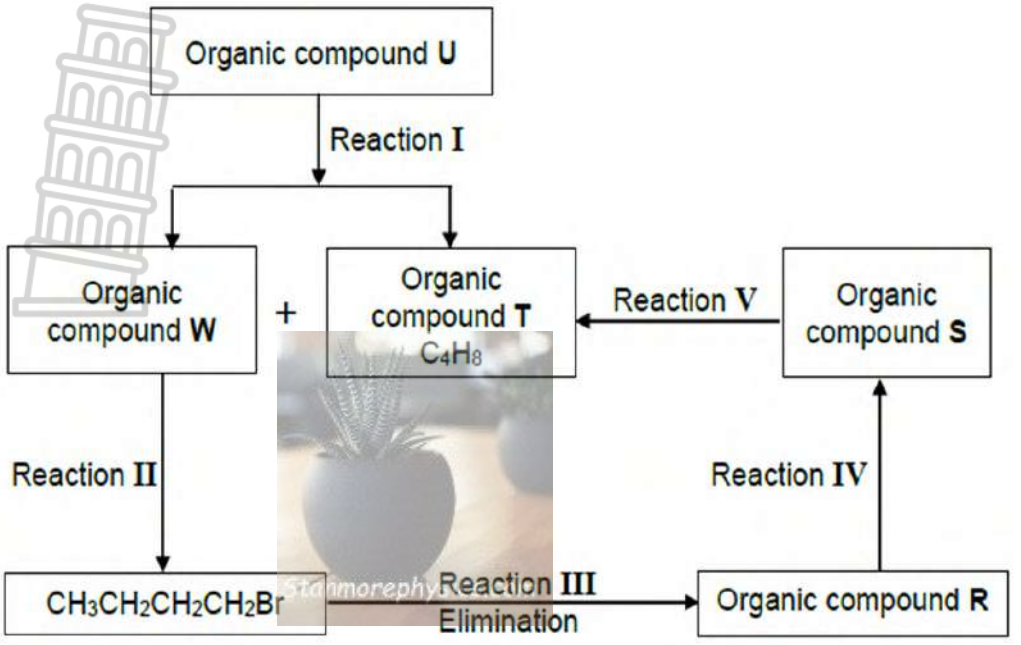


9.1. Define the term *cracking reaction.* (2)

9.2 Is the product in reaction II a PRIMARY, SECONDARY or TERTIARY haloalkane? Give a reason for the answer. (2)

9.3. Write down the:

9.3.1 STRUCTURAL FORMULA of compound W (3)

9.3.2 MOLECULAR formula of compound U (1)

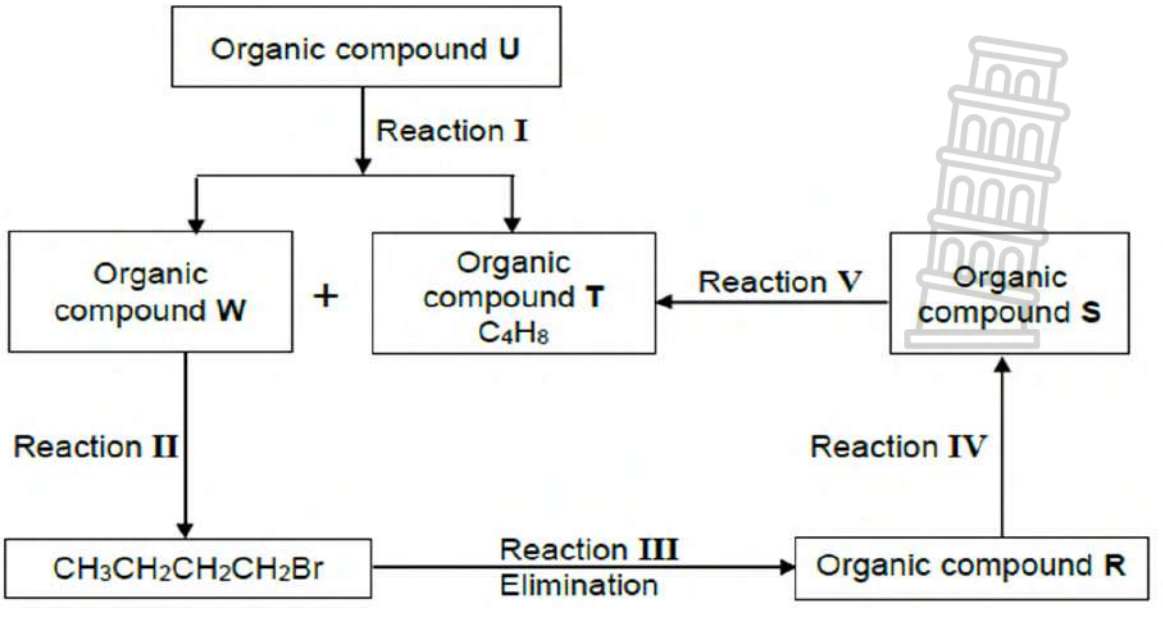
9.4 For reaction II, write down:

9.4.1 The NAME or FORMULA of the inorganic reactant (1)

9.4.2 The type of reaction (Choose from SUBSTITUTION, ADDITION or ELIMINATION.) (1)

9.4.3 ONE reaction condition (1)

The flow diagram above is redrawn below for easy reference.



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9.5 Write down the TYPE of elimination in reaction III. (1)

9.6 Compounds R and T are positional isomers. The inorganic reagents shown below are available for reactions IV and V.

Br_2	H_2SO_4(conc.)	NaOH(conc.)	HBr	H_2

Write down:

9.6.1 The balanced equation for reaction IV, using STRUCTURAL FORMULAE and the correct inorganic reagent shown above (5)

9.6.2 The balanced equation for reaction V, using STRUCTURAL formulae and the correct reagent shown above (3)

9.6.3 The IUPAC name of compound T (2)

[22]

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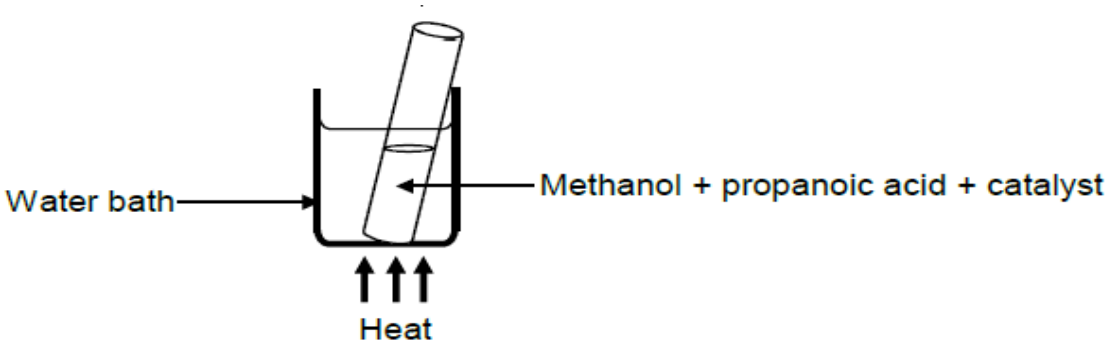
QUESTION 10

10.1 In an experiment, a test tube containing methanol, propanoic acid and a catalyst is heated in a water bath.



Write dawn the:

10.1.1 The NAME or FORMULA of the catalyst (1)

10.1.2 The type of reaction taking place (1)

10.1.3 TWO reasons why the use of a water bath is preferred in this experiment (2)

10.1.4 The balanced equation for this reaction using STRUCTURAL FORMULAE (5)

10.1.5 The IUPAC name of the organic product for this reaction (2)

10.2 Compound A, a six-carbon branched haloalkane, is used in a two-step reaction to prepare compound C.

Reaction 2 is an ADDITION reaction.

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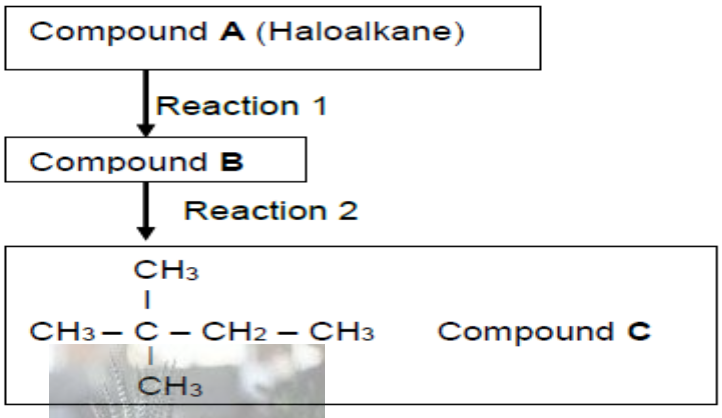


Write down:

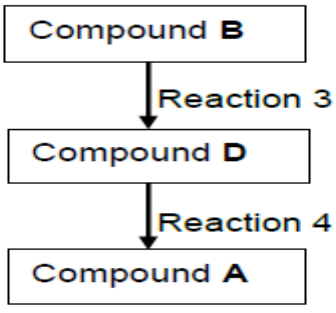
10.2.1 The NAME or FORMULA of the inorganic reactant in reaction 2 (1)

10.2.2 The IUPAC name of compound B (2)

10.2.3 The type of reaction represented by reaction 1 (1)

Compound B is now used in two-step reaction to prepare compound A.

Reaction 4 is a SUBSTITUTION reaction.



Write dawn:

10.2.4 The NAME or FORMULA of the catalyst used in reaction 3 (1)

10.2.5 The IUPAC name of compound D (2)

10.2.6 The type of reaction represented by reaction 3 (1)

10.2.7 The type of haloalkane represented by compound A (Choose from primary, secondary or tertiary.) (1)

[20]

QUESTION 11

Consider the three organic reactions, I, II and III below:

I	Pent-1-ene + HCℓ → Organic compound **P** (Major product)
II	Organic compound **P** + NaOH → secondary alcohol **Q** + NaCℓ
III	Organic compound **P** + NaOH → Organic compound **R** + NaCℓ + H_2O (Major product)

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11.1 Is pent-1-ene SATURATED or UNSATURATED? Give a reason for the answer. (2)

Write down the type of reaction represented by:

11.2 Reaction II (1)

11.3 Reaction III (1)

Write down the:

11.4 STRUCTURAL FORMULA of compound P. (2)

11.5 IUPAC name of compound Q. (2)

11.6 Reactions II and III require the use of a strong base. (2)

Write down the conditions that will prefer reaction II over reaction III.

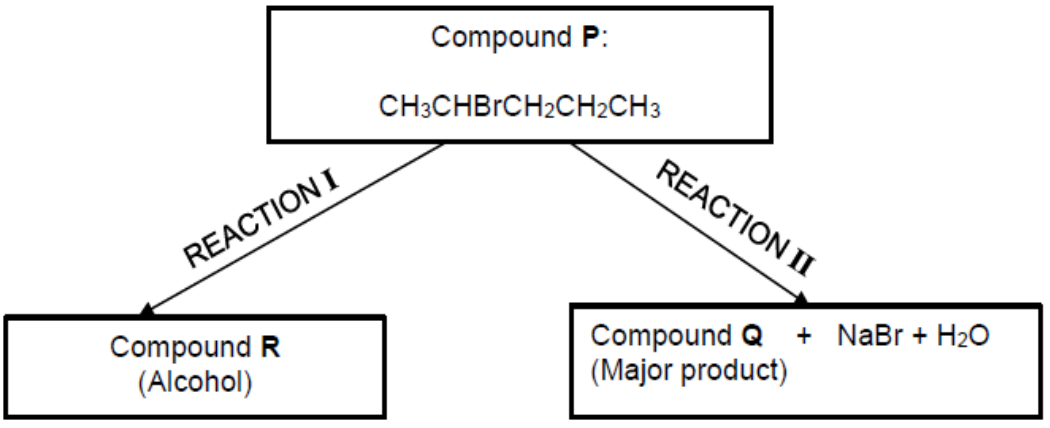
11.7 Pent-1-ene and organic compound R are isomers. What type of isomer is pent-1-ene and organic compound R?

Choose from FUNCTIONAL, POSITIONAL or CHAIN. (2)

[12]

QUESTION 12

12.1 The flow diagram below shows how compound P can be converted to organic compounds Q and R.



For reaction I write down the:

12.1.1 Name of the type of substitution reaction (1)

12.1.2 IUPAC name of compound R (2)

For reaction II write down:

12.1.3 One reaction condition other than heat (1)

12.1.4 The structural formula of compound Q (2)

Compound R can be converted to compound Q.

For the conversion of compound R to compound Q write down the:

12.1.5 Formula or name of the inorganic reagent needed (1)

12.1.6 Type of reaction (1)

12.2 A mixture of ethanoic acid (CH_3COOH) and propan-1-ol ($CH_3CH_2CH_2OH$) is heated in the presence of concentrated sulphuric acid (H_2SO_4) in a water bath as shown below.

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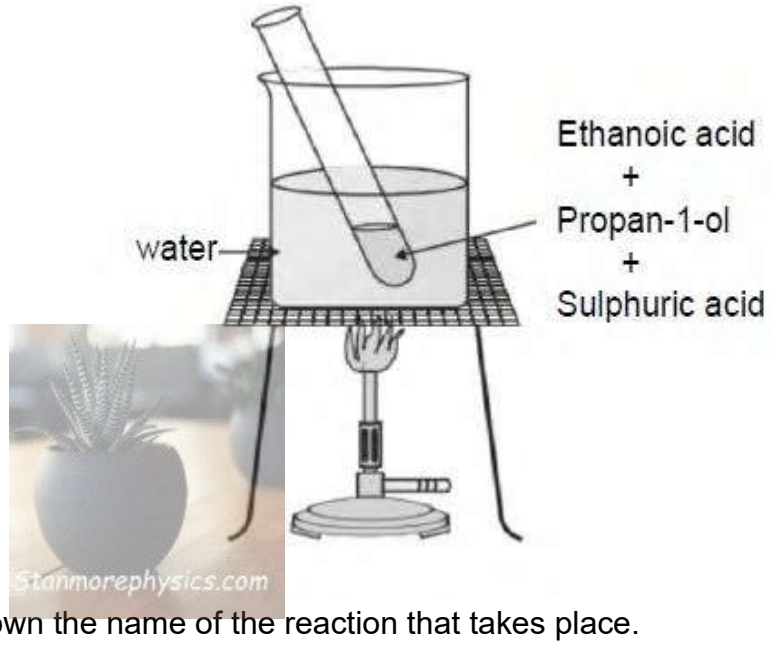

12.2.1	Write down the name of the reaction that takes place.	(1)
12.2.2	Give a reason why the reaction mixture is heated in a water bath.	(1)
12.2.3	Write down the structural formula and IUPAC name of the product formed	(4)
		[14]

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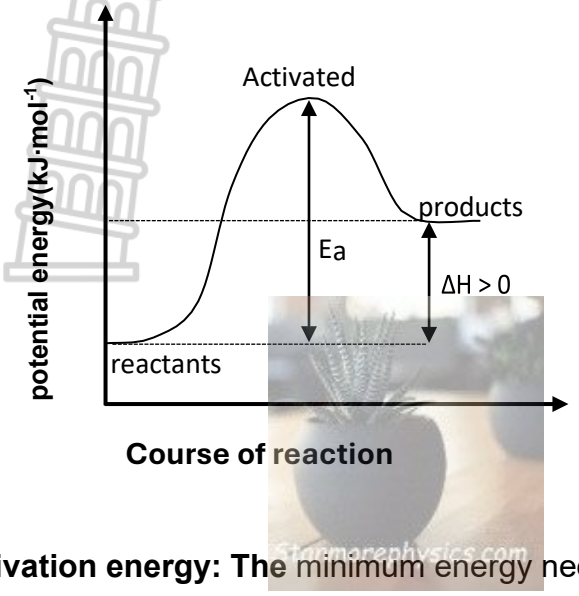
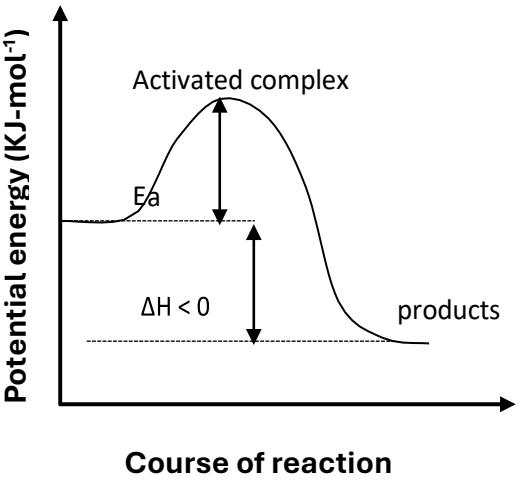
Rate of reaction and energy changes

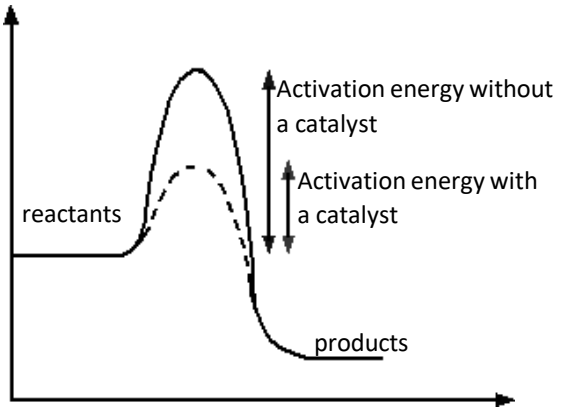




Activation energy: The minimum energy needed for a reaction to take place.

Activated complex: The unstable transition state from reactants to products.

EFFECT OF A CATALYST



Catalyst

Increases reaction rate without undergoing a permanent change.

Mechanism of catalyst:
Increase reaction rate by lowering the total activation energy

FACTORS THAT AFFECT THE RATE OF REACTIONS

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 effective collisions per unit time.

The reaction rate increases.

NB: vice versa when the temperature is decreased

Concentration

Concentration is the number moles of solute per unit volume of solvent

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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 particles with sufficient kinetic energy and correct orientation.
More effective collisions of particles per unit time.
The reaction rate increases.

Surface area / State of division (SOLIDS ONLY)

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 for collisions to occur
More particles with correct orientation
More effective collisions per unit time.
The reaction rate increases.

Pressure (GASES ONLY)

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 effective collisions of particles with enough energy and correct orientation per unit time.
The reaction rate increases.

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. Eg. Simple and complex molecules, strong and weak acids, pure and impure substances.

6. Catalyst

A **catalyst** is a substance that increases the rate of chemical reaction without itself undergoing any permanent change
When a catalyst is added, the rate of a chemical reaction increases. This is why:
The catalyst provides an alternative path of lower activation energy.
More particles have average kinetic energy greater than activation energy
More effective collisions of particles per unit time.
Reaction rate increases.
Adding a catalyst doesn't change the value of heat of reaction.

BOLTZMANN-MAXWELL DISTRIBUTION CURVE OR ENERGY DISTRIBUTION CURVE

As energy is one of the determining factors for a reaction, it is necessary to know which **number of particles (e.g. molecules) have kinetic energies equal to or greater than the activation energy**. Particles in any system represent a variety of kinetic energies. This distribution of kinetic energies can be shown on a curve known as the Maxwell-Boltzmann distribution curve.

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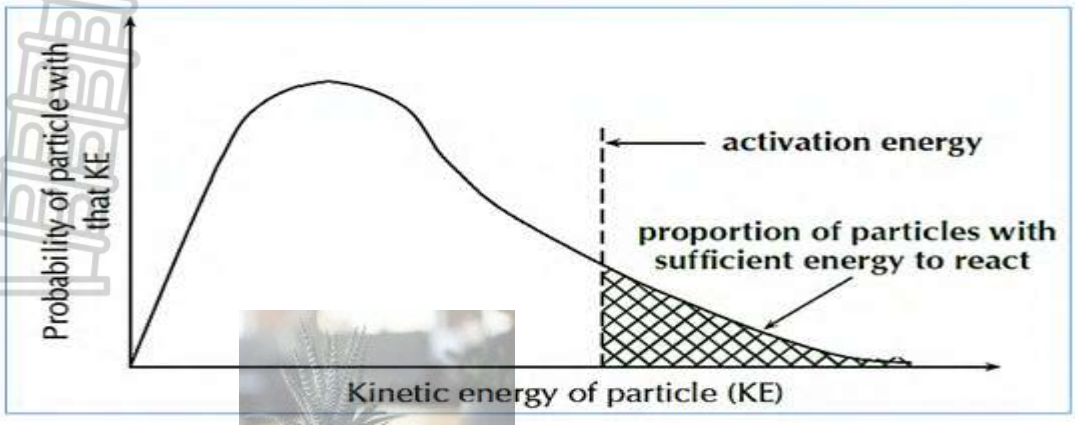


The Maxwell-Boltzmann distribution curve is affected by changes in **temperature**, **Concentration** and **catalyst.**

Maxwell-Boltzmann distribution curve: The effect of temperature

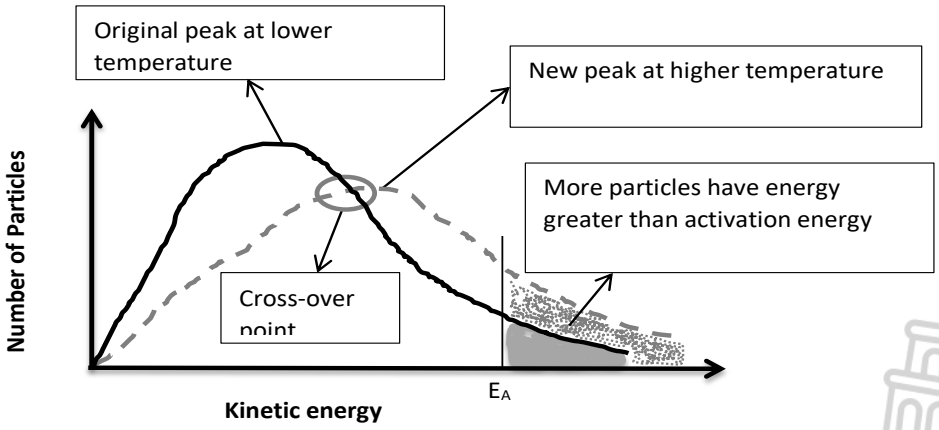
An increase in temperature increases the average kinetic energy of the particles. This means that particles will move to the left of the energy scale or x-axis (higher energy values). The graph below shows the effect of an increase in temperature on the curve.

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 represents the average kinetic energy.



MULTIPLE CHOICE QUESTIONS

Worked examples.

Various options are provided as possible answers to the following questions. Choose the answer and write only the letter (A–D) next to the question numbers in the ANSWER BOOK, e.g., 1.4 D.

Hydrochloric acid reacts with EXCESS zinc according to the balanced equation.

$$2HCl_{(aq)} + Zn_{(s)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

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1.1 Which ONE of the following factors will influence the yield of $H_2(g)$ but not on the rate of production of H_2 (g)?

A. Temperature
B. Volume of HCℓ
C. State of division of Zn
D. Concentration of HCℓ (2)

Answer: **B** ✓✓

1.2 Which ONE of the following best describes the effect of temperature on the reaction rate?

A. Hydrogen peroxide decomposes faster in the presence of manganese (IV) oxide
B. 5 g sodium reacts faster with the same volume oxygen than 5 g of copper.
C. 10 g of calcium carbonate reacts faster with 0,4 mol.dm-3 hydrochloric acid than 0,04 mol.dm-3 of HCl
D. 10 g of sodium reacts slower with 100 mℓ water at 50 °C than at 100 °C. (2)

Answer: **D**✓✓

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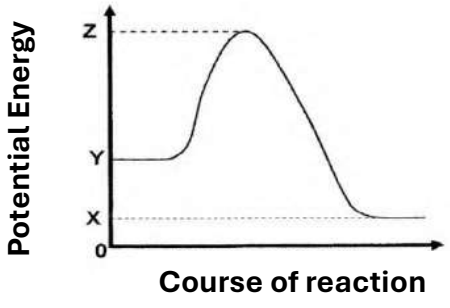
MULTIPLE CHOICE QUESTIONS

Question 1

Various options are provided as possible answers to the following questions. Choose the answer and write only the letter (A–D) next to the question numbers.

1.1 The potential energy diagram for chemical reaction is shown below



Which ONE of the following combinations is correct

	ΔH	ACTIVATION ENERGY	POTENTIAL ENERGY OF THE ACTIVATION COMPLEX
A.	Y-X	Z+Y	Z
B.	Y-X	Z-Y	Z+Y
C.	X-Y	Z-Y	Z
D.	X-Y	Z	Z-Y

(2)

1.2 The Maxwell-Boltzmann energy distribution curves below show the number of particles as a function of their kinetic energy for a reaction at four different temperatures. The minimum kinetic energy needed for effective collisions to take place is represented by **E**.

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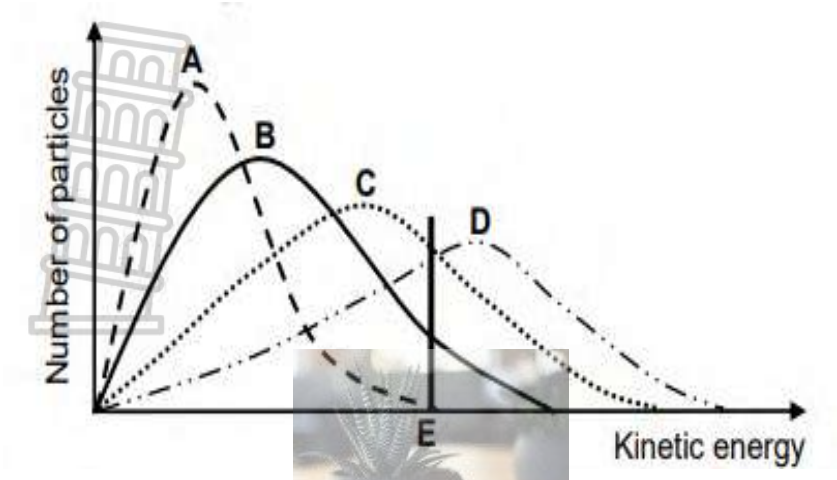
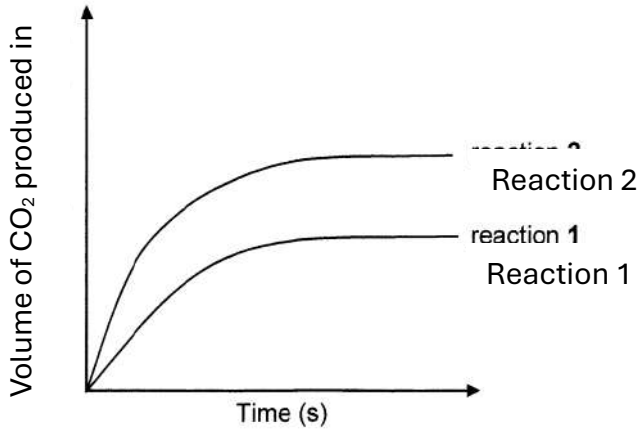


Which ONE of these curves represents the reaction with the highest rate?

A A
B B
C C
D D

(2)

1.3 Two DIFFERENT samples of IMPURE $CaCO_3$ of EQUAL masses react with 0.1 mol.dm^{-3} H_2SO_4.assume that the impurities do not react. The Graph below shows the volume $CO_{2(g)}$produced for each reaction.



Time (s)

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

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

(2)

1.4 Consider the balanced equation for a chemical reaction below.
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

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The activation energy of the forward and reverse reactions are 156 kJ·mol-1 and 175 kJ·mol-1 respectively. The heat of reaction, in kJ·mol-1, for this reaction is…

A –19.
B +19.
C +331.
D –331.

(2)

1.5 2 g piece of magnesium reacts with EXCESS hydrochloric acid according to the following balanced equation:

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

Which ONE of the following changes will INCREASE the YIELD of $H_2(g)$?

A Crush the piece of magnesium.
B Use a 3 g piece of magnesium.
C Use a greater volume of the acid.
D Use a higher concentration of the acid. (2)

[10]

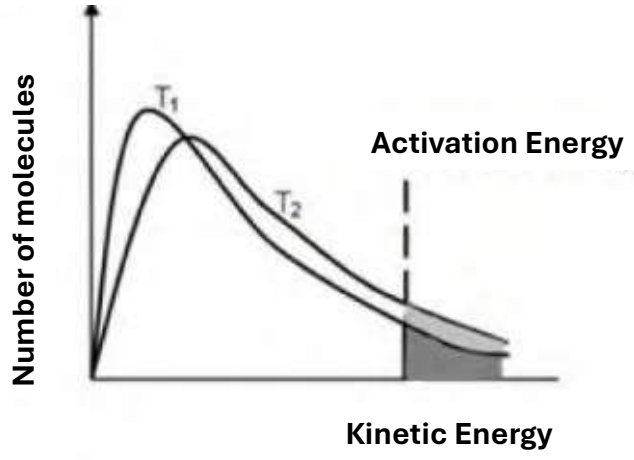
LONG QUESTIONS

Worked example

The collision theory can be used to explain how different factors affect the rate of chemical reaction

1.1 Name TWO conditions that determine whether a collision between two molecules **A** and **B** will lead to chemical reaction. (2)

1.2 The following graphs show two identical reactions taking place at different temparatures



1.2.1 In terms of collision theory, Explain why the rate of chemical reaction increases with Increase in temperature (2)

1.2.2 Which graph represents the reaction taking place at higher temperature? Write T_1 or T_2 (1)

1.2.3 What is represented by the TOTAL area under each graph? (1)

1.2.4 What is represented by shaded area? (2)

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1.3 A group of learners use the reaction between zinc and sulphuric acid to investigate one factors that factors that affect reaction rates. The equation below represents the reaction take place

$$Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + H_{2(g)}$$

They add 6.5g of zinc granules to excess DILUTE sulphuric acid and measure the **Mass of zinc used per unit time.** The learners then repeat the expiriment using excess concentrated sulphuric acid

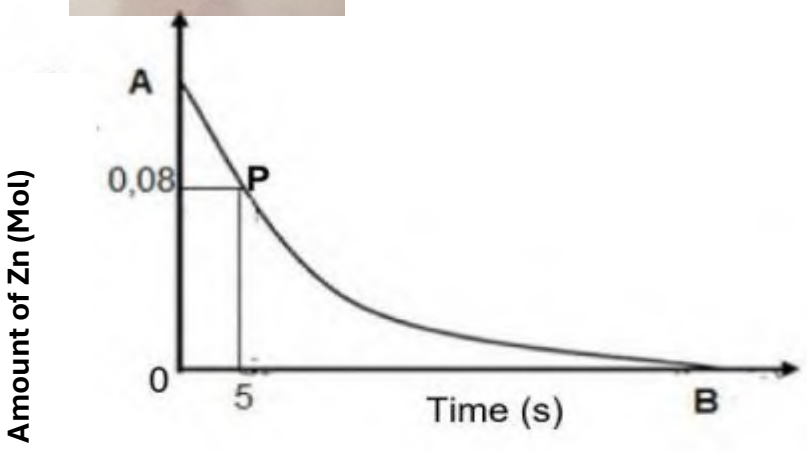
1.3.1 Define the term reaction rate (2)

1.3.2 Which factor influencing reaction rate is investigated (1)

1.3.3 Write down hypothesis for this investigation (2)

1.3.4 The learners must use the same mass of ZINC GRANULES in both experiments. Which variable is controlled by doing this? (1)

1.4 The results obtained for the reaction using DILUTE sulphuric acid are represented in the graph below



1.4.1 Calculate the Value of **A**on Y-axis (3)

1.4.2 Calculate the value of **B** on the x-axis if the average rate of the reaction was 0.15 gs^{-1} for the part of the graph represented by **BP** where **P** is at t= 5s (3)

1.4.3 Copy the above graph into your answer book on the same set of axes use dotted line to draw the curve that will be obtained when concentrated acid used (3)

[25]

Solutions

1.1 Correct orientation and sufficient kinetic energy ✓✓ (2)

1.2 1.2.1 Higher temperature causes an increase in average kinetic energy of the reacting particles, more particles with enough energy to react or greater than activation energy, more effective collision per unit time✓✓ (2)

1.2.2 T_2✓ (1)

1.2.3 The amount of molecules or particles which can react ✓ (1)

1.2.4 The number of molecules with kinetic energy higher than activation energy or more particles with enough energy to react✓✓ (2)

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1.3 1.3.1 Reaction rate is the change in concentration of reactants or product per unit time✓✓ (2)

1.3.2 Concentration ✓ (1)

1.3.3 An increase in concentration of reactants will/ will not lead to an increase reaction rate ✓✓ (2)

1.3.4 Surface area ✓ (1)

1.4 1.4.1

$$n = {}^{m}/_{M} \checkmark = {}^{6.5}/_{65} \checkmark = 0.1mol \checkmark$$ (3)

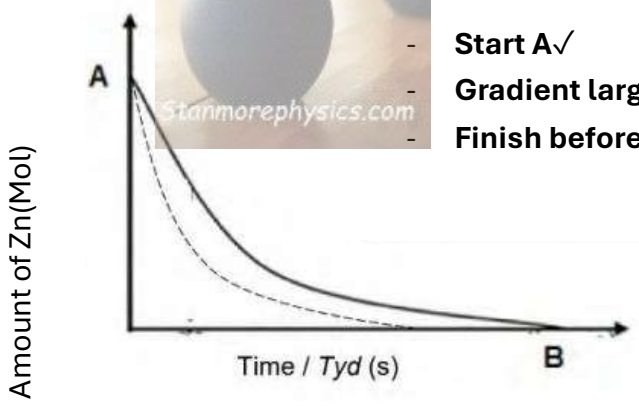
1.4.2

$$average\ rate = -\frac{\Delta m}{\Delta t} \checkmark = 0.15 = -\frac{0-5.2}{B-5} \checkmark B = 39.67s \checkmark$$ (3)

1.4.3

Marking criteria

- **Start A✓**
- **Gradient larger ✓**
- **Finish before B✓**



Time

(3)

[25]

Question 1

The calcium carbonate (CaCO3) in antacid tablets reacts with dilute hydrochloric acid (HCℓ) according to the following balanced equation:

$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + CO2(g) + H_2O(\ell)$ $\Delta H < 0$

1.1 Is the above reaction EXOTHERMIC or ENDOTHERMIC? Give a reason for the answer.

An antacid tablet of mass 2 g is placed in HCℓ(aq). After 30 s the mass of the tablet was found to be 0,25 g.

1.2 Calculate the average rate (in $g \cdot s^{-1}$) of the above reaction. (3)

The antacid tablet contains 40% calcium carbonate. Another antacid tablet of mass 2 g is allowed to react completely with HCℓ(aq).

1.3 Calculate the volume of carbon dioxide, $CO_2(g)$ that will be collected at STP.

Assume that all the $CO_2(g)$ produced is from the calcium carbonate. (5)

The reaction rate of similar antacid tablets with excess HCℓ(aq) of concentration 0,1 $mol \cdot dm^{-3}$ at DIFFERENT TEMPERATURES is measured. The graph below was obtained.

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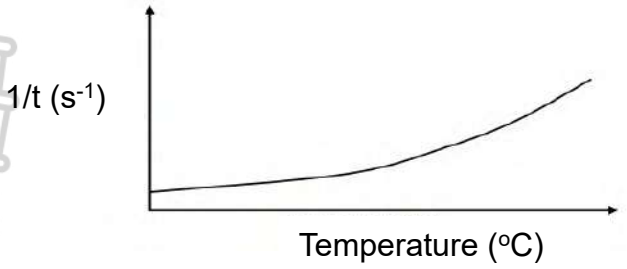


Use the information in the graph to answer the following questions.

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

1.5 Write down a conclusion that can be made from the graph. (2)

1.6 Use the collision theory to fully explain the answer to **QUESTION 1.5** (3)

1.7 Redraw the graph above in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained if HCℓ(aq) of concentration 0,2 mol·dm^{-3} is now used. Label this curve **Y**. (2)

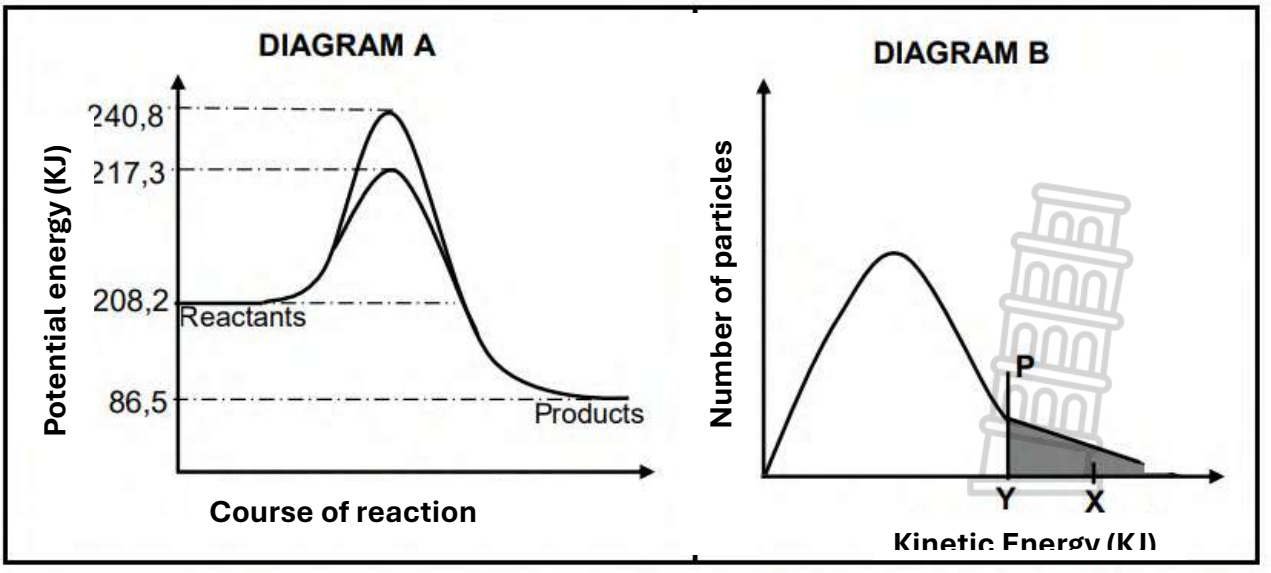
[18]

Question 2

The reaction between aluminium and EXCESS sulphuric acid is used to investigate factors affecting rates of reactions. $2Al_{(s)} + 3H_2SO_{3(aq)} \rightarrow Al_2(SO_4)_{3(aq)} + 3H_{2(g)}$

2.1 **INVESTIGATION I**

The effect of a catalyst on the rate of reaction is determined. Aluminium powder of mass 5 g reacts with excess 0,1 mol·dm^{-3} H_2SO_4 at 60 °C. Consider the following energy diagrams (not drawn to scale) for this investigation. X and Y in diagram B represent the activation energies.



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

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

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

2.2 **INVESTIGATION II** The investigation is now repeated at 30 °C using the same reactants (5g Aℓ powder and excess 0,1 mol·dm^{-3} H_2SO_4) and catalyst. How will this affect EACH of the following when compared to INVESTIGATION I? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

2.2.1 The size of the shaded area (diagram B) (1)

2.2.2 The value of **Y** (1)

2.2.3 The TOTAL volume of hydrogen gas produced (1)

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

$2Al_{(s)} + 3H_2SO_{4(aq)} \rightarrow Al_2(SO_4)_{(aq)} + 3H_{2(g)}$

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

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

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

2.3.3 The time for the reaction to reach completion in RUN 3 is 2,6 minutes. Calculate the percentage purity of the aluminium. Take the molar gas volume at 60 °C to be 27 000 cm^3.mol^{-1} (6)

[19]

Question 3

Learners use the reaction of $MgCO_{3(s)}$ with EXCESS dilute $HCl_{(aq)}$ to investigate the relationship between temperature and the rate of chemical reaction. The balanced equation for the reaction is

$$MgCO_{3(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

The results obtained are represented in the graph below

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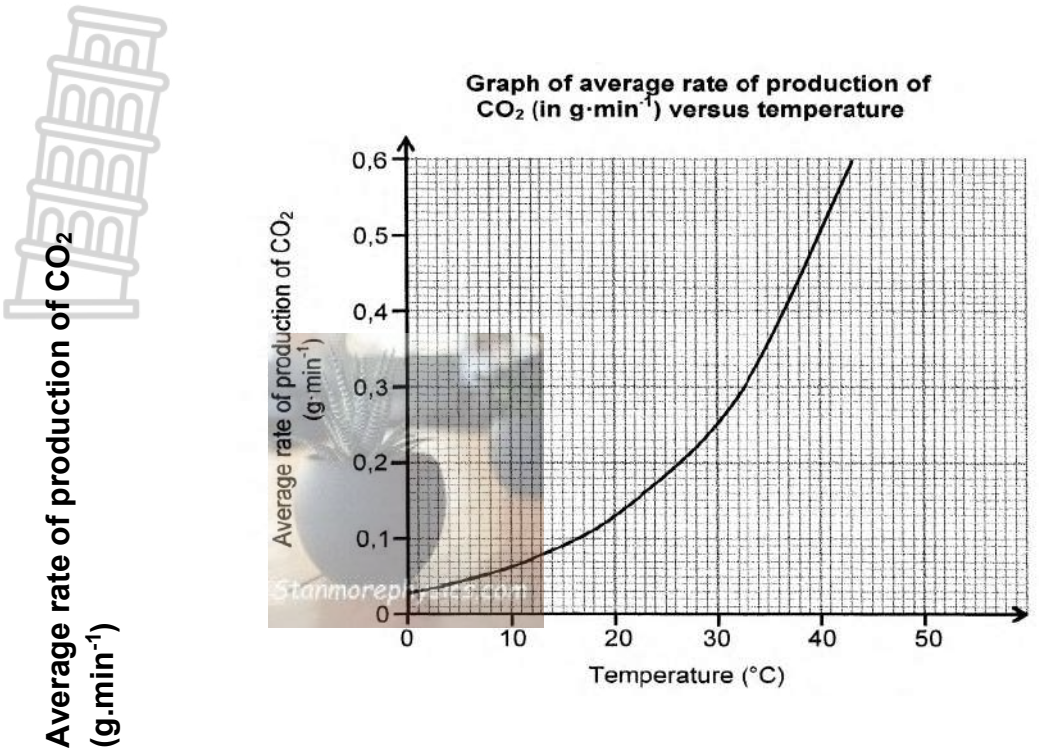


3.1 Define the term reaction rate. (2)

3.2 State TWO conditions that must be kept constant during this investigation (2)

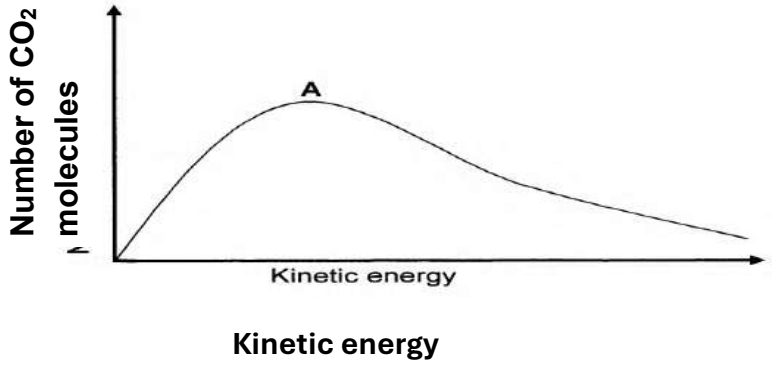
3.3 Use the collision theory to explain the relationship shown in the graph (4)

3.4 The learners obtained the graph above using 5g $MgCO_{3\,(aq)}$ with EXCESS HCl at 40^0C. Calculate (1)

3.4.1 Time taken for the reaction to run to completion (6)

3.4.2 Molar gas volume at 40^0C if 1.5 dm^3 CO_2 is collected in syringe (2)

The graph below represents the Maxwell-Boltzman distribution curve for CO_2 at 40^0C



Kinetic energy

3.5 Redraw the graph above the ANSWER BOOK. Clearly label the curve as **A**. On the same set of axes, sketch the curve that will be obtained for the $CO_{2(g)}$ at 20^0C. label this curve as **B** (2)

[19]

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Question 4

Three experiments, A, B and C, are carried out to investigate some of the factors that affect the rate of decomposition of hydrogen peroxide, $H_2O_{2(l)}$. The balanced equation for the reaction is:

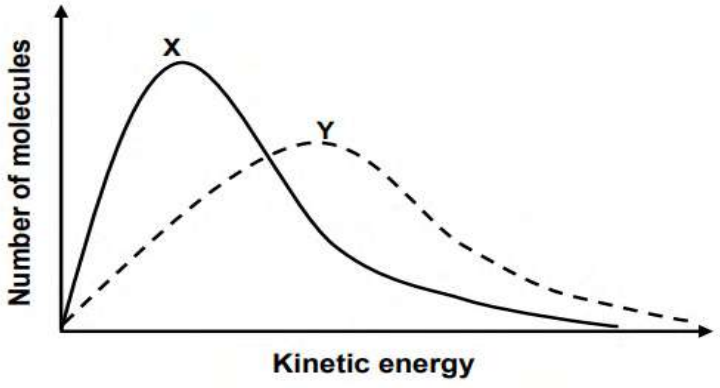
$$H_2O_{2(l)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$$

Identical samples of hydrogen peroxide are used in each experiment. The conditions used in each experiment are summarized in the table below.

EXPERIMENT	TEMPERATURE (°C)	
A	25	Without catalyst
B	25	With catalyst
C	35	Without catalyst

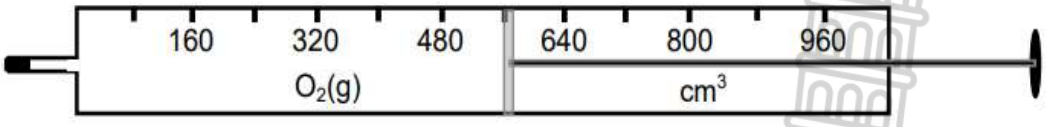
4.1 In which experiment, A or B, is the reaction rate higher? Use the collision theory to explain the answer. (4)

4.2 The Maxwell-Boltzmann distribution curves, X and Y, for two of the above experiments are shown below.



Identify the curve (X or Y) that represents experiment C. (2)

4.3 The volume of oxygen gas, O2(g), produced in experiment B during the first 3,6 s is collected in a syringe, as shown below.



4.3.1 Write down the volume of $O_2(g)$ collected in the syringe. (2)

4.3.2 The balanced equation for the reaction is:

$$2H_2O_{2(l)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$$

Calculate the mass of water, $H_2O_{(l)}$, that was produced during the first 3,6 s. Take the molar gas volume to be 24 000 $cm^3 .mol^{-1}$ 25 °C. (4)

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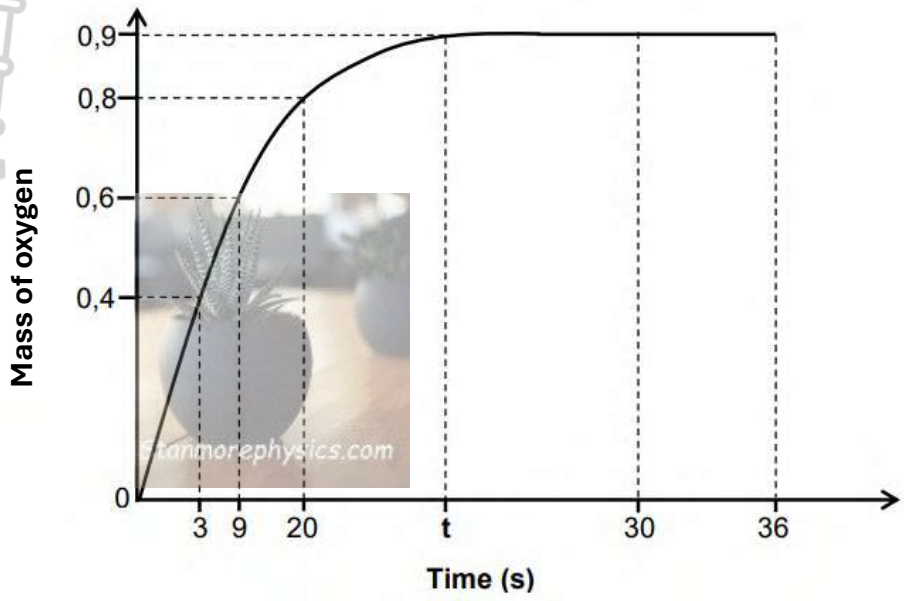
4.4 The graph below, NOT drawn to scale, is obtained for the mass of oxygen gas produced over a period of time in experiment A.



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

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

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

4.4.3 The average rate of decomposition of hydrogen peroxide is 2,1 x 10^{-3} mol·s^{-1}. Calculate the value of time t on the graph. (5)

[19]

Question 5

The reaction of calcium carbonate ($CaCO_3$) and EXCESS dilute hydrochloric acid (HCℓ) is used to investigate one of the factors that affects reaction rate. The balanced equation for the reaction is: $CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

The same mass of $CaCO_3$ is used in all the experiments and the temperature of the hydrochloric acid in all experiments is 40 °C. The reaction conditions for each experiment are summarized in the table below.

EXPERIMENT	VOLUME OF HCℓ(aq) (cm^3)	CONCENTRATION OF HCℓ(aq) (mol·dm^{-3})	STATE OF DIVISION OF $CaCO_3$
A	500	0,1	granules
B	500	0,1	lumps
C	500	0,1	powder

5.1 For this investigation write down the:

5.1.1 Dependent variable (1)

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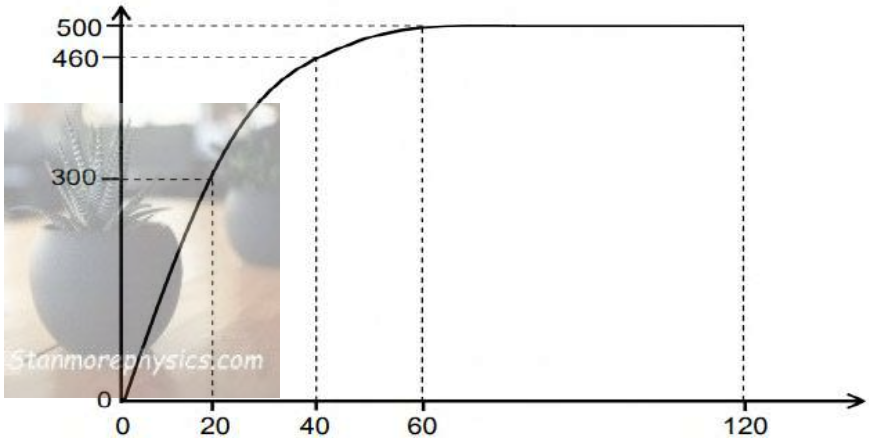
5.1.2 Independent variable (1)

The carbon dioxide gas, $CO_2(g)$, produced during EXPERIMENT A, is collected in a gas syringe. The volume of gas collected is measured every 20 s and the results obtained are shown in the graph below.



5.2 What can be deduced from the graph regarding the RATE OF THE REACTION during the time interval:

5.2.1 20 s to 40 s (1)

5.2.2 60 s to 120 s (1)

5.3 Calculate the average rate (in $cm^3.s^{-1}$) at which $CO_2(g)$ is produced in the experiment. (3)

5.4 How will the volume of $CO_2(g)$ produced in experiment B compare to that produced in experiment A? Choose from GREATER THAN, SMALLER THAN or EQUAL TO. (1)

5.5 A graph is now drawn for experiment C on the same set of axes. How will the gradient of this graph compare to the gradient of the graph for experiment A? Choose from GREATER THAN, SMALLER THAN or EQUAL TO. Use the collision theory to fully explain the answer. (4)

5.6 Assume that the molar gas volume at 40 °C is 25,7 $dm^3 \cdot mol^{-1}$. Calculate the mass of $CaCO_3(s)$ used in experiment A. (4)

[16]

Question 6

The reaction of zinc and EXCESS dilute hydrochloric acid is used to investigate factors that affect reaction rate. The balanced equation for the reaction is:

$Zn(s) + 2HC\ell(aq) \longrightarrow ZnC\ell_2(aq) + H_2(g)$

The reaction conditions used and the results obtained for each experiment are summarized in the table below.

The same mass of zinc is used in all the experiments. The zinc is completely covered in all reactions. The reaction time is the time it takes the reaction to be completed.

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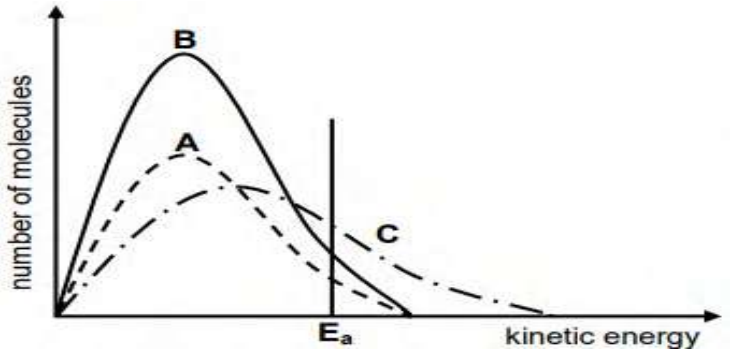
EXPERIMENT	CONCENTRATION OF HCℓ (mol·dm^{-3})	VOLUME OF HCℓ (cm^3)	STATE OF DIVISION OF Zn	TEMPERATURE OF HCℓ (°C)	REACTION TIME (min.)
1	2,0	200	powder	25	7
2	1,5	200	granules	25	14
3	5,0	200	powder	25	5
4	1,5	400	granules	25	x
5	2,0	200	powder	35	4

6.1 Experiment **1** and experiment **5** are compared. Write down the independent variable. (1)

6.2 Define reaction rate. (2)

6.3 Write down the value of x in experiment **4**. (2)

6.4 The Maxwell-Boltzmann energy distribution curves for particles in each of experiments **1**, **3** and **5** are shown below. (2)



Identify the graph (**A** or **B** or **C**) that represents the following:

6.4.1 Experiment **03** give reason for your answer (1)

6.4.2 Experiment **05** give reason for your answer (1)

6.5 Experiment **6** is now conducted using a catalyst and the SAME reaction conditions as for Experiment **1**.

6.5.1 What is the function of the catalyst in this experiment? (1)

6.5.2 How will the heat of reaction in experiment **6** compare to that in experiment **1**? Choose from: GREATER THAN, EQUAL TO or LESS THAN. (1)

6.5.3 Calculate the average rate of the reaction (in mol·min^{-1}) with respect to zinc for experiment **2** if 1,5 g of zinc is used. (4)

[15]

Question 7

Learners use the reaction between IMPURE POWDERED calcium carbonate and excess hydrochloric acid to investigate reaction rate. The balanced equation for the reaction is:

$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H2O(\ell) + CO_2(g)$

They perform four experiments under different conditions of concentration, mass and temperature as shown in the table below. They use identical apparatus in the four experiments and measure the volume of gas released in each experiment.

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	EXPERIMENT			
	1	2	3	4
Concentration of acid (mol·dm^{-3})	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid (°C)	30	30	40	40

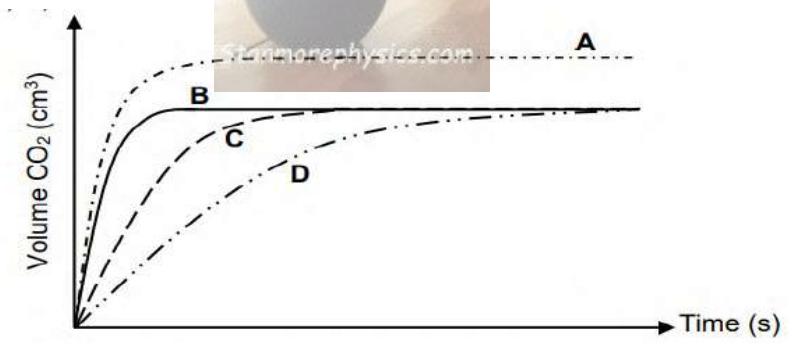
7.1 The results of experiments 1 and 3 are compared in the investigation. Write down the:

7.1.1 Independent variable (1)

7.1.2 Dependent variable (1)

7.2 Use the collision theory to explain why the reaction rate in experiment 4 will be higher than that in experiment 2. (3)

The learners obtain graphs A, B, C and D below from their results.



7.3 Which ONE of the graphs (A, B, C or D) represents experiment 1? Fully explain the answer by comparing experiment 1 with experiments 2, 3 and 4. (6)

7.4 When the reaction in experiment 4 reaches completion, the volume of gas formed is 4,5 dm^3 Assume that the molar gas volume at 40 °C is equal to 25,7 dm^3.

Calculate the mass of the impurities present in the calcium carbonate. (5)

[18]

DOPPLER EFFECT

DOPPLER EFFECT WITH SOUND

Wavelength (λ): The distance between two consecutive points that are in phase. E.g. successive compressions or rarefactions. **Units:** m

Frequency (*f*): The number of complete waves that passes through a point in one second. **Units:** Hz

Frequency is a measure of the pitch of sound. High frequency; high pitch. Low frequency; low pitch.

Frequency and wavelength are inversely proportional to each other. $f \alpha \frac{1}{\lambda}$

Period (T): The time taken for one complete wave to move past a fixed point. **Units:** s

$$T = \frac{1}{f} \qquad f = \frac{1}{T}$$

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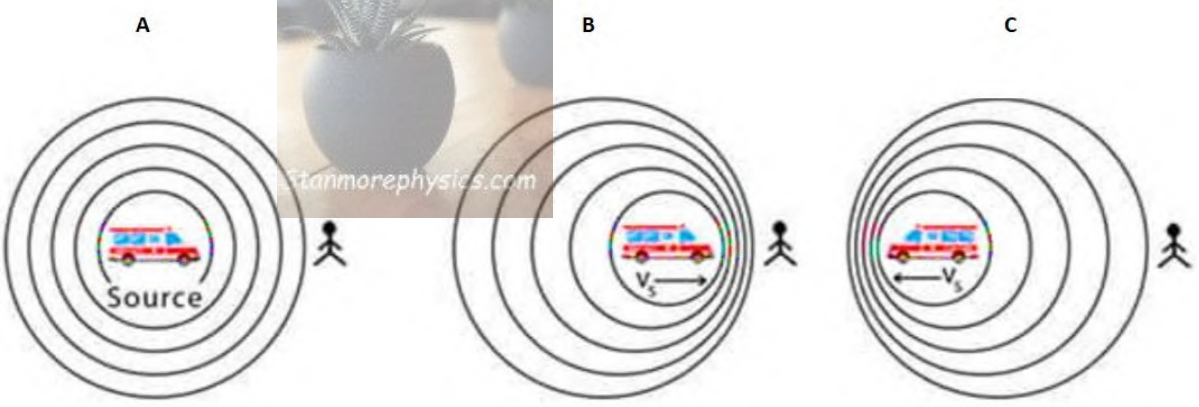
Speed of a wave (v): The speed at which a wave is transmitted through a medium/ vacuum or the rate of change of the distance covered. **Units:** m.s^{-1}

$$Speed\ (v) = \frac{distance\ covered\ (\Delta x)}{time\ (\Delta t)} = \frac{\lambda}{T} \qquad (\frac{1}{T} = f)$$

$$\therefore v = f\lambda$$

$$The\ speed\ of\ sound\ in\ air\ is\ usually\ 340\ m.s^{-1}$$

Doppler Effect: 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.



A: Stationary source and stationary observer - sound waves are emitted in regular equidistant patterns.
B: Source moves towards the stationary observer, the sound waves go through compressions which means the distance between two consecutive points becomes smaller (λ is shorter), frequency increases, which means the pitch increases.
C: Source moves away from the stationary observer, the sound waves go through rarefactions which means the distance between two consecutive points becomes bigger (λ is longer), frequency decreases, which means the pitch decreases.

Calculations involving the Doppler Effect

The **Doppler equation** can be used to calculate the frequency of the sound a listener hears when the sound source and/or the observer/ listener move towards or away from one another.

+ observer toward source
- observer away from source

$$f = f_o\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

- source toward observer
+ source away from observer

f_L = frequency heard by the listener/observer in Hertz (Hz)
f_S = frequency of the source in Hertz (Hz)
v_L = speed of the listener/observer in meter per second (m.s^{-1})

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v_S = speed of the sound source in meter per second ($m.s^{-1}$)
v= speed of sound in the medium in meter per second ($m.s^{-1}$)

Applications of the Doppler Effect

IN ASTRONOMY: To study the motion of galaxies and stars, to determine their relative velocities.
SONAR TECHNOLOGY: For underwater navigation, fish finding, and submarine detection by measuring shift in sound waves reflected off moving objects.
MEDICAL APPLICATIONS: (i) To determine the blood flow rate (ii) To detect the heartbeat of an unborn foetus
SPEED ENFORCEMENT: Doppler radar traffic cameras measure the speed of moving vehicles for enforcing speed limits.

Doppler Effect with Light

Light travels with a speed $c = 3 \times 10^8$ $m.s^{-1}$.
Red light has the longest wavelength and the lowest frequency, while blue light has a shorter wavelength and a higher frequency.
A change in the frequency of light is observed as a colour change.
If the frequency/ colour of light being observed differs from that which is emitted, it is called a shift.

Line Absorption Spectra

When white light is shone through a glass prism, it is split into its spectrum of colours. (Red, Orange, Yellow, Green, Blue, Indigo, Violet)
When white light is shone through a cool gas, not all the light will make it through, some are absorbed; and a line absorption spectrum is produced.
Photons of the appropriate energies are absorbed by the atoms in the gas, resulting in dark lines of the spectrum.
Each gas has its own unique absorption spectrum; making is possible to determine what gases are in a star's atmosphere.

Red Shift and the Explanation of an Expanding Universe

The **Big Bang Theory** is the leading explanation about how the universe began.
The further away the light source is, in the form of a distant galaxy, the greater the degree of shift towards the red end of the spectrum.
The further away a galaxy is from us, the faster it is moving away from us; resulting in a red shift in the spectrum; suggesting that the universe is expanding.
If a star is moving away from earth, there will be a shift of the spectral lines to a lower frequency (longer wavelength) i.e. a **RED SHIFT** takes place.

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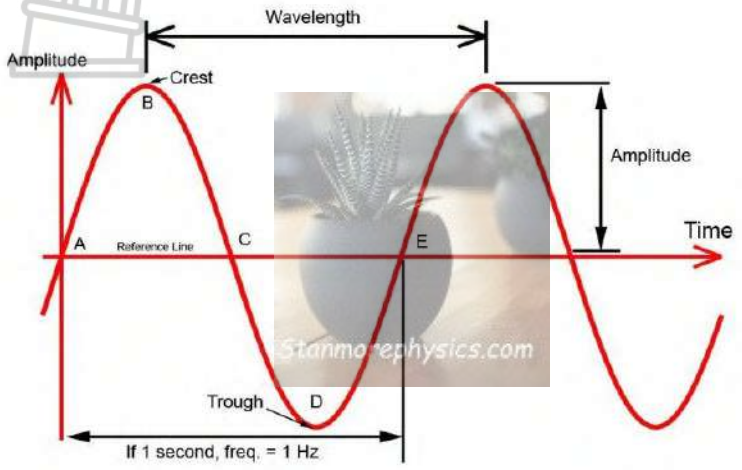
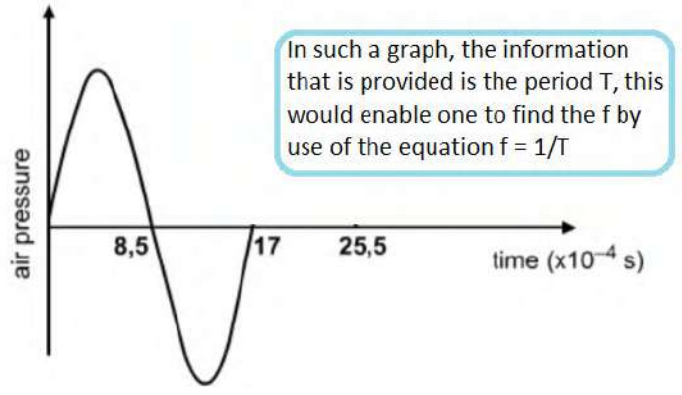
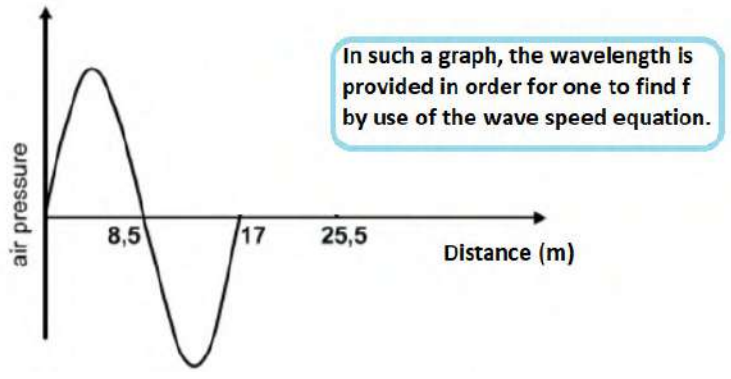
If a star is moving towards earth, there will be a shift of the spectral lines to higher frequencies (shorter wavelength), i.e. a **BLUE SHIFT** takes place.
Note: The greater the shift, the greater the speed of the star.

Interpretation of Graphs







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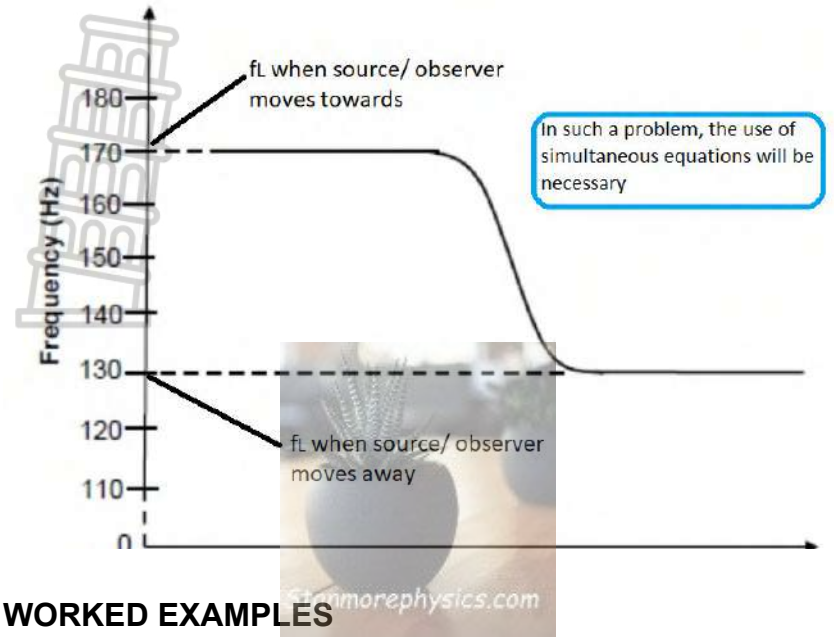

WORKED EXAMPLES

WORKED EXAMPLE 1.

The siren of a stationary ambulance emits a note of frequency 1 130 Hz. When the ambulance moves at a constant speed, a stationary observer detects a frequency that is 70 Hz higher than that emitted by the siren.

1.1 State the Doppler effect in words. (2)

An apparent change in observed/detected frequency/pitch/wavelength as a result of the relative motion between a source and an observer/listener.✓✓

1.2 Is the ambulance moving towards or away from the observer? Give a reason. (2)

Towards. Observed/detected frequency is greater than the actual frequency. ✓✓

1.3 Calculate the speed at which the ambulance is travelling. Take the speed of sound in air as 343 $m \cdot s^{-1}$. (5)

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

$\therefore 1200$ ✓ $= \frac{343}{342 - v_s}$ ✓(1130) ✓ $\therefore v_s = 20{,}01\ m.s^{-1}$ ✓

WORKED EXAMPLE 2.

The Doppler effect is applicable to both sound and light waves. It also has very important applications in our everyday lives

2.1 A hooter on a stationary train emits sound with a frequency of 520 Hz, as detected by a person standing on the platform. Assume that the speed of sound is 340 $m \cdot s^{-1}$ in still air.

Calculate the:

2.1.1 Wavelength of the sound detected by the person (2)

$v = f\lambda$

$\lambda = \frac{340}{520}$ ✓

$\lambda = 0.65\ m$ ✓

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2.1.2 Wavelength of the sound detected by the person when the train moves towards him/her at a constant speed of 15 m·s^{-1} with the hooter still emitting sound (6)

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

$f_L = \frac{340}{340-15}$ ✓(520)✓

f_L=544 Hz

v=fλ✓

$\lambda = \frac{340}{544}$✓

λ=0.63 m✓

2.2 Explain why the wavelength calculated in QUESTION 2.1.1 differs from that obtained in QUESTION 2.1.2. (2)

The wavelength in QUESTION 2.1.2 is shorter because the waves are compressed as they approach the observer.✓✓

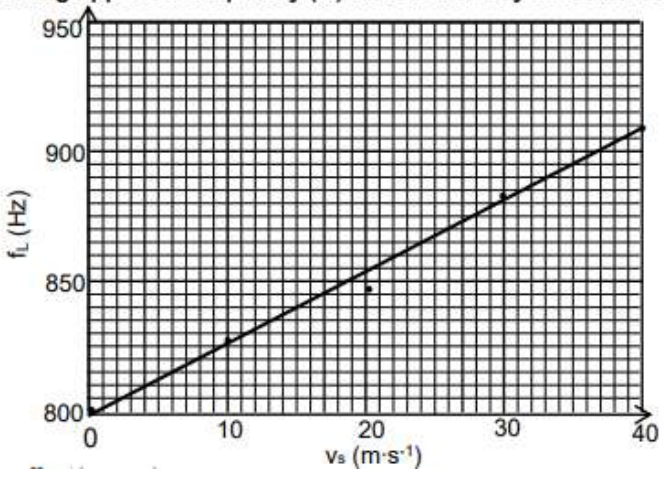
2.3 Use your knowledge of the Doppler effect to explain red shifts. (2)

The red shift occurs when the spectrum of a distant star moving away from the earth is shifted toward the red end of the spectrum. ✓✓

WORKED EXAMPLE 3.

The graph below shows the relationship between the apparent frequency (f_L) of the sound heard by a STATIONARY listener and the velocity (vs) of the source travelling TOWARDS the listener

Graph showing apparent frequency (f_L) versus velocity of sound source (v_s)



3.1 Use the information in the graph to calculate the speed of sound in air. (5)

$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$ ✓ *The following values are obtained using other points*

825 ✓$= \frac{v}{v - v_s}$(800)✓

(1,03125)(v – 10)= v ✓

v = 330 m·s^{-1}✓

v_s (m·s^{-1})	Frequencies	v (m·s^{-1})
v_s = 20	850	310
v_s = 20	845	375,56
vs =30	880	330
40	910	331

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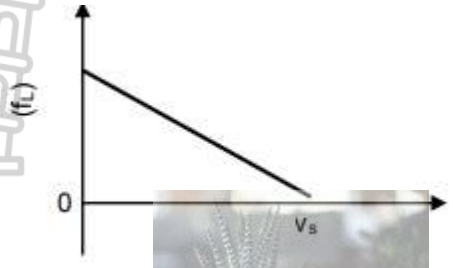
3.2 Sketch a graph of apparent frequency (f_L) versus velocity (v_s) of the sound source if the source was moving AWAY from the listener. It is not necessary to use numerical values for the graph. (2)

Straight line with negative gradient / frequency decreases (linearly).



✓✓

WORKED EXAMPLE 4.

4.1 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 number	1	2	3	4
Velocity of the sound source ($m \cdot s^{-1}$)	0	10	20	30
Frequency (Hz) of the sound detected by the stationary listener	900	874	850	827

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

Frequency (of sound detected by the listener (observer) ✓

4.1.2 What phenomenon is the above investigation illustrating? (1)

Doppler Effect✓

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

Away. Detected frequency of source decreases ✓✓

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

EXPERIMENT 2

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

874 ✓$= \frac{v}{v-10}$ ✓(900)✓

$v = 336{,}15\ m.s^{-1}$ ✓

EXPERIMENT 3

$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

$850 = \frac{v}{v-20}(900)$

$v = 340\ m.s^{-1}$

EXPERIMENT

$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

$827 = \frac{v}{v-30}(90($

$v = 339{,}86\ m.s^{-1}$

4.2 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)

Away from the earth. ✓

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MULTIPLE CHOICE QUESTIONS

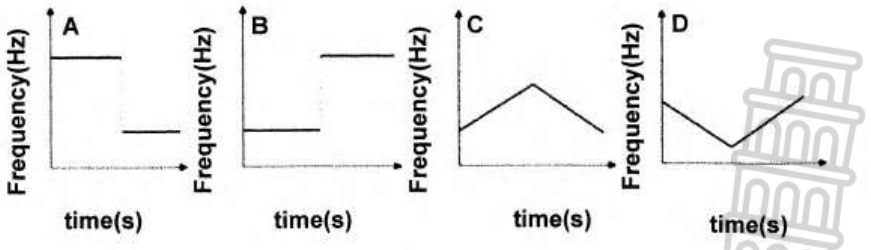
1 A hooter of a car emits sound waves of constant frequency as the car moves away from a stationary listener. (2)
Which of the following properties of sound waves heard by the listener will NOT change?

A velocity
B frequency
C wavelength and frequency
D frequency and loudness

2 A trumpet player standing on the stage of a hall is playing some musical notes through his trumpet. (2)
Which one of the following situations may result in a listener in an audience hearing a note at a lower pitch?

A Listener must be facing away from the stage
B Listener must run away from the stage
C Listener must run towards the stage
D The trumpet player must play seated on stage

3 A source of sound approaches a stationary listener in a straight line at constant velocity. It passes the listener and moves away from him in the same straight line at the same constant velocity. Which ONE of the following graphs best represents the change in observed frequency against time? (2)



4 The shifting of a spectrum for a BLUE SHIFT is … (2)

A to a longer wavelength.
B to a lower energy.
C towards the red end of the spectrum.
D to a higher energy.

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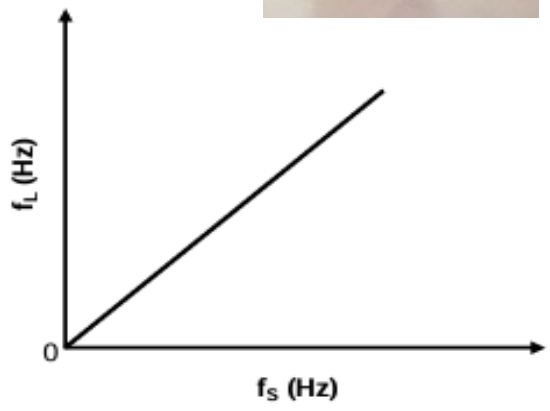
5 An observer moves away from a stationary source. The pitch heard by the observer appears to change because … (2)

A loudness of the source appears to increase
B frequency of the source appears to increase
C frequency of the source appears to decrease
D wavelength of the source appears to decrease

QUESTION 1

A learner investigate the relationship between the observed frequency and the frequency of the sound waves emitted by a stationary source. The learner moves towards the source at a constant velocity and records the observed frequency **(f_L)** for a given source frequency **(f_S)**.This process is repeated for different frequencies of the source, with the learner moving at the same constant velocity each time.
The graph below shows how the observed frequency changes as the frequency of sound waves emitted by the source changes.



1.1 Write down the use of Doppler effect in :
1.1.1 Traffic (1)
1.1.2 Home safety (1)
1.1.3 Marine navigation (1)

1.2 Write down the proportionality that exists between **f_L** and **f_S** as illustrated in the graph. (1)

1.3 The gradient of the graph obtained is found to be 1,06. If the speed of the sound in air is 340 m.s^{-1}, calculate the magnitude of velocity at which the learner approaches the source. (5)

1.4 The investigation is now repeated with a learner moving at a HIGHER constant velocity towards the sound source. Copy the graph above in your ANSWER BOOK and label it as **A**. on the same set of axes, sketch the graph that will be obtained when a leaner is moving at a HIGHER velocity. Label this graph **B**. (2)

QUESTION 2

An ambulance moves away from an accident scene at a constant speed with its siren producing sound waves. A detector at the scene measure 90% of the frequency of sound waves produced by the siren as the ambulance moves away.

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2.1 Explain, in terms of wave motion, why the detector measures 90% of the frequency of sound waves emitted by the ambulance. (2)

2.2 **Assume that the speed of sound in air is 340m.s^{-1}.** (5)
Calculate the speed of the ambulance.

2.3 The diagram below shows spectral lines for a nearby star and a distant star as observed from earth.

2.3.1 Define Red Shift. (2)

2.3.2 Is the star moving towards or away from earth (1)

2.3.3 Compare the motion of the nearby star and a distant star as observed from the Earth. Which ONE of them is moving faster? (2)

QUESTION 3

An ambulance, with its siren on, is moving at a constant speed along a straight horizontal road towards a stationery detector. The detector registers sound waves with a frequency of 450Hz as the ambulance approaches it. As the ambulance moves away from the detector, the detector registers sound waves with a frequency of 385 Hz**. Assume that the speed of sound in the air is 340 m.s^{-1}**.

3.1 Calculate the speed of the ambulance (6)

3.2 Calculate the frequency of sound waves emitted by the siren. (2)

3.3 What will be the frequency of the sound waves heard by the driver of the ambulance? (1)

QUESTION 4

Learner is sitting at the side of the road with a detector that can measure several frequencies of sound waves. A fire engine and an ambulance travel at a constant velocity in the same direction and on the same road where a learner is sitting. The siren of the ambulance emits sound waves with a constant frequency of 920 Hz, while the siren of the fire engine emits sound waves with a constant frequency of 900Hz. The detector that a learner has measures the frequency of the sound waves emitted from the ambulance as 1030Hz and that of a fire engine as 850Hz.

4.1 Which vehicle (the ambulance or fire engine) is travelling towards a learner? (1)

4.2 Which vehicle (the ambulance or fire) engine is travelling away from a learner? (1)

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4.3 The fire engine is travelling at 20 m.s^{-1}. Calculate the speed with which the ambulance is travelling. (6)

4.4 Most scientists subscribe to the theory that the universe is expanding. Briefly explain how the Doppler effect is used to support this theory (4)

QUESTION 5

Some motion-sensor burglar alarms installed in homes make use of ultrasound waves that have a frequency of 30 kHz. Waves sent out of the device are reflected by objects in a room. If the objects are stationary, then the reflected waves reach the device with the same frequency as the outgoing wave (30 kHz). If an object moves, the frequency of reflected waves is altered. Such change in frequency will trigger the alarm.

(Take the speed of sound in air as 340 m.s^{-1})

5.1 Name and state the scientific phenomenon upon which this technology is based. (3)

5.2 Calculate the wavelength of the waves being generated by the device. (3)

5.3 How will the frequency of the wave detected by the device change when it is reflected off an object moving towards the device? (Choose from INCREASE, DECREASE, REMAINS THE SAME) (1)

5.4 A wave reflected off a moving object in the room is detected at a frequency of 29 500 Hz. Calculate the velocity of the object. (6)

QUESTION 6

A stationery source emits a sound wave of frequency 5000 Hz. An object approaches this source with an unknown velocity. The sound wave is reflected from the moving object which is detected by the source.

(Take the speed of sound in the air as 340 m.s^{-1})

6.1 State the definition of Doppler effect. (2)

6.2 Calculate the wavelength of the waves being generated by the source. (3)

6.3 Calculate the velocity of the object if the detected wave, by the source, has frequency of 5104 Hz. (6)

6.4 State TWO applications of the Doppler Effect in Medical Science. (2)

QUESTION 7

A man mounts a siren on the roof of his car. The siren produces a constant frequency of 600 Hz. He drives the car at a constant speed up and down a straight road while a stationary listener takes some readings. After a while, the listener obtains the following pressure-time graph from the readings taken.

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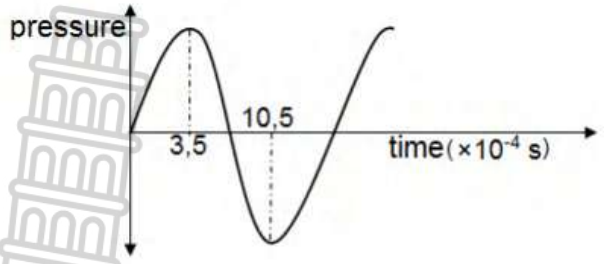

Take the speed of sound in air as 340 m.s^{-1}.

7.1 How many waves are depicted in the diagram above? (1)

7.2 Determine the period of the detected wave. (2)

7.3 Calculate the frequency of the detected sound wave (3)

7.4 Calculate the speed of the moving car. (5)

QUESTION 8

The alarm of a vehicle parked next to a straight horizontal road goes off, emitting sound with wavelength 0,34m. A patrol car is moving at a constant speed on the same road. The driver of the patrol car hears a sound with a frequency of 50 Hz **lower than** the sound emitted by an alarm. Take the speed of sound in air as 340 m.s^{-1}.

8.1 Is the patrol car moving TOWARDS or AWAY from the parked vehicle? Give a reason for your answer. (2)

8.2 Calculate the frequency of the sound emitted by the alarm. (3)

8.3 The patrol car moves a distance of *x* in 10 seconds. Calculate the distance *x*. (6)

QUESTION 9

An ambulance approaches a stationary observer at constant speed of 10,6 m.s^{-1}, while its siren produces sound at a constant frequency of 954,3 Hz. The stationary observer measures the frequency of the sound 3,25 % higher than the frequency of the siren.

9.1 Name the medical instrument that makes use of the Doppler Effect. (1)

9.2 Calculate the frequency measured by the stationary observer. (2)

9.3 Calculate the speed of sound. (4)

9.4 How would the wavelength of the sound wave produced by the siren of the ambulance change if the frequency of the wave were higher than 954,3Hz? Write down only INCREASE, DECREASE or STAYS THE SAME. (1)

9.5 Give a reason for the answer to QUESTION 5.4. (2)

QUESTION 10

A patrol car is moving at a constant speed towards a stationary observer. The driver switches on the siren of the car when it is 300 m away from the observer. The observer records the detected frequency of the sound waves of the siren as the patrol car approaches, passes and moves away from him. The information obtained is shown in the graph.Take the speed of sound in air as 340 m·s^{-1}.

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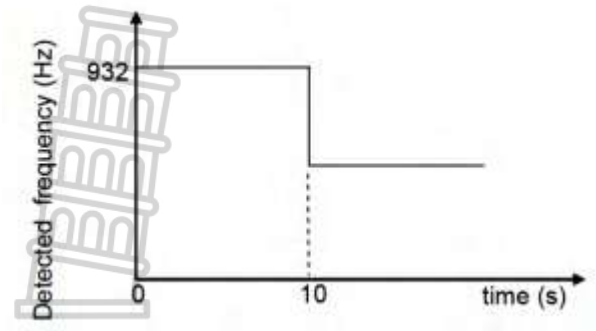

10.1 Calculate the speed of the patrol car. (2)
10.2 State the Doppler effect. (2)
10.3 The detected frequency suddenly changes at t = 10 s. Give a reason for this change. (1)
10.4 Calculate the frequency of the sound emitted by the siren. (4)
10.5 State TWO applications of the Doppler effect (2)

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ACIDS AND BASES

IMPORTANT TERMS AND DEFINITIONS

Acid-base indicator: A dye used to distinguish between acidic and basic solutions by means of the colour changes it undergoes in these solutions.
Amphiprotic substance OR ampholyte: A substance that can act as either an acid or a base.
Arrhenius theory: An acid is a substance that produces hydrogen ions (H+)/ hydronium ions (H_3O^+) when it dissolves in water.
A base is a substance that produces hydroxide ions (OH^-) when it dissolves in water.
Auto-ionisation of water A reaction in which water reacts with itself to form ions (hydronium ions and hydroxide ions).
Concentrated acids/bases Contain a large amount (number of moles) of acid/base in proportion to the volume of water.
Conjugate acid-base pair A pair of compounds or ions that differ by the presence of one H_3O^+ ion.
Dilute acids/bases Contain a small amount (number of moles) of acid/base in proportion to the volume of water.
Diprotic acid: An acid that can donate two protons. Example: H_2SO_4
Dissociation The process in which ionic compounds split into ions.
Endpoint The point in a titration where the indicator changes colour.
Equivalence point The point in a reaction where equivalent amounts of acid and base have reacted completely.

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Hydrolysis The reaction of a salt with water. OR The reaction of an ion with water to produce the conjugate acid and a hydroxide ion or the conjugate base and a hydronium ion.
Ionisation The process in which ions are formed during a chemical reaction.
Ion product of water The product of the ions formed during auto-ionisation of water i.e. $[H_3O^+][OH^-]$ at 25 °C.
Ionisation constant of water (Kw) The equilibrium value of the ion product [H3O+][OH–] at 25 °C.
Ka value Ionisation constant for an acid
Kb value Dissociation or ionisation constant for a base
Lowry-Brønsted theory An acid is a proton (H+ ion) donor./A base is a proton (H+ ion) acceptor.
Monoprotic acid An acid that can donate one proton. Example: HCℓ
Neutralisation: the reaction of an acid with a base to form a salt (ionic compound) and water.
Salt The ionic compound that is the product of a neutralisation reaction.
Standard solution A solution of precisely known concentration.
Strong bases Dissociate completely in water to form a high concentration of OH- ions. **Examples:** sodium hydroxide and potassium hydroxide.
Strong acids Ionise completely in water to form a high concentration of H3O+ ions. Examples: hydrochloric acid, sulphuric acid and nitric acid
Weak acids Ionise incompletely in water to form a low concentration of H3O+ ions. Examples: ethanoic acid and oxalic acid
Weak bases Dissociate/ionise incompletely in water to form a low concentration of OH- ions. Examples: ammonia, sodium carbonate, potassium carbonate, calcium carbonate and sodium hydrogen carbonate

NOTES/SUMMARY

Acid (Arrhenius) is a substance that produces hydrogen ions (H+) / hydronium ions (H3O+) in aqueous solution.

$HC\ell(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + Cl^-(aq)$

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.

$HC\ell(aq) + NH_3(l) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$

Base(Lowry-Bronsted) A base is a proton (H+ ion) acceptor.

$HC\ell(aq) + NH_3(g) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$

Strong acid is an acid which ionise completely in water to form a high concentration of hydronium ions(H_3O^+)

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Examples:
$HC\ell$
HNO_3
H_2SO_4
Weak acid is an acid which partially ionises in water to form a low concentration of hydronium ions (H_3O^+).

Examples:
CH_3COOH
H_2CO_3
$(COOH)_2$ etc

A strong base is a base which dissociate completely in water to form a high concentration of hydroxide ions. (OH^-)
Examples:
NaOH
KOH
$Mg(OH)_2$
$Ba(OH)_2$

A weak base is a base which dissociate/ionise partially in water to form a low concentration of hydroxide ions (OH^-)
Example:
NH_3
Concentrated acid/base is a base/acid which contains a large amount of acid/base in proportion to the volume of water.
Dilute acid/base is a base/ acid which contains a small amount of acid/base in proportion to the volume of water.
Monoprotic an acid that donates with one proton per molecule
Diprotic an acid that donates with two protons per molecule.
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:
Example :
Will a solution of $NH_4C\ell$ be basic, acidic or neutral? Use hydrolysis to fully explain the answer.
Step 1: The two ions present in this salt are NH_3 and $C\ell^-$.
NH_3 comes from a weak base, NH_3. $C\ell^-$ comes from a strong acid, $HC\ell$.
Step 2: $C\ell^-$ will not undergo hydrolysis because it is the conjugate base of a strong acid.
NH_4^+ is the conjugate acid of a weak base and will undergo hydrolysis.

Step 3:NH_3 will undergo hydrolysis according to the following equation:

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

The forward reaction will be favoured above the reverse reaction, because NH_3 is a weak base and will ionise only partially.

Step 4: The salt is acidic because H_3O^+ ions are formed during hydrolysis. The pH of the salt will be less than 7.

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

A salt from a weak acid and a strong base will be basic (pH > 7).

SUMMARY

Hydrolysis of the salt of a weak acid and a strong base forms an alkaline solution, i.e. the pH > 7. Examples of such salts are sodium ethanoate, sodium oxalate and sodium carbonate.

Hydrolysis of the salt of a strong acid and a weak base forms acidic solution, i.e. the pH < 7. An example of such a salt is ammonium chloride.

The salt of a strong acid and a strong bases does not undergo hydrolysis and the solution of the salt will be neutral, i.e. pH = 7.

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

Example

Reaction 1:

$H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$

acid 1 base 2 acid 2 base 1

Reaction 2:

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

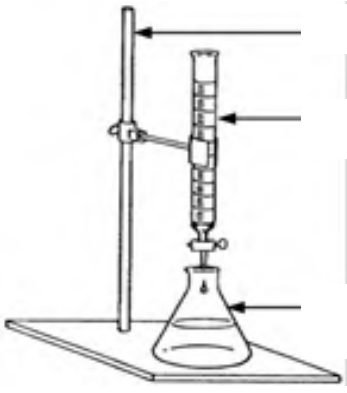
acid 1 base 2 acid 2 base 1

In reaction 1, HSO_4^- acts as a base. In reaction 2, HSO_4^- acts as an acid. HSO_4^- can either donate or accept a proton and is an amphiprotic substance

Titration is a technique of finding the unknown concentration using a solution of known concentration (standard solution)

Apparatus used for titration:

Pipette



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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.

Indicators

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 p**henolphthalein**.

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**.

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WORKED EXAMPLES

EXAMPLE 1

A standard solution is prepared in a 200 cm^3 volumetric flask by dissolving 4, 9 g of pure sulphuric acid in water and filling the flask to the mark. During a titration, 20, 7 cm^3 of this standard solution completely neutralise 10, 0 cm^3 of a sodium hydroxide solution of unknown concentration.

Write the balanced equation for the titration reaction.

H_2SO_4 (aq) + 2NaOH (aq) ✓ → Na_2SO_4(aq) + 2H_2O(ℓ) ✓bal. ✓

Calculate the concentration of the sulphuric acid solution.

$$c = \frac{\text{m}}{\text{MV}} ✓ = \frac{4,9}{98(0,2)} ✓ \quad c = 0,25\ mol.dm^{-3} ✓$$

Calculate the number of moles of Sulphuric acid neutralised.

$$\text{c} = \frac{n}{\text{V}} ✓ \quad 0,25 = \frac{\text{n}}{0,0207} ✓ \quad n = 5,175\ x10^{-3}\text{mol} ✓$$

Calculate the concentration of the sodium hydroxide.

$$\frac{\text{na}}{\text{nb}} = \frac{\text{caVa}}{cbVb} ✓$$

$$\frac{1}{2} ✓ = \frac{(0,25)(20,7)}{(cb)(10)} ✓$$

Cb=1,035 mol.dm^{-3}

EXAMPLE 2

A 1,034 g sample of impure oxalic acid is dissolved in water and an acid-base indicator is added. The sample requires 34, 47 cm^3 of 0,485 mol•dm^{-3} NaOH to reach the equivalence point. Calculate the mass of oxalic acid and hence the percentage purity of the sample.

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Step 1: Write the balanced equation for the reaction.

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

Step 2: Calculate the number of moles of sodium hydroxide (nb) neutralised.

nb = cbVb = (0,485)(34,47 x 10^{-3}) = 1,67 x 10^{-2} mol

Step 3: Calculate the number of moles of oxalic acid (na) neutralised.

The balanced equation shows that 1 mole $(COOH)_2$ requires 2 moles NaOH to completely react. This is the required stoichiometric factor to obtain the amount of $(COOH)_2$ that has reacted.

At the equivalence point:

na : nb 1:2

= ½nb = ½(1,67 x 10^{-2}) = 8,36 x 10^{-3} mol✓

Step 4: Calculate the mass of oxalic acid that has reacted.

$n = \frac{m}{M}$ ✓8,36x10^{-3}= $\frac{m}{90}$ ✓ m=0,75 g

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Step 5: Calculate the percentage of oxalic acid in the sample.

$\%\ \text{purity} = \frac{\text{Pure mass}}{\text{Impure mass}}$X 100

$\%\text{purity} = \frac{0{,}75\ g}{1{,}034\ g}$X100 ✓

%purity= 72,76%✓

EXAMPLE 3

Carbonic acid (H_2CO_3) ionises according to the following equation:

3.1. $H_2CO_3(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + HCO_3^-(aq)$

Is carbonic acid, $H_2CO_3(aq)$, a strong acid or a weak acid?Give a reason for the answer

Two beakers **A** and **B** contain the acid and a strong base respectively

Beaker A: 0,5 dm^3 of carbonic acid, $H_2CO_3(aq)$ of concentration 0,10 mol.dm $^{-3}$

Beaker B: 0,75 dm^3 of sodium hydroxide, NaOH(aq) of concentration 0,25 mol.dm^{-3}

When a 0,10 mol•dm^{-3} solution of H_2CO_3 is prepared, it is found that the concentration of $HCO_3^-(aq)$ ions is 0,012 mol.dm^{-3} at 25 °C

3.2. Calculate the number of moles of H3O+(aq) ions present in H_2CO_3 solution in beaker A.

The contents of beakers A and B are added together in beaker C. The solution in beaker C has an unknown pH.

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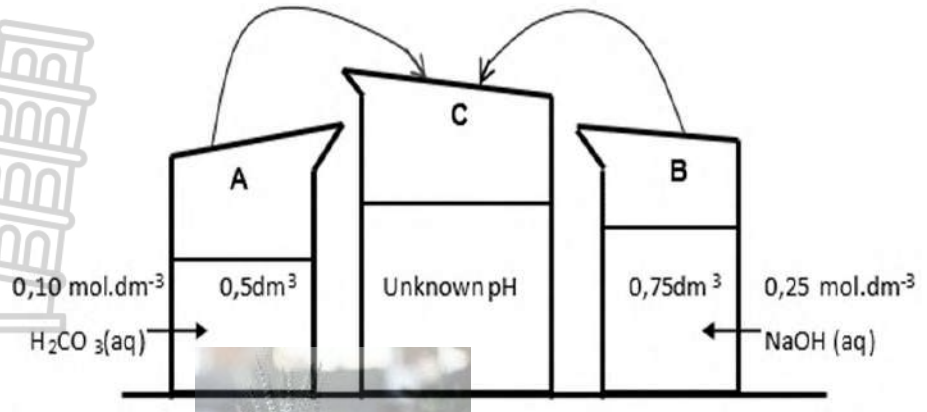

$H_2CO_3(aq) + NaOH(aq) \rightarrow NaHCO_3(aq) + H_2O(\ell)$

3.3 Calculate the:

3.3.1 Number of moles of hydroxide (OH^-) ions in beaker **B**.

3.3.2 pH of the solution at the completion of the reaction in beaker **C**.

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SOLUTION:

3.1 Weak acid: It <u>ionises incompletely/does not ionise completely in water</u> (to form a low concentration of H_3O^+)✓✓ (2)

3.2 $[H_3O^+] = [HCO_3^-] = 0{,}012\ mol.dm^{-3}$ (3)

n = cV ✓

n= 0,012 x 0,5 ✓

n = 0.006 mol ✓

3.3.1 n (NaOH) = cV ✓ (3)

$n_{(NaOH)} = 0{,}25 \times 0{,}75$ ✓

n = 0,1875 mol

Therefore $n(OH^-) = 0{,}1875$ mol ✓

3.3.2 0,006 mol of acid neutralises 0,006 mol of base ✓ (7)

n(OH-) in excess 0,1875- 0,006✓= 0,1815 mol

$[OH^-] = n/V$

$[OH^-] = 0{,}1815/(0{,}5+0{,}75)$ ✓

[OH-] = 0,1452 $mol.dm^{-3}$

$Kw = [H_3O+][OH^-] = 1 \times 10^{-14}$,

therefore $[H_3O^+] = 10^{-14}/0{,}1452$ ✓

$= 6{,}89 \times 10^{-13}\ mol.dm^{-3}$

pH = -log [H3O+] ✓

pH = -log(6,89x10-14) ✓

pH = 13,16✓

Example 4

4.1. In an experiment 1,5 g of a powdered impure calcium carbonate sample, $CaCO_3$, is reacted with $200cm^3$ of a 0,15 $mol.dm^{-3}$ hydrochloric acid solution, $HC\ell(aq)$ the balanced equation for the reaction is:

$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

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All the CO_2 (s) formed escapes from the solution
The resulting solution has a pH of 1.61 and a volume of 200 cm^3
Assume that ALL the $CaCO_3$ (s) in the impure sample reacted with the HCℓ and none of the impurities reacted.

Calculate the mass of the impurities present in the 1,5 g sample of impure $CaCO_3$(s) (9)

Solution

Convert pH to concentration
pH + -log [H_3O^+]
1,61 = log[H_3O^+]✓
[H_3O^+] = 0,0245 mol.dm^{-3}✓
Calc. excess n of H_3O^+
$.c = \frac{n}{V}$ ✓
$0{,}0245 = \frac{n}{0{,}2}$✓
n(excess) = 4,9 x 10^{-3} mol
Calc. initial n of HCℓ…
$c = \frac{n}{V}$ n=0,15 x 0,2 ✓ n= 3 X 10^{-2} mol
calc. reacted n of HCℓ
n(reacted) = n(initial) – n(excess)
n(reacted)= 3x10^{-2} -4,9 x10^{-3} ✓
n(reacted)= 2,6 x 10^{-2} mol
use ratio determine n of $CaCO_3$:
$CaCO_3$: HCℓ 1:2 ∴n = 2 x 10^{-2} ÷ 2 ✓ ∴n = 1,3 x 10^{-2} mol
Determine the m of $CaCO_3$

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

$1{,}3\ x10^{-2} = \frac{m}{100}$ ✓
∴m = 1, 3 g ✓
Mass of impurities = 1,5 -1,3 ✓ = 0,2 g ✓

ACTIVITY

QUESTION 1: MULTIPLE CHOICE QUESTION

1.1 Which ONE of the following statements is ALWAYS true for mono protic acids?

A The lower the concentration of the acid solution, the weaker the acid.
B There will be more H_3O^+ ions in 100 cm^3 of a strong acid solution than in 100 cm^3 of a weak acid solution.
C The pH of a strong acid is lower than the pH of a weak acid.
D One mole of a strong acid will produce more H_3O^+ ions in water than one mole of a weak acid. (2)

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1.2. During a titration to determine the concentration of an acid using a standard solution of a base, a learner pipettes the base into a conical flask. The learner then uses a small amount of water to rinse the inside of the flask so that all the base is part of the solution in the flask. How will the extra water added to the flask affect the results of this titration?

A cannot be determined
B will be lower than expected
C Will be higher than expected.
D will be the same as expected. (2)

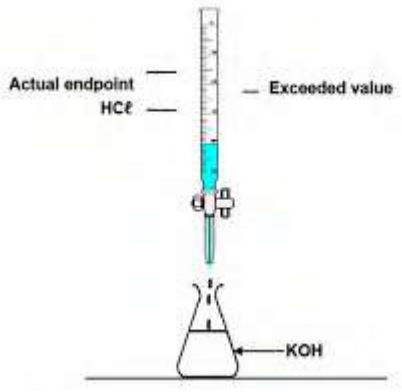
1.3. Which statement best describes the difference between the endpoint and the equivalence point in a titration?

A The endpoint occurs when the acid or base has completely reacted with each other, while the equivalence point is when the indicator changes colour.
B The equivalence point occurs when the acid or base has completely reacted with each other, while the endpoint is when the indicator changes colour.
C The endpoint and equivalence point occur at different times and have no connection in a titration.
D The equivalence point and endpoint are always exactly the same in every titration. (2)

1.4 Which ONE of the following statements regarding a weak acid is FALSE? A weak acid …

A is a proton donor.
B has a pH value of between 8 and 9.
C undergoes a neutralisation reaction with sodium hydroxide.
D reacts with sodium carbonate to release carbon dioxide gas. (2)

1.5 In a titration involving HCℓ and KOH, as shown in the sketch below, a learner accidentally exceeded the endpoint.



Which one of the following is correct for the solution that is now in the flask?

A [H+] < [OH-] and acidic
B [H+] > [OH-] and basic

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C [H+] < [OH-] and basic
D [H+] > [OH-] and acidic (2)

1.6. Which one of the following compounds is diprotic?
A SO_4^{2-}
B HS^-
C H_2S
D SO_4^{2-} (2)

[12]

LONG QUESTIONS

Question 1

H_2SO_4 is a strong, diprotic acid and ionises as shown below.

$$H_2SO_4\,(aq) + H_2O\,(\ell) \rightleftharpoons X\,(aq) + 2H_3O^+\,(aq)$$

1.1. Define the term diprotic acid. (2)

1.2. Consider the reaction:

1.2.1 Write down the NAME and FORMULA of the conjugate acid of H_2O (ℓ). (2)

1.2.2 Write down the formula of X. (2)

1.2.3. Complete the following sentence:
H_2O is an ampholyte because H_2O can form H_3O^+ or … (1)

1.3. A learner adds 0,06 mole of NaOH to 1 dm^3 of a 0,5 mol•dm^{-3} HCℓ solution.

1.3.1. Write down a balanced equation for the reaction that takes place. (3)

1.3.2. Calculate the initial number of moles of HCℓ present in the solution (3)

1.3.3. Write down the number of moles of NaOH needed to react with the acid. (1)

1.3.4 Which one of the two substances is in excess? (1)

1.3.5. Calculate the pH of the final solution (6)

[18]

Question 2

2.1. Learners use the reaction of a sulphuric acid solution with two different hydroxide solutions. In this reaction, sodium hydroxide is used. The balanced equation for the reaction is:

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

The learner transfers 25 cm^3 of the sulphuric acid solution to an Erlenmeyer flask by using apparatus A. It is then titrated with a standard solution of 0, 2 mol·dm^{-3} sodium hydroxide.

The above is repeated with two other sulphuric acid solutions

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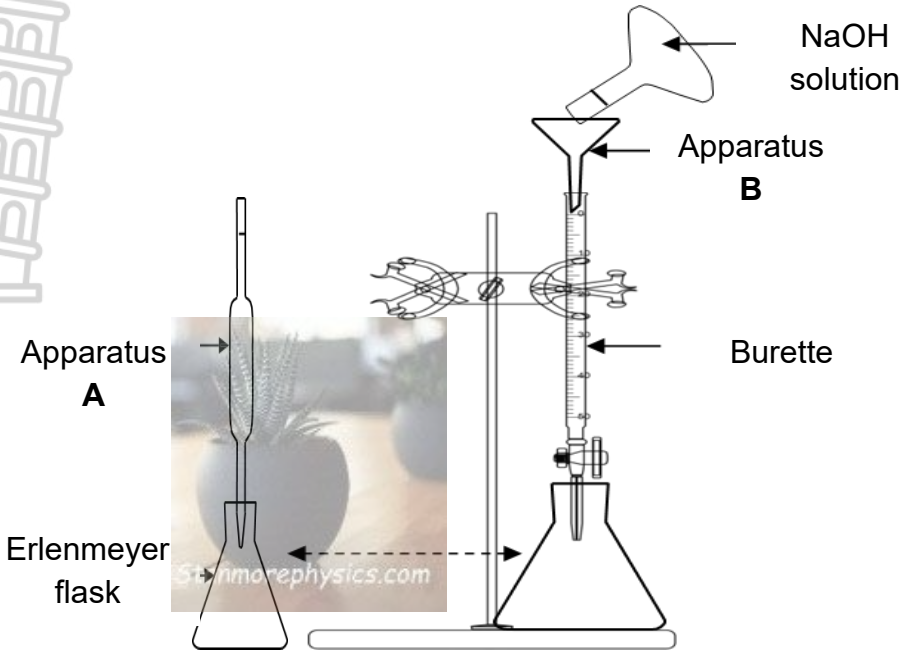

The results are shown below.

Sample Volume of NaOH (cm^3)	Sample Volume of NaOH (cm^3)
1	14,9
2	14,2
3	14,3

2.1. Define the term standard solution. (2)

2.2. Write down the name of apparatus:

2.2.1 A (2)

2.2.2. B

2.3 Explain why the volume of sodium hydroxide used in the calculation is taken as 14, 25 cm^3, although this is not the average of the three volumes in the table.

2.4. Calculate the concentration of the sulphuric acid. (4)

2.5. The first step in the ionisation of sulphuric acid is given below:

$H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons HSO_4^-(aq) + H_3O^+(aq)$ (3)

2.5.1. Why sulphuric acid is considered a strong acid? (2)

2.5.2. For HSO_4^-, identify its: (1)

(a) Conjugate acid

(b) Conjugate base (1)

2.5.3. What is the name given to a substance like HSO_4^- that can act as both an acid and a base? (1)

2.5.4. Use the above equation to write down the name or formula of another substance that can act as the one mentioned in QUESTION 2.5.3. (1)

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2.6. In a separate experiment sulphuric acid reacts with calcium hydroxide to form salt P and product Q as shown.

$H_2SO_4 + Ca(OH)_2 \rightarrow$ salt P + product Q

2.6.1. Define a base according to the Arrhenius theory. (2)

2.6.2. Write down the FORMULA of salt P. (1)

2.6.3. Write down the NAME of product Q. (1)

[22]

Question 3

3.1 The dissociation constant of some substances is given below

Name of substance	Formula	Ka (298 K)
Hydrogen sulphate ion	HSO_4^-	$1,2 \times 10^{-2}$
Ammonium ion	NH_4^+	$5,6 \times 10^{-10}$
Phosphoric acid	H_3PO_4	$7,5 \times 10^{-3}$
Hydrocyanic acid	HCN	$4,9 \times 10^{-10}$

3.1.1. Write down the FORMULA of the substance that has the highest tendency to dissociate. (1)

3.1.2. write down the formula of the conjugate base of hydrocyanic acid (1)

3.2. 7,6 g of impure commercial washing soda ($Na_2CO_3.10H_2O$) is dissolved in water. The solution is diluted to 500 cm^3 in a measuring flask. 25cm^3 of this solution is titrated with standard HCℓ solution of concentrated 0, 1 $mol.dm^{-3}$.

$Na_2CO_3.10H_2O + HC\ell \rightarrow NaCl + H_2O + H_2O + CO_2$

3.2.1. Rewrite and balance the chemical equation for the above reaction. (1)

3.2.2. Three indicators are available to indicate the equivalence point of this titration.

Methyl orange

Bromothymol blue

Phenolphthalein

Choose from the list of indicators, the ONE which will be the most suitable for this titration. (1)

3.2.3. Give a reason for the answer in Question 3.2.2. (2)

3.2.4. What colour change will be observed during the titration of the base with the acid (1)

3.2.5. Calculate the mass of pure Na_2CO_3 in commercial washing soda if 24,8 cm^3 of the HCℓ solution was needed to reach the equivalence point in the titration (5)

3.2.6. Calculate the percentage purity of the Na_2CO_3 in the original mass of commercial washing soda. (3)

[16]

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Question 4

4.1. Define an acid according to the BrØnsted-Lowry theory. (2)

4.2. Calculate the pH of a sodium hydroxide solution of concentration 0, 75 mol•dm^{-3}. (5)

4.3. Seashells contain calcium carbonate ($CaCO_3$). In a test to find the percentage of calcium carbonate ($CaCO_3$) present in seashells, 75 cm^3 of a 0,5 mol•dm^{-3} hydrochloric acid (HCℓ) solution is added to a 5 g sample of seashells. The acid is in excess.

The balanced equation for the reaction is given below.

$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + CO_2(g) + H2O(\ell)$

The excess acid required 22 cm^3 of the above sodium hydroxide solution for complete neutralisation according to the following balanced equation

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

Calculate the percentage of calcium carbonate ($CaCO_3$) in the sample of seashells (8)

[15]

Question 5

A monoprotic acid HY ionises completely when dissolved in water. The hydroxide ion concentration [OH$^-$] in the solution is 1 x 10^{-11} mol•dm^{-3}

5.1.1. Define an acid in terms of the Arrhenius theory. (2)

5.1.2. Define the term monoprotic acid (2)

5.1.3. Is acid HY a WEAK or a STRONG acid? Give a reason for your answer. (2)

5.1.4. Calculate the following:

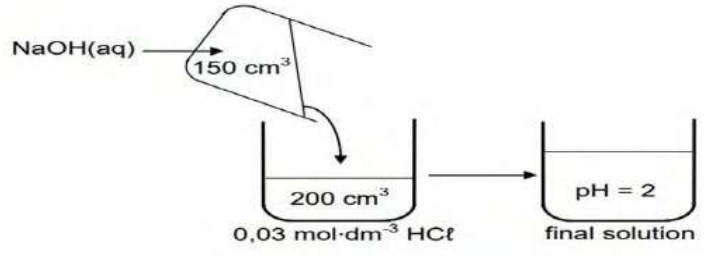
The concentration of hydronium ions [H_3O^+] in the solution. (3)

The pH of the solution (3)

[12]

Question 6

Learners add 150 cm^3 of a sodium hydroxide solution, NaOH, of unknown concentration to 200 cm^3 of a 0, 03 mol·dm^{-3} hydrochloric acid solution, HCℓ, as illustrated below. They find that the pH of the final solution is 2. Assume that the volumes are additive



The balanced equation for the reaction is:

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

Calculate the

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6.1. Concentration of the H_3O^+ ions in the final solution. (3)

6.2. Initial concentration of the NaOH (aq). (7)

Question 7 [10]

Consider the following reaction:

$$H_2SO_4(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$$

7.1. Which substance/s in the above equation can act as an ampholyte? (2)

7.2. A solution of hydrochloric acid has a concentration of 0,1 $mol.dm^{-3}$.

7.2.1. Define a strong acid. (2)

7.2.2. Calculate the pH of this solution. (3)

7.3. A flask contains 200 cm^3 of an aqueous solution of sodium hydroxide (NaOH) of concentration 0, 1 $mol.dm^{-3}$. To this flask, 50 cm^3 of an aqueous solution of barium hydroxide, $Ba(OH)_2$, of UNKNOWN concentration is added, giving a total volume of 250 cm^3.

In a titration, 20 cm^3 of this mixture is completely neutralised by 30 cm^3 of a hydrochloric acid solution of concentration 0,1 $mol.dm^{-3}$.

The ionic reaction is represented by the following equation:

$$H_3O^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

7.3.1. What is the pH of the solution when the endpoint of the titration is reached? Choose from LESS THAN 7, GREATER THAN 7 or EQUAL TO 7. (1)

7.3.2. Calculate the number of moles of hydroxide ions (OH^-) present in 20 cm^3 of the mixture of sodium hydroxide and barium hydroxide solutions. (4)

7.3.3. Calculate the initial concentration of the barium hydroxide, $Ba(OH)_2$, solution that was added to the solution of sodium hydroxide. (7)

[19]

Question 8

8.1. Consider the following balanced chemical equations showing some acid-base reactions.

A $HNO_3 + KOH \rightarrow KNO_3 + H_2O$

B $H_2SO_3 + H_2O \rightleftharpoons HSO_3^- + H_3O^+$

Consider the chemical equations (A and B) above.

8.1.1. Describe the term amphoteric substance. (2)

8.1.2. Write down the formula of an amphoteric chemical substance (other than H_2O) (1)

8.1.3. Write down the formulae of the conjugate acid-base pairs in reaction B. (2)

8.3. Which indicator must be used in reaction A. Choose from METHYL ORANGE, BROMOTHYMOL BLUE or PHENOLPHTHALEIN? Give a reason for the answer. (3)

8.4. Consider reactions A and C, shown below.

A $HNO_3 + KOH \rightarrow KNO_3 + H2O$

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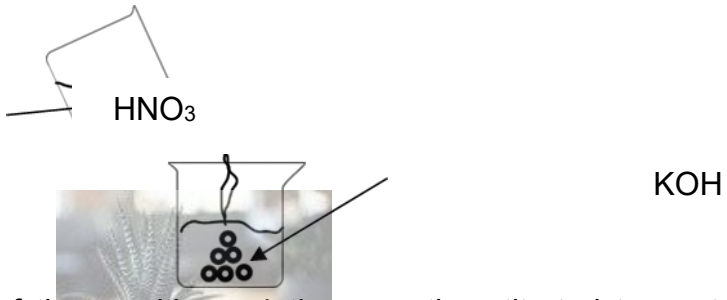
C $2HNO_3 + Na_2CO_3 \rightarrow 2NaNO_3 + CO_2 + H_2O$

A 13 g, impure sample of KOH is initially dissolved in 200 cm^3 of a 1,2 $mol{\bullet}dm^{-3}$ nitric acid solution. The nitric acid was in EXCESS. Assume that the volume remains constant.



50 cm^3 of the resulting solution was then titrated to neutralisation using 23, 67 cm^3 of a standard 0, 85 $mol{\bullet}dm^{-3}$ sodium carbonate solution.

8.4.1. Determine the amount (in mol) of nitric acid that was added to the KOH. (2)

8.4.2. Calculate the percentage purity of the KOH sample (9)

[19]

QUESTION 9

Oxalic acid ($H_2C_2O_4$) is an organic diprotic acid commonly found in plants such as spinach. It is used in various industrial and laboratory applications, including cleaning, bleaching, and as a standard solution in acid-base titrations.

When oxalic acid ionizes in water, it follows the steps given below:

STEP 1 $H_2C_2O_4(aq) + H_2O(l) \rightarrow HC_2O4\text{-}(aq) + H_3O^+(aq)$

STEP 2 $HC_2O_4^-(aq) + H_2O(l) \rightarrow C_2O_4^{2-}(aq) + H_3O^+(aq)$

9.1. Define a weak acid. (2)

9.2. Identify the acid-base conjugate pair in STEP 1. (2)

9.3. Give a reason why oxalic acid is referred to as a diprotic acid. (1)

9.4. The oxalate ion ($HC_2O_4^-$) can act as an ampholyte. Give a reason for this statement. (1)

9.5. In a volumetric flask 2, 25 g of oxalic acid is added to water to make up a standard solution to 250 $cm^{3.}$

9.5.1. Calculate the concentration of the oxalic acid solution.

9.5.2. 25 cm^3 of the oxalic acid solution is titrated against sodium hydroxide. The average volume of NaOH required for neutralisation is 28, 60 cm^3.

$H_2C_2O_4(aq) + 2NaOH(aq) \rightarrow Na_2C_2O_4(aq) + 2H_2O(l)$ (4)

Calculate the concentration of the sodium hydroxide.

9.5.3. Explain why phenolphthalein would be a suitable indicator for this reaction. (2)

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9.6. You are given the following ionisation reaction of ethanoic acid in water: $CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$ $K_a = 1{,}8 \times 10^{-5}$

9.6.1. 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 $mol \cdot dm^{-3}$? (3)

9.6.2. Assume 100% dissociation of magnesium hydroxide in water.What will the concentration of the hydroxide ions in the solution be? (2)

9.6.3. The pH of any medicine safe for human consumption must lie between pH = 4 and pH =9.

Will this solution that the learners prepare be safe for human consumption? Show all calculations. (5)

9.7. The reaction between EXCESS magnesium hydroxide ($Mg(OH)_2$), a slightly soluble base, and nitric acid (HNO_3), occurs in aqueous solution, where it produces magnesium nitrate ($Mg(NO_3)_2$), a soluble salt and water, according to the following balanced equation below.

$$Mg(OH)_2(aq) + 2HNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + 2H_2O(l).$$

0,05 dm^3 of the $Mg(OH)_2$ solution has a concentration 0,115 $mol.dm^{-3}$ and is added to 0,025 dm^3 of a 0,095 $mol.dm^{-3}$ HNO_3 solution.

Calculate the pH of the FINAL solution. (10)

[25]

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MOMENTUM AND IMPULSE

Definitions and Key Concepts

Momentum is the product of an object's mass and its velocity.
Linear momentum is a vector quantity with the same direction as the velocity of the object.
State the principle of ***conservation of linear momentum***: The total linear momentum of an isolated system remains constant (is conserved)
State ***Newton's second law of motion in terms of momentum:*** The net (or resultant) force acting on an object is equal to the rate of change of momentum of the object in the direction of the net force.
Impulse is the product of the resultant/net force acting on an object and the time the net force acts on the object.
An ***isolated system*** (in Physics), i.e. a system on which the net external force is zero.
Elastic collision is a collision where both total momentum and total kinetic energy are conserved.
Inelastic Collision is a collision where only total momentum is conserved but not kinetic energy.

Summary of notes

Calculate the momentum of a moving object using. $p = mv$

S.I units for momentum ($kg.m.s^{-1}$) and it is a vector quantity(both magnitude and direction)
Describe the vector nature of momentum and draw vector diagrams.
State Newton's Second Law in terms of momentum:
Use Momentum-Impulse theorem: $F_{net} = \frac{\Delta p}{\Delta t}$
Impulse S.I unit (N.s)/ $kg.m.s^{-1}$
Explain how the concept of impulse applies to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds.
Apply the conservation of momentum to the collision of two objects moving in one dimension (along a straight line) with the aid of an appropriate sign convention.

$\Sigma p_i = \Sigma p_f$

$m_1v_i + m_2v_i = m_1v_f + m_2v_f$ (two objects collide and then separate)

$m_1v_i + m_2v_i = (m_1 + m_2)v_f$ (two objects collide and stick together)

$(m_1 + m_2)v_i = m_1v_f + m_2v_f$ (two moving objects initially joined then separated)

- Distinguish between elastic collisions and inelastic collisions by calculation.

ELASTIC & INELASTIC COLLISION.

If the collision is Elastic $\Sigma E_{k_i} = \Sigma E_{k_f}$ (Total kinetic Energy before =Total kinetic Energy after).
If the collision is Inelastic ∴ $\Sigma E_{k_i} \neq \Sigma E_{k_f}$ (Total kinetic Energy before≠ Total kinetic Energy after).

$\Sigma E_{k_i} = \frac{1}{2}m_Av_i^2 + \frac{1}{2}m_Bv_i^2$ (total kinetic energy before)

$\Sigma E_{k_f} = \frac{1}{2}m_Av_f^2 + \frac{1}{2}m_Bv_f^2$ (total kinetic energy after)

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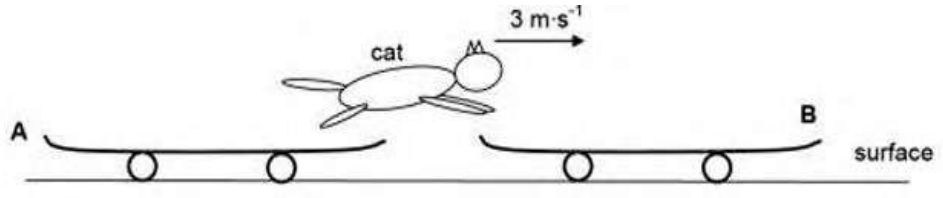
S.I unit :Joule(J) S.I unit :Joule(J)

Worked Examples

1. The diagram below shows two skateboards, A and B, initially at rest, with a cat standing on skateboard A. The skateboards are in a straight line, one in front of the other and a short distance apart. The surface is flat, frictionless and horizontal.

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

EACH skateboard has a mass of 3,5 kg. The cat, of mass 2,6 kg, jumps from skateboard A with a horizontal velocity of 3 $m \cdot s^{-1}$ and lands on skateboard B with the same velocity. Refer to the diagram below.



1.2 Calculate the velocity of skateboard A just after the cat has jumped from it. (5)

1.3 Immediately after the cat has landed, the cat and skateboard B move horizontally to the right at 1, 28 $m \cdot s^{-1}$. Calculate the magnitude of the impulse on skateboard B as a result of the cat's landing. (3)

[10]

SOLUTIONS

2.1 The total linear momentum of a closed/isolated system remains constant/is conserved.✓✓ (2)

2.2

$\Sigma pi = \Sigma pf$
$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$ ✓any one

For the system cat-skate board A

3,5)(0) + (2,6)(0) ✓ = (3,5)$v_{skateboard}$ + (2,6)(3) ✓

∴ $v_{skateboard}$ = 2,23 $m \cdot s^{-1}$ ✓to the left ✓ (5)

2.3 OPTION 1 OPTION 2

$F_{net}\Delta t = \Delta p = mv_f - mv_i$ ✓ $F_{net}\Delta t = \Delta p = mv_f - mv_i$ ✓

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= (3,5)(1,28 – 0)✓ = 4,48 N·s ✓ = (2,6)(1,28 – 3)✓ = - 4,48 N·s ✓

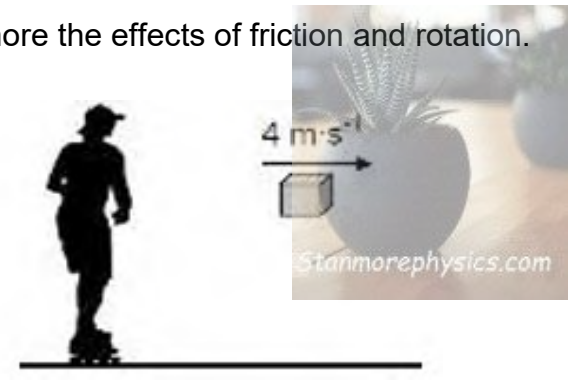
(3)

[10]

QUESTION 3

Initially a girl on roller skates is at rest on a smooth horizontal pavement. The girl throws a parcel, of mass 8 kg, horizontally to the right at a speed of 4 $m \cdot s^{-1}$. Immediately after the parcel has been thrown, the girl-roller-skate combination moves at a speed of 0,6 $m \cdot s^{-1}$.

Ignore the effects of friction and rotation.



3.1 Define the term momentum in words. (2)

3.2 Will the girl-roller-skate combination move TO THE RIGHT or TO THE LEFT after the parcel is thrown? NAME the law in physics that can be used to explain your choice of direction. (2)

The total mass of the roller skates is 2 kg.

3.3 Calculate the mass of the girl. (5)

3.4 Calculate the magnitude of the impulse that the girl-roller-skate combination is experiencing while the parcel is being thrown. (3)

3.5 Without any further calculation, write down the change in momentum experienced by the parcel while it is being thrown. (2)

[14]

SOLUTIONS

3.1 Momentum is the product of the mass of an object and its velocity. ✓✓ (2)

3.2 To the left✓ Newton's third law ✓ (2)

3.3 OPTION 1

$\sum p_i = \sum p_f$ ✓

$m_1v_{1i} + m_2v_{2i} = m_1v_{2f} + m_2v_{2f}$

0✓ = (8)(4) ✓+ m_2(-0,6) ✓

∴ m_2 = 53,33 kg ∴ m_{girl} = 53,33 – 2 = 51,33 kg ✓

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OPTION 2

$\sum p_i = \sum p_f$ ✓

$m_1v_{1i} + m_2v_{2i} = m_1v_{2f} + m_2v_{2f}$ (5)

mass of girl is m

{(m + 2)(0)} + {8(0)}✓ = {(m + 2)(-0,6)} ✓ + (8)(4)✓ ∴ m = 51,33 kg ✓

3.4 Impulse = Δp = m(vf – vi) ✓ = (51,33 + 2)(-0,6 – 0) ✓ = -32 N·s/kg·m·s^{-1}

Magnitude of impulse is 32 N·s /32 kg·m·s^{-1} ✓ (3)

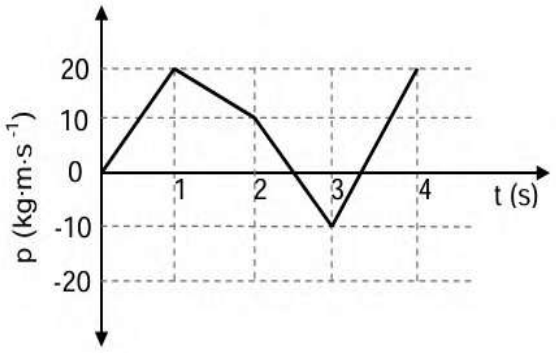
3.5 32 kg·m·s-1 ✓ to the right/opposite direction ✓ (2)

[14]

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 The graph below shows how the momentum (p) of an object changes with time (t).



During which ONE of the following time intervals, measured in seconds, is the magnitude of the net force acting on the object the greatest?

A 0-1
B 1-2
C 3-2
D 3-4 (2)

1.2 Ball P and ball Q, of the same mass, are dropped onto a concrete floor. Both balls hit the concrete floor at the same speed, v. Ball P rebounds with the same vertical speed, v, but ball Q rebounds with speed ½v.

Refer to the diagram below. Ignore air resistance.

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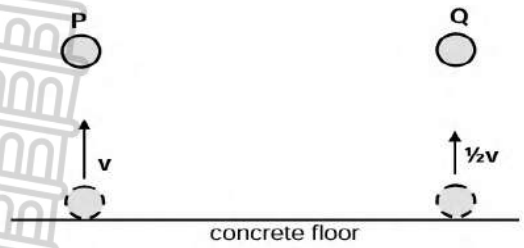


Which ONE of the following statements regarding the collision of EACH ball with the concrete floor is CORRECT?

A. Kinetic energy is conserved for both balls P and Q.

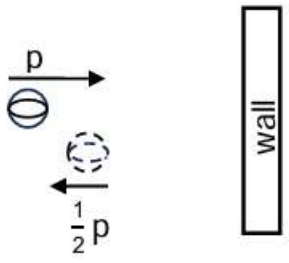
B. The change in momentum of ball P is greater than that of ball Q.

C. The contact time with the floor is the same for both balls P and Q.

D. Momentum is conserved for the collision of ball P, but not for that of ball Q. (2)

1.3 A ball moving horizontally has constant momentum p and kinetic energy K. The ball collides with a wall and bounces back horizontally.

Immediately after the collision, the ball has momentum $\frac{1}{2}$ p.
The mass of the ball remains constant.



Which ONE of the following is the kinetic energy of the ball immediately after the collision?

A $\frac{1}{2}$ K

B $\frac{1}{2}$ K

C 2K

D 4K (2)

1.4 The diagram below shows a cricket player moving his hands downwards from position 1 to 2 to 3 while catching a ball.

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Which ONE of the following statements CORRECTLY explains why the cricket player moves his hands downwards?

A. The impulse on the ball is decreased.

B. The change in momentum of the ball is increased.

C. The change in momentum of the ball is decreased.

D. The time it takes to change the momentum of the ball is increased. (2)

[8]

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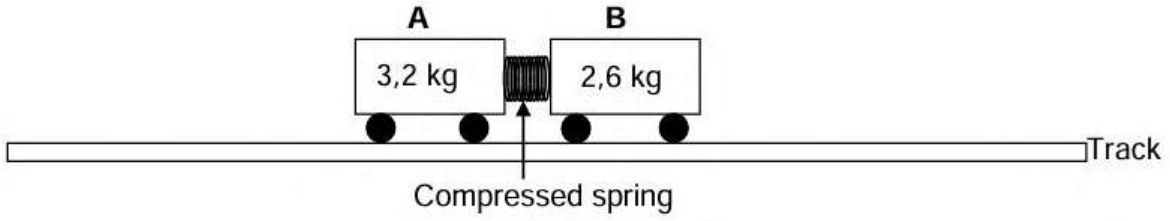
LONG QUESTIONS

QUESTION 2

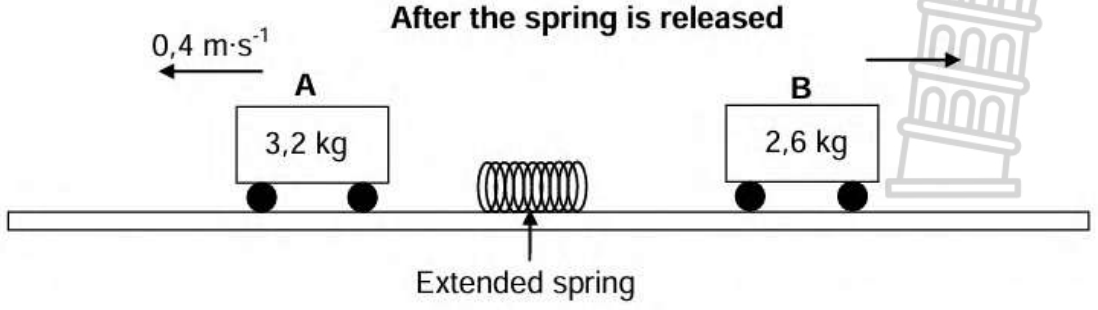
Two trolleys A and B of mass 3,2 kg and 2,6 kg respectively are held at rest on a straight horizontal, frictionless track, with a compressed spring between them, as shown in the diagram below.

Before the spring is released



After the trolleys are released, the spring extends to its natural length and then falls onto the track. Trolley A now moves with a constant velocity of 0,4 m·s-1 to the left, while trolley B moves with a constant unknown velocity to the right. Trolley B reaches the end of the track after 1,3 s.

After the spring is released



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

2.2 Calculate the distance travelled by trolley B in 1,3 s. (5)

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The average force exerted by the extended spring on each trolley while they were in contact with the spring was 4,2 N.

2.3 Calculate the time it took the spring to extend to its natural length. (3)

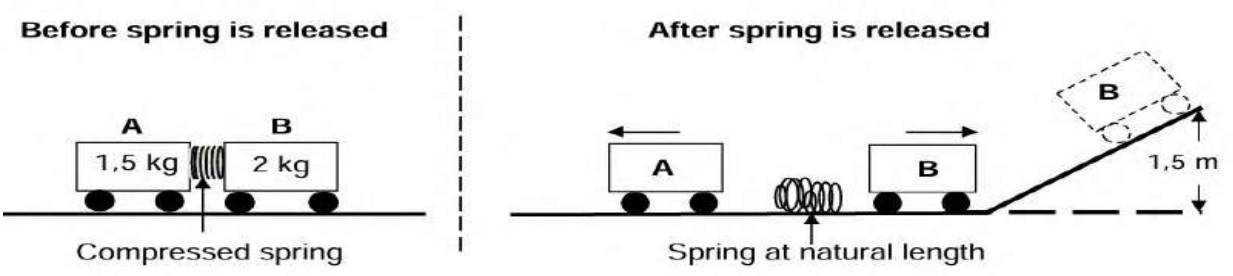
2.4 Trolley B is now replaced by trolley C, which has a larger mass. The same compressed spring is placed between trollies A and C. The trolleys are then released. The average force exerted by the extended spring on the trolleys remains at 4,2 N for the same period of time as calculated in QUESTION 2.3. (3)

How does the magnitude of the velocity of trolley C compare to the magnitude of the velocity of trolley B after the spring has fallen to the track? Write only GREATER THAN, LESS THAN or EQUAL TO. Explain the answer.

[13]

QUESTION 3

Two trolleys, A and B, of masses of 1,5 kg and 2 kg respectively, are held in a stationary position on a straight, horizontal, frictionless track, with a compressed spring between them. The trolleys are released and the spring takes t seconds to return to its natural length. The spring then falls to the ground. Trolley A moves to the left, while trolley B moves to the right and then up a frictionless inclined plane, rising to a maximum vertical height of 1,5 m, as shown in the diagram below.



Ignore the rotational effects of the wheels.

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

3.2 Calculate the speed of trolley B at the bottom of the inclined plane. (4)

3.3 For the t seconds that the spring takes to return to its natural length:

3.3.1 Calculate the change in momentum of trolley B (3)

3.3.2 Write down the change in momentum of trolley A (1)

3.4 Calculate the speed of trolley A after t seconds. (2)

[12]

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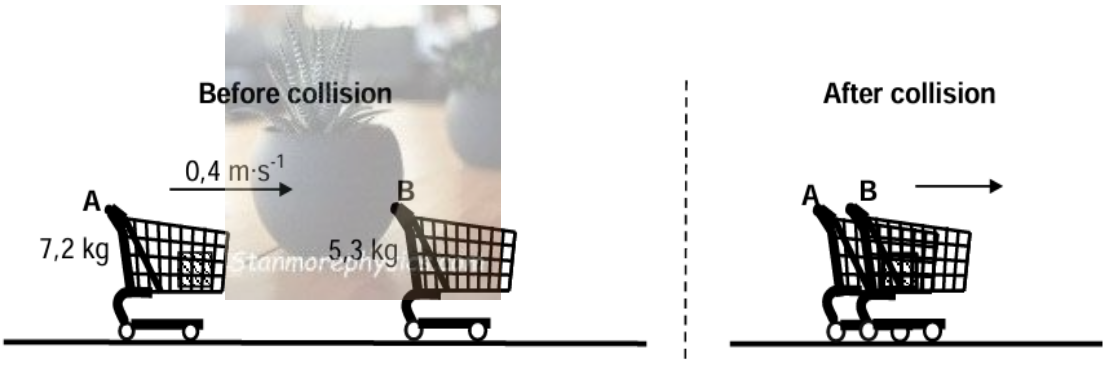
QUESTION 4

Trolley A of mass 7,2 kg moves to the right at 0,4 m·s^{-1} in a straight line on a horizontal floor. It collides with a stationary trolley B of mass 5,3 kg.

After the collision, the trolleys lock together and move to the right, as shown in the diagram below.
Ignore any frictional effects.



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

4.2 Calculate the magnitude of the:

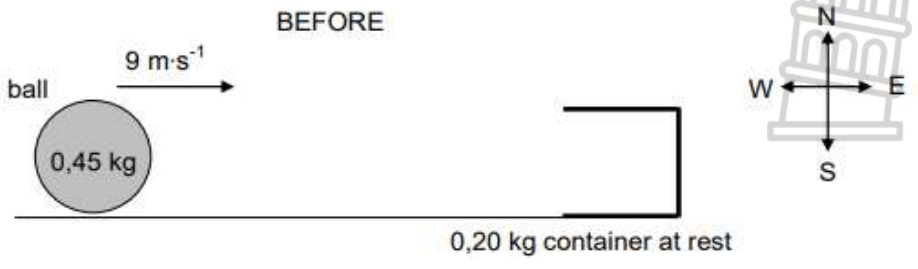
4.2.1 Velocity of the trolleys immediately after the collision (3)

4.2.2 Average net force exerted by trolley A on trolley B during the collision, if the collision time is 0,02 s (3)

[8]

QUESTION 5

A soccer player kicks a ball of mass 0,45 kg to the east. The ball travels horizontally at a velocity of 9 m·s^{-1} along a straight line, without touching the ground, and enters a container lying at rest on its side, as shown in the diagram below. The mass of the container is 0,20 kg.



The ball is stuck in the container after the collision. The ball and container now move together along a straight line towards the east. Ignore friction and rotational effects.

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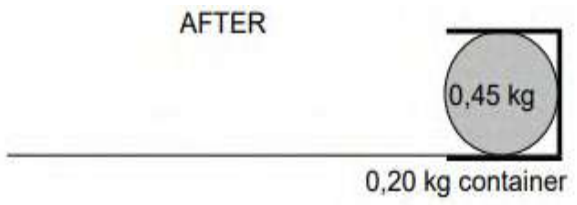

5.1 State the principle of conservation of linear momentum in words. (2)

5.2 Calculate the magnitude of the velocity of the ball-container system immediately after the collision. (4)

5.3 Determine, by means of a suitable calculation, whether the collision between the ball and container is elastic or inelastic. (5)

[11]

QUESTION 6

A man of mass 87 kg on roller skates, moving horizontally at constant speed in a straight line, sees a boy of mass 22 kg standing directly in his path. The man grabs the boy and they both continue in a straight line at 2,4 $m \cdot s^{-1}$.

6.1 Calculate the man's speed just before he grabs the boy. Ignore the effects of friction. (4)

6.2 Is the collision elastic? Use a calculation to support your answer. (6)

6.3 After grabbing the boy, they both continue at a velocity of 2,4 $m \cdot s^{-1}$ along a straight line until they arrive at a loose gravel surface near the end of the path. They now move at constant acceleration in a straight line through the loose gravel for 2 m before coming to rest.

Calculate the magnitude of the force exerted by the gravel surface on the man and the boy. (5)

[15]

QUESTION 7

A bullet moves east at a velocity of 480 $m \cdot s^{-1}$. It hits a wooden block that is fixed to the floor. The bullet takes 0,01 s to move through the stationary block and emerges from the block at a velocity of 80 $m \cdot s^{-1}$ east. See the diagram below. Ignore the effects of air resistance. Consider the block-bullet system as an isolated system.

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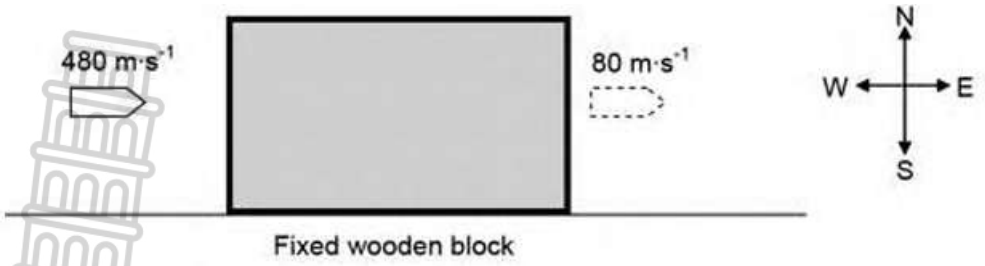


7.1 Explain what is meant by an isolated system as used in Physics. (2)

The magnitude of the momentum of the bullet before it enters the block is 24 kg·m·s^{-1}.

7.2 Calculate:

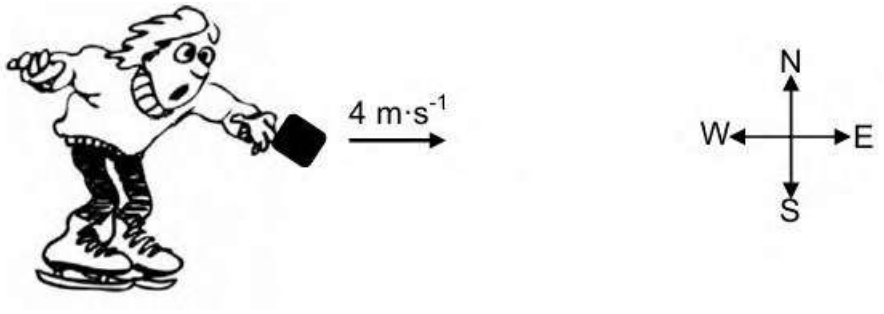
7.2.1 Mass of the bullet (3)

7.2.2 Average net force exerted by the wooden block on the bullet (5)

[10]

QUESTION 8

A boy on ice skates is stationary on a frozen lake (no friction). He throws a package of mass 5 kg at 4 m·s-1 horizontally east as shown below. The mass of the boy is 60 kg.



At the instant the package leaves the boy's hand, the boy starts moving.

8.1 In which direction does the boy move? Write down only EAST or WEST. (1)

8.2 Which ONE of Newton's laws of motion explains the direction in which the boy experiences a force when he throws the package? Name and state this law in words. (3)

8.3 Calculate the magnitude of the velocity of the boy immediately after the package leaves his hand. Ignore the effects of friction. (5)

8.4 How will the answer to QUESTION 4.3 be affected if:
(Write down INCREASES, DECREASES or REMAINS THE SAME.)

8.4.1 The boy throws the same package at a higher velocity in the same direction (1)

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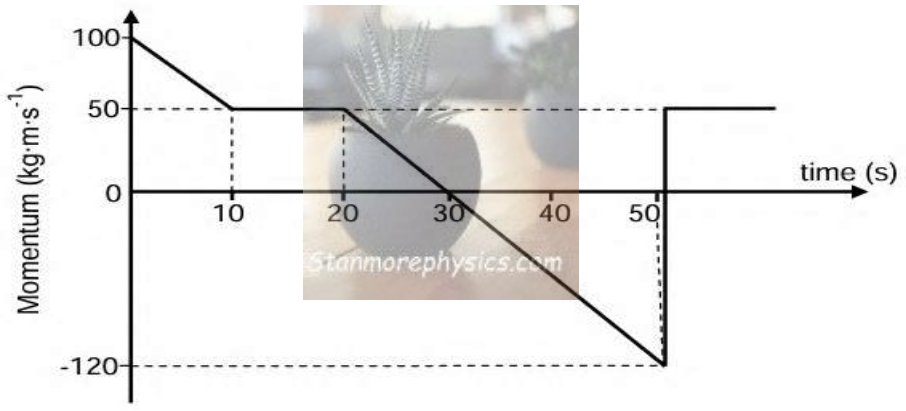
8.4.2 The boy throws a package of double the mass at the same velocity as in QUESTION 4.3. Explain the answer. (3)

[13]

QUESTION 9

The momentum versus time graph of object A, originally moving horizontally EAST, is shown below.



9.1 Write down the definition of momentum in words. (2)

9.2 The net force acting on object A is zero between t = 10 s and t = 20 s. (2)

Use the graph and a relevant equation to explain why this statement is TRUE.

9.3 Calculate the magnitude of the impulse that object A experiences between t = 20 s and t = 50 s. (2)

9.4 At t = 50 s, object A collides with another object, B, which has a momentum of 70 kg·m·s-1 EAST.

Use the information from the graph and the relevant principle to calculate the momentum of object B after the collision. (5)

[12]

QUESTION 10

The bounce of a cricket ball is tested before it is used. The standard test is to drop a ball from a certain height onto a hard surface and then measure how high it bounces.

During such a test, a cricket ball of mass 0,15 kg is dropped from rest from a certain height and it strikes the floor at a speed of 6,2 m·s^{-1}. The ball bounces straight upwards at a velocity of 3,62 m·s^{-1} to a height of 0,65 m, as shown in the diagram below. The effects of air friction may be ignored.

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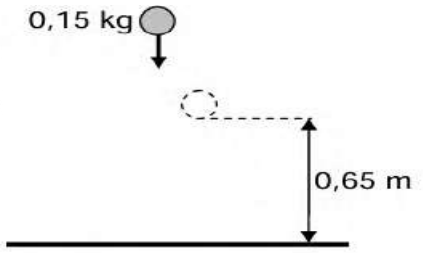

10.1 Define the term impulse in words. (2)

10.2 Calculate the magnitude of the impulse of the net force applied to the ball during its collision with the floor. (3)

10.3 To meet the requirements, a cricket ball must bounce to one third of the height that it is initially dropped from.

Use ENERGY PRINCIPLES to determine whether this ball meets the minimum requirements. (5)

[10]

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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:

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

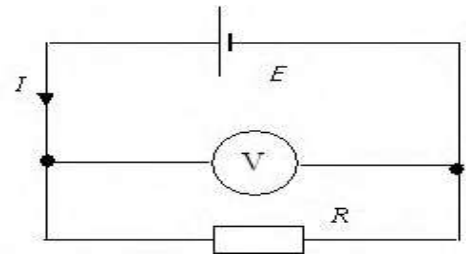
The same equation can be used to define the following:
EMF as the **maximum or total energy transferred per unit charge by the battery:**
'Lost volts'' as the **energy transferred per unit charge inside the battery.**
Ohm's Law: potential difference (V) across a conductor is directly proportional to the current (I) in a conductor at constant temperature. In symbols:

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

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

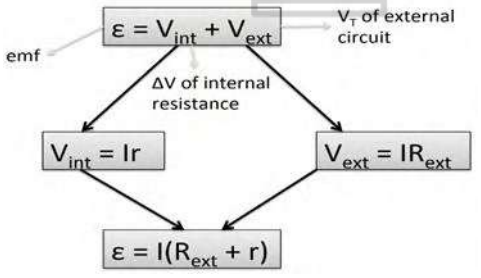
Internal resistance is defined as **the opposition of flow of charge within the battery.** A battery is said to produce an **emf** (electromotive force). EMF is equivalent to the reading on the voltmeter across the terminals of the battery when there is no current flowing.
Suppose we now add a load (component with resistance) as shown in the circuit diagram below. We will assume the wires have **negligible** resistance



The 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:

$$\varepsilon = V_{terminal} + V_{lost}$$
$$= I(R + r)$$
$$= IR + Ir$$



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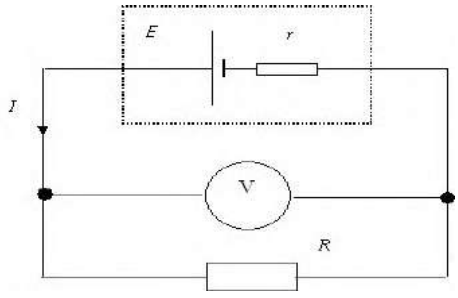
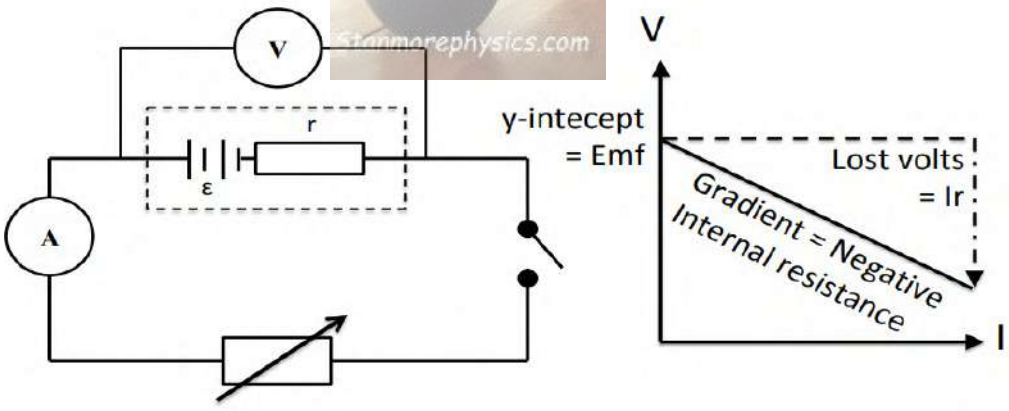
We can thus represent the circuit as in the accompanying circuit diagram.



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)

Determining the emf and internal resistance:



Graph interpretation:
Independent variable: current
Dependent variable: Potential difference
Controlled variable: Temperature
Cost of electricity

$$Cost\ of\ electricity = Power \times time \times cost\ per\ unit$$

Note:
Power in Kw
Time in hrs

WORKED EXAMPLE 1
Two identical cells, EACH with an emf of 1,5 V and an internal resistance **r**, are connected in series with each other and to the resistors as shown below.

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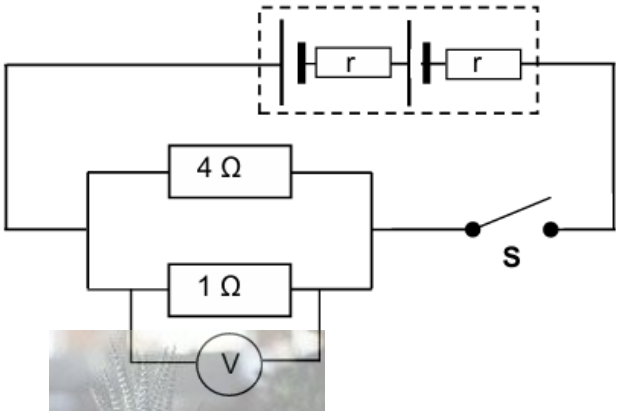

1.1 Define the term electromotive force (emf). (2)

1.2 Write down the total emf of the circuit. (1)

When switch **S** is closed, the potential difference across the 4 Ω resistor is 2,8 V.

1.3 Calculate the total current in the circuit. (5)

1.4 Calculate the internal resistance r of EACH cell. (5)

1.5 An unknown resistor is now connected in parallel with the 4 Ω and 1 Ω resistors. How will this change affect the magnitude of:

1.5.1 The internal resistance of the battery.
Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

1.5.2 The reading on the voltmeter. Write down INCREASES, DECREASES or REMAINS THE SAME. Explain the answer. (4)

[18]

SOLUTION:

1.1 The maximum energy provided by a battery per unit charge passing through it. ✓✓ (2)

1.2 3 V ✓ (1)

1.3 **OPTION 1**

$\frac{1}{R_P}=\frac{1}{R_1}+\frac{1}{R_2}$ ✓

$=\frac{1}{4}+\frac{1}{1}$ ✓

$\therefore R_P=0{,}8\ \Omega$

V=IR ✓

2,8=I(0,8) ✓

I=3,5 A ✓

OPTION 2

Current through 4 Ω resistor

V=IR ✓

2,8=I(4) ✓

∴I=0,7 A

Current through 1 Ω resistor

V=IR

2,8=I(1) ✓

∴I=2,8 A

Total current through the battery

$I_T=I_1+I_2$

=0,7+2,8 ✓

=3,5 A ✓ (5)

1.4 ε=I(R+r) ✓

3✓=3,5(0,8+2r) ✓

2r=0,06 Ω ✓

∴r=0,03 Ω ✓ (5)

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1.5.1 Remains the same ✓ (1)

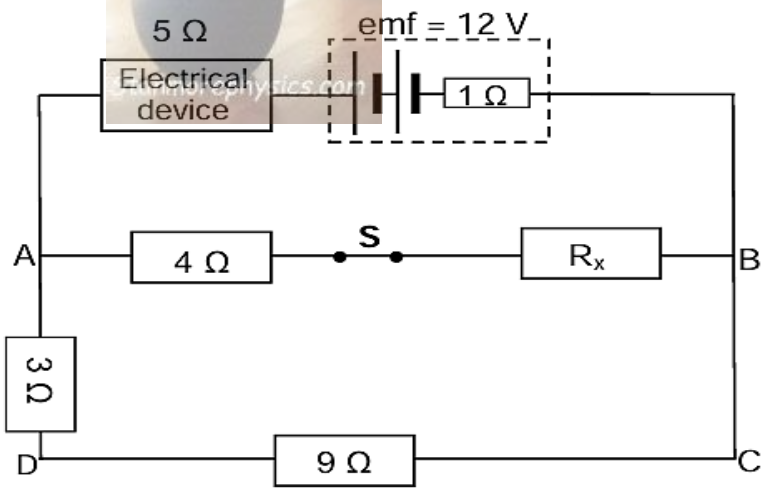
1.5.2 Decreases ✓
Total resistance decreases ✓
Current (through battery) increases ✓
'Lost volts' increases ✓ (4)

[18]

WORKED EXAMPLE 2

A learner wants to use a 12 V battery with an internal resistance of 1 Ω to operate an electrical device. He uses the circuit below to obtain the desired potential difference for the device to function. The resistance of the device is 5 Ω.

When switch S is closed as shown, the device functions at its maximum power of 5 W.



2.1 Explain, in words, the meaning of an emf of 12 V. (2)

2.2 Calculate the current that passes through the electrical device. (3)

2.3 Calculate the resistance of resistor Rx. (7)

2.4 Switch **S** is now **opened**. Will the device still function at maximum power? Write down YES or NO. Explain the answer without doing any calculations. (4)

[16]

SOLUTION:

2.1 The battery supplies 12 J of energy per coulomb of charge✓✓ (2)

2.2

OPTION 1	**OPTION 2**	**OPTION 3**
$P=I^2R$ ✓	$P=\frac{V^2}{R}$	$P=\frac{V^2}{R}$
$5=I^2(5)$ ✓	$5=\frac{V^2}{5}$	$5=\frac{V^2}{5}$
∴I=1 A ✓	V=5 V	V=5 V
	P=VI ✓	V=IR ✓
	5=(5)I ✓	5=I(5) ✓
	∴I=1 A ✓	∴I=1 A ✓

(3)

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2.3

OPTION 1

$\varepsilon = I(R+r)$ ✓

$12 = (1)(R+1)$ ✓

$R = 11\ \Omega$

$R_P = 11 - 5$ ✓ $= 6\ \Omega$

OPTION 2

$V = IR_T$ ✓

$12 = (1)R_T$ ✓

$R_T = 12\ \Omega$

$R_P = R_T - (5+1)$

$= 12 - 6$ ✓

$= 6\ \Omega$

$\frac{1}{R_P} = \frac{1}{R_{12}} + \frac{1}{R}$ ✓

$\frac{1}{6}$ ✓ $= \frac{1}{12} + \frac{1}{(4+R_x)}$ ✓

$\frac{1}{12} = \frac{1}{4+R_x}$

$4 + R_x = 12$

$\therefore R_x = 8\ \Omega$ ✓

OPTION 3

$V_{5\Omega} = IR$ ✓

$= (1)(5)$

$= 5\ V$

$V_{int} = Ir$

$= (1)(1)$

$= 1\ V$

$V_P = 12$ ✓ $- (1+5)$ ✓

$= 6\ V$

$V_P = IR$

$6 = I(12)$ ✓

$\therefore I = 0{,}5\ A$

$I_{Rx} = 1 - 0{,}5$ ✓

$= 0{,}5\ A$

$V = IR$

$6 = (0{,}5)(4 + R_X)$ ✓

$\therefore R_X = 8\ \Omega$ ✓ (7)

2.4 No ✓

Total resistance increases. ✓

Current decreases ✓

(For a constant R), power ($P = I^2R$) decreases ✓ (4)

[16]

WORKED EXAMPLE 3

A battery of emf 12 V and internal resistance 0,2 Ω is connected to three resistors, a high-resistance voltmeter and two switches, an ammeter and connecting wires of negligible resistance, as shown in the circuit diagram below. The three resistors have different and unknown resistances.

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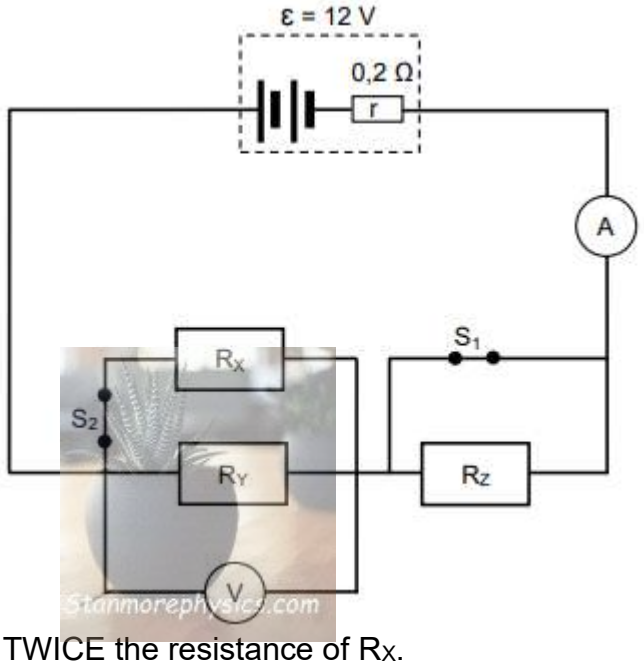

The resistance of R_Y is TWICE the resistance of R_X.
When both switches are CLOSED, the reading on the ammeter is 5,5 A

3.1 Give a reason why there is no current through resistor R_Z. (1)

3.2 Calculate the resistance of resistor R_Y (5)

3.3 Calculate the power dissipated by resistor R_X. (4)

When both switches are now OPENED, the reading on the ammeter is 1,3 A.

3.4 Calculate the reading on the voltmeter. (3)

Switch S_1 remains OPEN while switch S_2 is now CLOSED.

3.5 Calculate the reading on the ammeter. (6)

[19]

SOLUTION:

3.1 The resistor/R_Z is short circuited. ✓ (1)

3.2 **OPTION 1**

$\frac{1}{R_P}=\frac{1}{R_X}+\frac{1}{R_Y}$ ✓

$\frac{1}{R_P}=\frac{1}{R}+\frac{1}{2R}$ ✓

$R_P=0,67R$

$\varepsilon=I(R+r)$ ✓

$12=5,5(0,67R+0,2)$ ✓

$R=2,97\ \Omega$

$R_Y=2(2,97)$

$=5,95\ \Omega$ ✓

OPTION 2

$\varepsilon=I(R+r)$ ✓

$12=5,5(R+0,2)$ ✓

$R=1,98\ \Omega$

$\frac{1}{R_P}=\frac{1}{R_X}+\frac{1}{R_Y}$ ✓

$\frac{1}{1,98}=\frac{1}{R}+\frac{1}{2R}$ ✓ ($R_X = R$)

$R=2,97\ \Omega$

$R=2(2,97)$

$=5,95\ \Omega$ ✓

(5)

3.3 **OPTION 1**

$V_P=I_TR_p$

$=(5,5)(1,98)$ ✓

$=10,9$ V

OPTION 2

$\varepsilon=I(R+r)$ ✓

$=V_{ext}+Ir$

$12=V_{ext}+5,5(0,2)$

OPTION 3

$I_x=\frac{V_p}{R_x}$

$=\frac{10,9}{2,97}$ ✓

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$V_{ext}=V_p=10,9$ V

$P=\frac{V^2}{R}$ ✓
$=\frac{(10,9)^2}{2,97}$ ✓
$=40$ W ✓

$P=VI$ ✓
$=(10,9)(3,67)$ ✓
$=40$ W ✓

$=3,67$ A

$P=I^2R$ ✓
$=(3,67)^2(2,97)$ ✓
$=40$ W ✓

(4)

3.4 $V=IR$ ✓
$=(1,3)(5,95)$ ✓
$=7,72$ V ✓ (3)

3.5

OPTION 1 S_1 AND S_2 OPEN	OPTION 2 S_1 AND S_2 OPEN
$\varepsilon=I(R+r)$ ✓ $12=1,3(R_T+0,2)$ ✓ $R_T=9,03\ \Omega$ $R_T=R_Y+R_Z$ $9,03=5,95+R_Z$ ✓ $R_Z=3,08\ \Omega$ **S_1 OPEN AND S_2 CLOSED** $R_P=0,67R$ $=(0,67)(2,97)$ $=1,98\ \Omega$ $R_{ex}=3,08+1,98$ ✓ $=5,06\ \Omega$ $\varepsilon=I(R+r)$ $12=I(5,06+0,2)$ ✓ $I=2,28$ A ✓	$\varepsilon=I(R+r)$ ✓ $12=IR+(1,3\times0,2)$ $IR=11,74$ V$=V_{ext}$ $V_{ext}=V_{RY}+V_{RZ}$ $11,74=7,75+V_{RZ}$ ✓ $V_{RZ}=3,99$ V $V=IR$ $3,99=1,3R_Z$ $R_Z=3,07\ \Omega$ **S_1 OPEN AND S_2 CLOSED** $\varepsilon=I(R+r)$ $12=5,5(R+0,2)$ $R_P=1,98\ \Omega$ $R_{ext}=3,08+1,98$ ✓$=5,06\ \Omega$ $V=IR$ $12=I(5,26)$ ✓ $I=2,28$ A ✓

(7)

[19]

ACTIVITIES
MULTIPLE CHOICE QUESTIONS

1.1 Which one of the following combinations of SI units represents ohm (Ω)?
A $V\cdot A$
B $J\cdot C^{-1}$
C $C\cdot s^{-1}$
D $V\cdot A^{-1}$ (2)

1.2 How much will it cost to run a 14 W energy-saving light bulb in a 220 V mains circuit for three hours if the cost per kWh is R1,12?
A $14\times3\times220$ cents

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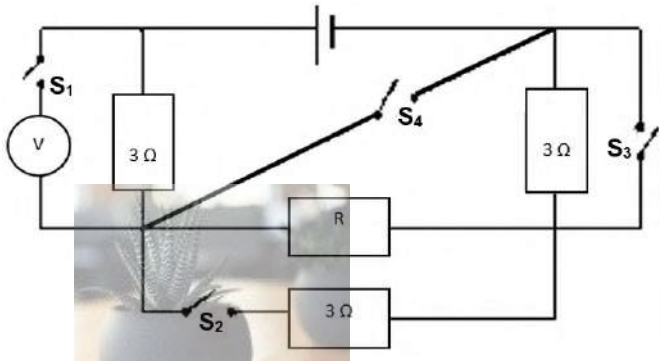
B 0,014×220 cents
C 0,014×3×112 cents
D 14×220×112 cents (2)

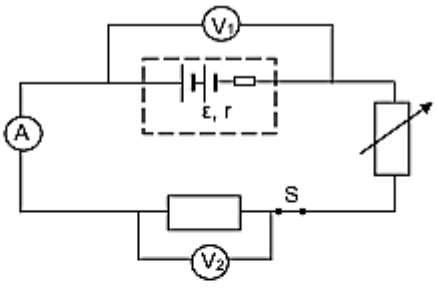
1.3 Consider the following circuit diagram

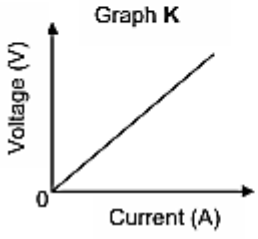


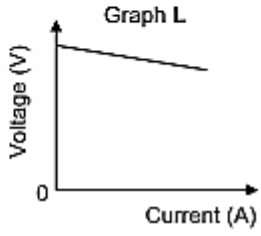
Which ONE of the switches must be closed to decrease the power dissipated by the resistor R the most?

A S_1
B S_2
C S_3
D S_4 (2)

1.4 The circuit below was used in a practical investigation. The battery has emf ε and internal resistance r. Ignore the resistance of the connecting wires. Graphs K and L below were obtained from the readings taken.







Which ONE of the combinations below CORRECTLY indicates the voltmeter readings taken to obtain graphs K and L?

	GRAPH K	GRAPH L
A	V_1	V_1
B	V_1	V_2
C	V_2	V_1
D	V_2	V_2

(2)

LONG QUESTIONS

QUESTION 2

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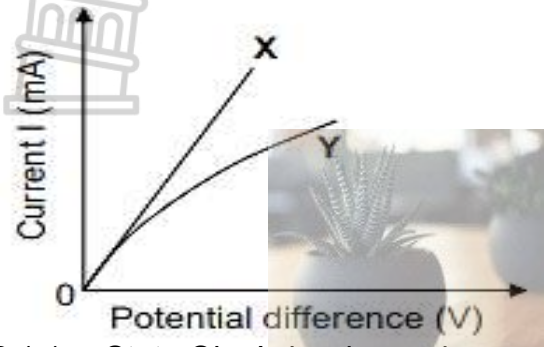
2.1 The two graphs below show the relationship between current and potential difference for two different conductors, X and Y.

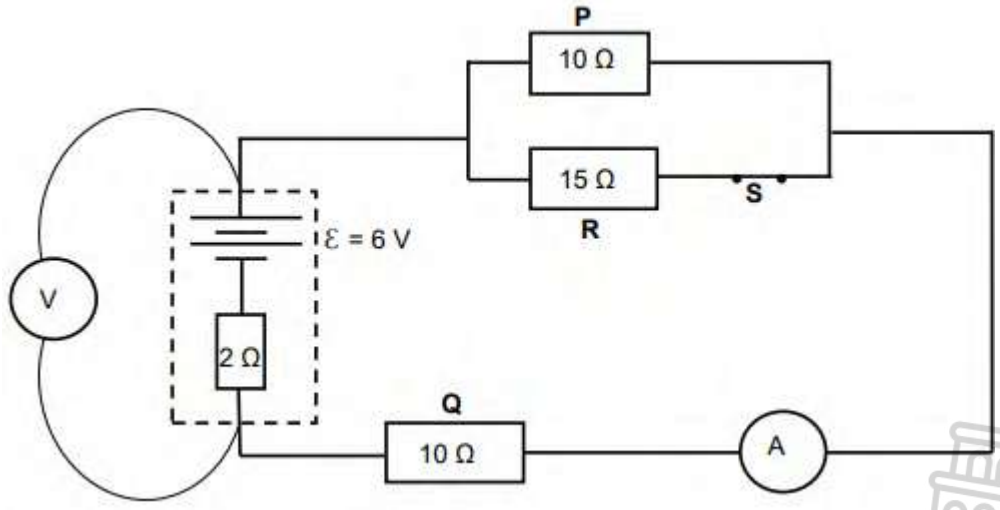
Graph of I versus V for two different conductors, X and Y



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

2.1.2 Which ONE of the two conductors, X or Y, is Ohmic? Refer to the graph and give a reason for the answer. (2)

2.2 In the diagram below, a battery with an emf of 6 V and an internal resistance of 2 Ω, is connected to three resistors P, Q and R. A voltmeter V is connected across the battery. The ammeter A has a negligible resistance.



2.2.1 Calculate the ammeter reading when switch S is closed. (5)

2.2.2 Will the ammeter reading in QUESTION 2.2.1 INCREASE, DECREASE or REMAIN THE SAME? Give a reason for the answer. (2)

2.2.3 How will the voltmeter reading now compare with the voltmeter reading when the switch is closed? Choose from INCREASE, DECREASE or REMAIN THE SAME. (1)

2.2.4 Explain the answer to QUESTION 2.2.3. (3)

[15]

QUESTION 3

3.1 In diagram 1, when two NON-IDENTICAL resistors X and Y are connected in parallel across a 6 V battery, the current through A_1 is found to be 2 A. In diagram 2, when the two resistors are connected in series to the 6 V battery, V_2 reads 4 V.

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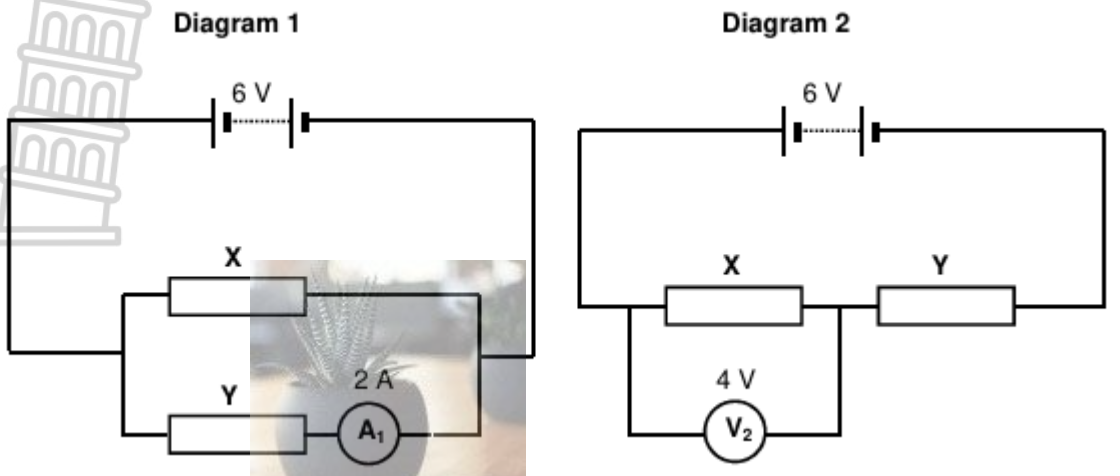
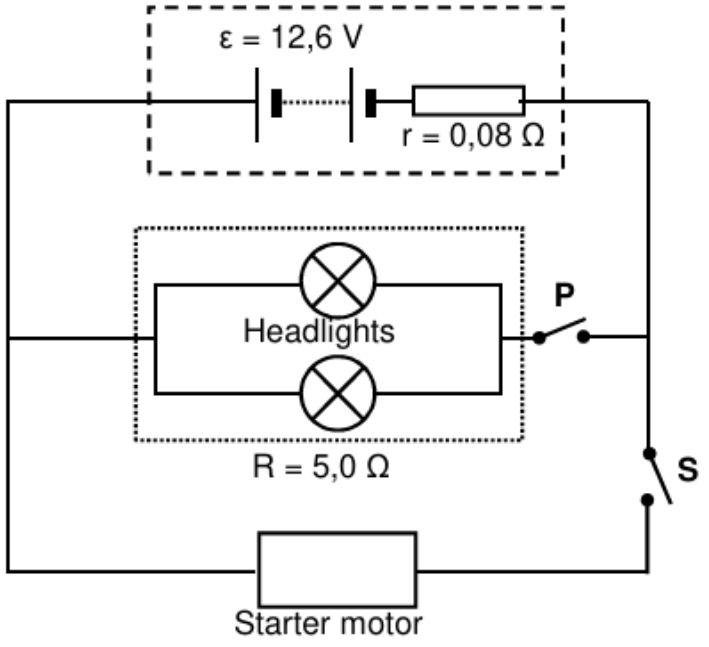
The internal resistance of the battery and the resistance of the conducting wires may be ignored.



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

3.1.2 Calculate the resistance of X and Y respectively. (6)

3.2 The headlights of a motor vehicle are connected in parallel to a battery with an emf of 12,6 V and an internal resistance of 0,08 Ω. The two headlights have a TOTAL resistance of 5,0 Ω. The starter motor is connected in parallel with the headlights as shown in the diagram below. Assume the headlights are Ohmic resistors.



3.2.1 Write down the magnitude of the potential difference across switch S when both switches are open. (1)

Switch P is now CLOSED but S remains OPEN.

3.2.2 Calculate the potential difference across the headlights when switch P is closed. (5)

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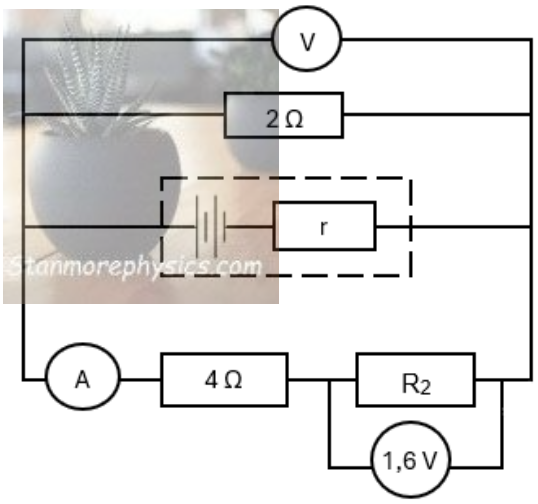
BOTH switches (P and S) are now CLOSED.

3.2.3 How will the brightness of the headlights be affected? Write down only INCREASE, DECREASE or THE SAME. Explain your answer. (4)

[18]

QUESTION 4

A battery of an emf of 3,11 V and unknown internal resistance, r is connected to three resistors, high-resistance voltmeters and an ammeter of negligible resistance, as shown below.



The reading on the ammeter is 0,2 A

4.1 What is meant by an emf of 3,11 V (2)

4.2 Calculate the:

4.2.1 Reading on the voltmeter (4)

4.2.2 Total current supplied by the battery (3)

4.2.3 Internal resistance of the battery (3)

4.2.4 Power dissipated by the battery to internal resistor (3)

[15]

QUESTION 5

A battery is connected to three resistors in parallel, the voltmeter reading over the battery is 10 V as shown in DIAGRAM A below. When the same battery is connected to a 5,5 Ω resistor, the voltmeter reading is 12 V as shown in the diagram below.

DIAGRAM A

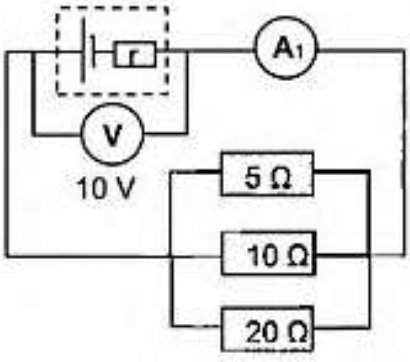
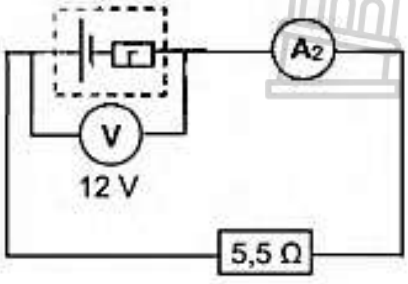


DIAGRAM B



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5.1 Define the term emf (2)

5.2 Calculate the total resistance of the parallel connection in DIAGRAM A (3)

5.3 Explain why the voltmeter reading is higher in DIAGRAM B than in DIAGRAM A. (3)

5.4 Calculate the:

5.4.1 Reading on ammeter A_1 (3)

5.4.2 Internal resistance of the battery (5)

5.4.3 Emf of the battery (2)

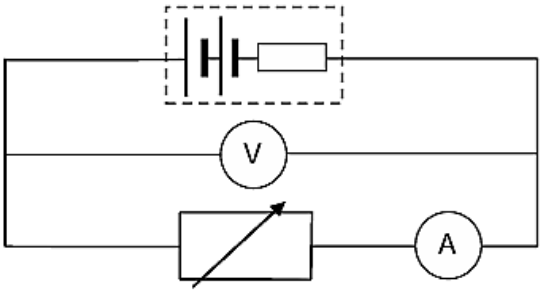
5.4.4 Power dissipated in the 5,5 Ω resistor (3)

5.5 The 5 Ω resistor in diagram A is removed, what will be the effect on the internal voltage ($V_{internal}$)? Choose from INCREASE, DECREASE or REMAINS THE SAME. Explain the answer. (3)

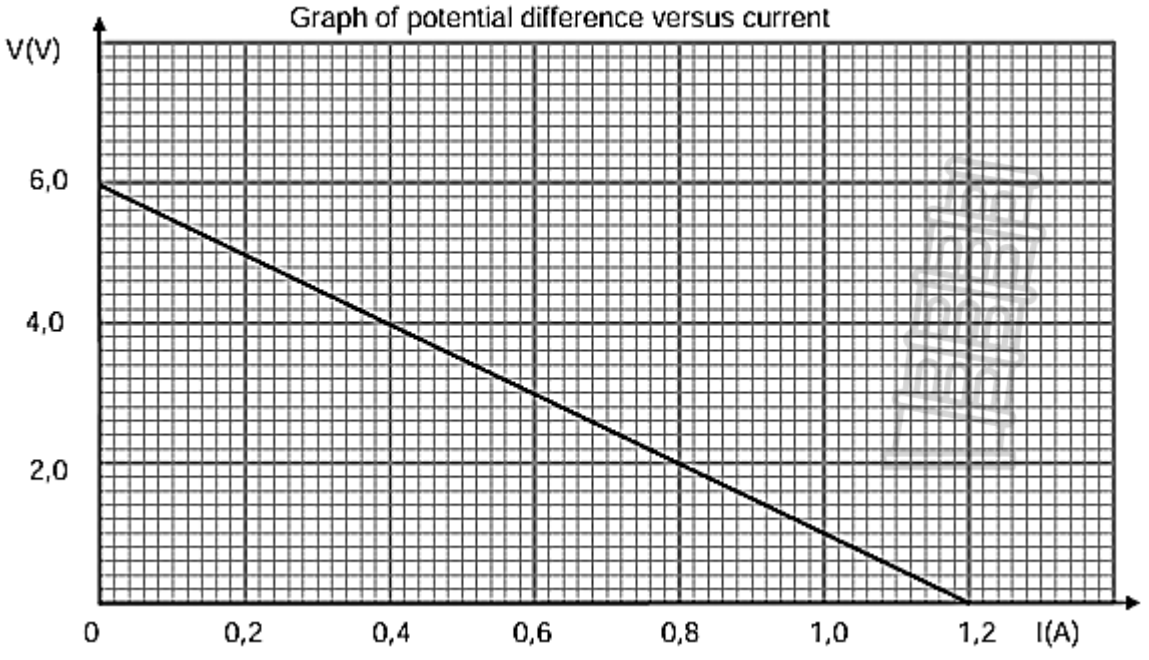
[24]

QUESTION 6

6.1 Learners conduct an investigation to determine the emf and internal resistance (r) of a battery. They connect the battery to a rheostat, an ammeter and a voltmeter as shown in the diagram below.



The results obtained are shown in the graph below



6.1.1 Explain the purpose of the rheostat. (2)

6.1.2 Name the independent variable in the experiment. (1)

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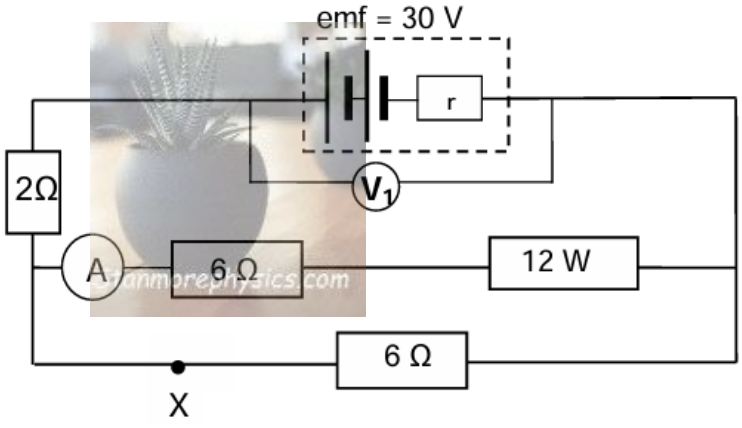
6.1.3 Which physical quantity is represented by the magnitude of the gradient of the graph? (1)

6.1.4 What is the value of the emf of the battery? (1)

6.1.5 Calculate $V_{internal}$ if the current in the circuit is equal to 0,8 A . (2)

6.2 Three resistors and an electrical device are connected to a 30 V battery with internal resistance r as shown in the circuit diagram below. The ammeter has a reading of 2 A.



6.2.1 Define the term emf of a battery. (2)

6.2.2 Calculate voltmeter reading V_1. (8)

6.2.3 Calculate the internal resistance of the battery. (3)

6.2.4 An additional resistor is connected at position X as indicated in the diagram. How will voltmeter reading V_1 be affected? Write down only INCREASE, DECREASE or STAYS THE SAME. Give an explanation for your answer. (4)

[15]

QUESTION 7

7.1 In the circuit diagram shown below, the battery has an emf of 15 V. The internal resistance of the battery is 0,45 Ω. Voltmeter V_2 with a very high resistance is placed between point **A** and **B**

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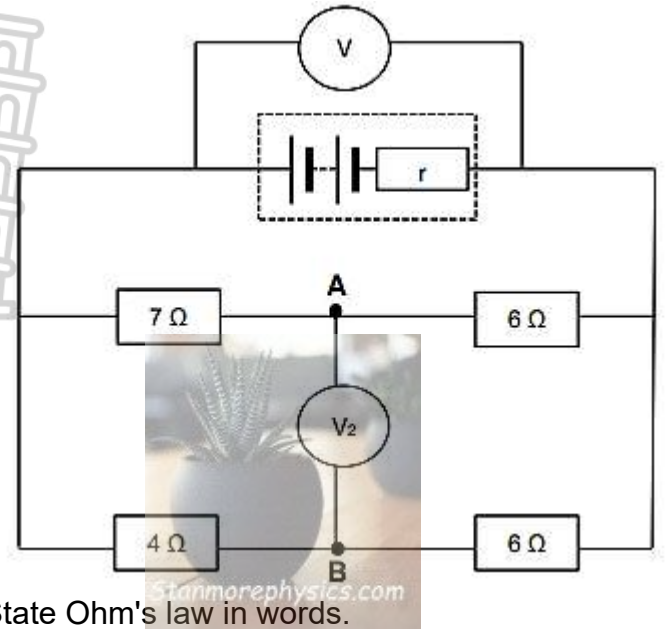

7.1.1 State Ohm's law in words. (2)

Calculate the:

7.1.2 Equivalent resistance of the external circuit (4)

7.1.3 Total current flowing through the circuit (3)

7.1.4 Reading on V_2 (7)

7.2 4 Ω and 6 Ω resistors alongside point B are removed. How will this change affect the V reading?

Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

7.3 Explain the answer to QUESTION 7.2 (2)

7.4 The cost of energy is R2,59 per kWh. How many 80 W light bulbs can you have on for 8 hours per day if your budget for lighting is R300 per month? Assume that an average month has 30 days (5)

[24]

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