KWAZULU-NATAL PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS) SUPPORT

LAST PUSH REVISION LEARNER DOCUMENT

PHYSICAL SCIENCES: PAPER 1 & 2

GRADE 12

2026

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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 $m \cdot s^{-1}$ and returns to the thrower's hand.

NOTE:

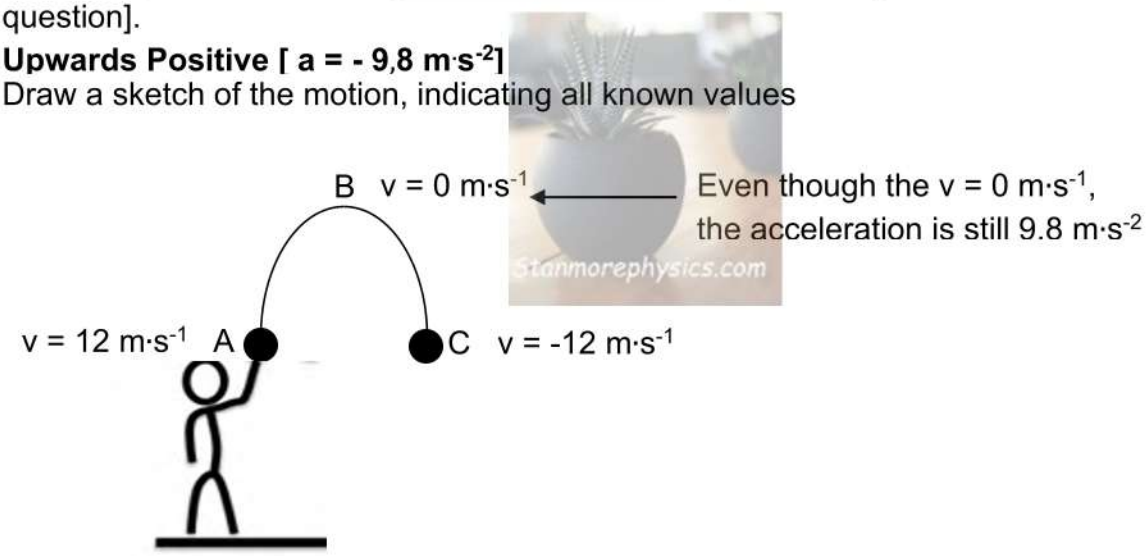
For a free-falling body that is thrown upwards and returns to the thrower's hand:

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

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

Upwards Positive [a = - 9,8 $m \cdot s^{-2}$]

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

$v_f = v_i + a\Delta t$

$0 = 12 + (-9,8)\,\Delta t$

$\Delta t = \underline{1,22\ s}$

Additional Note:

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]

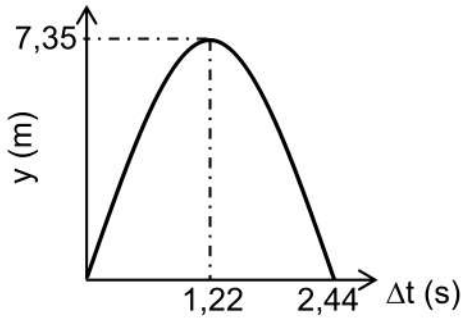
$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

$\Delta y = 12(1,22) + \frac{1}{2}(-9,8)(1,22)^2$

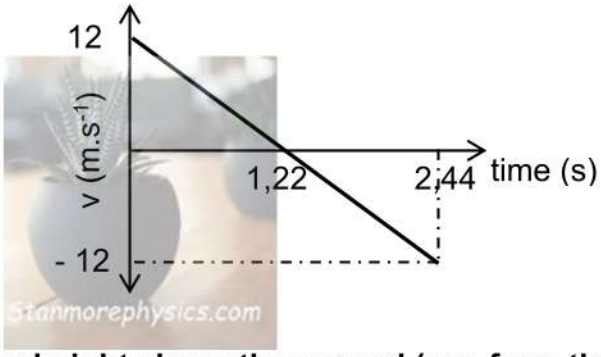
$\Delta y = 7,35\ m$

Graphs for this motion

Position – Time Graph



Velocity – Time Graph



Worked Example 2

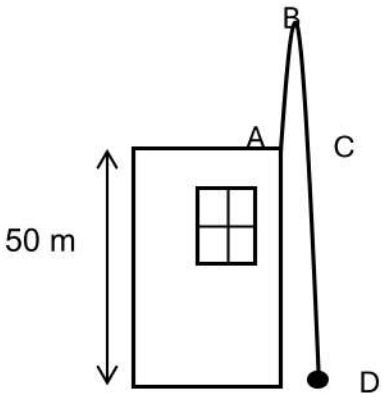
Scenario 2 - Object thrown upwards from some height above the ground (e.g. from the top of a building or a cliff).

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

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

Upwards Positive [a = - 9,8 $m{\cdot}s^{-2}$]

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



From the problem statement:

- v_A = 10 $m.s^{-1}$

From previous example:

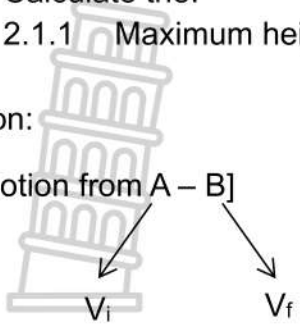
- $v_B = 0\ m.s^{-1}$
- $v_C = -10\ m.s^{-1}$

2.1 Calculate the:

2.1.1 Maximum height the object reaches above the ground

Solution:

[Motion from A – B]



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

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

$\Delta y = 5,1$ m

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

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

2.1.2 Velocity at which the object strikes the ground.

Solution:

[Motion from A – D]

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

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

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

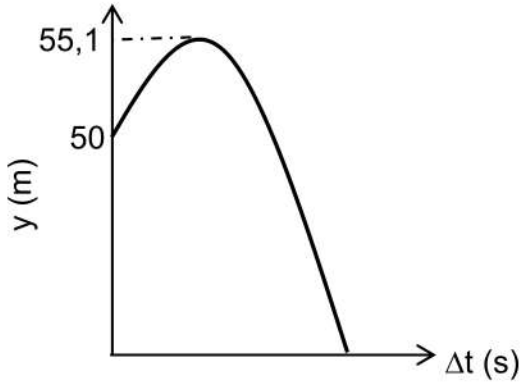
[Note: the negative answer obtained from the square root was taken since the object is moving downwards]

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

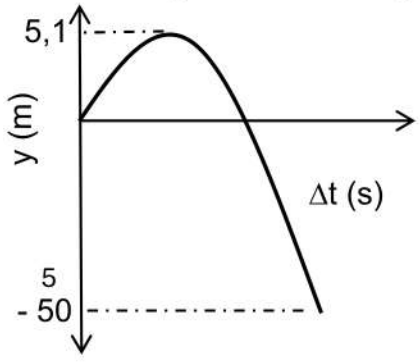
Graphs for this motion

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.

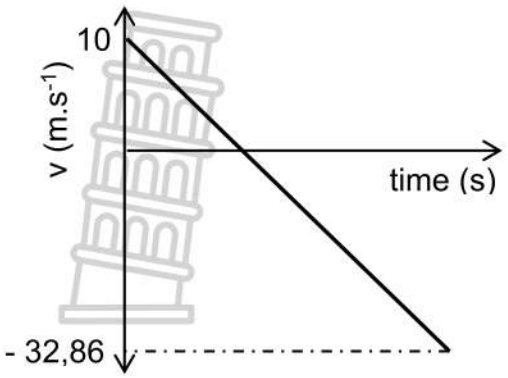
Position – Time Graph (Ground taken as Zero position)



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]



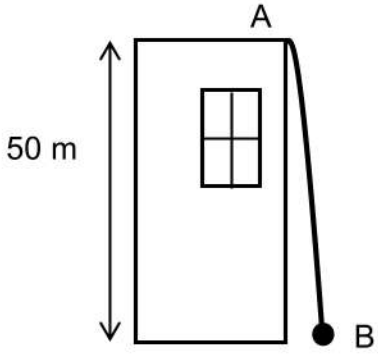
NB: The line below the x-axis must be longer than the line above the x-axis

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:

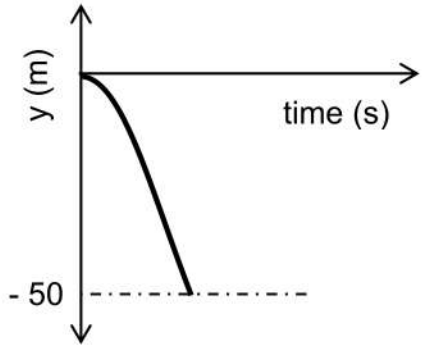
Motion	**v_i (m·s^{-1})**	**v_f (m·s^{-1})**	**Δy (m)**
A to B	$v_A = 10$	$v_B = 0$	5.1
B to C	$v_B = 0$	$v_C = -10$	- 5,1
B to D	$v_B = 0$	$v_D = -32,86$	- 55,1
A to D	$v_A = 10$	$v_D = -32,86$	- 50

Scenario 3 — Object dropped from starting point (Upward taken as positive and the top of the building taken as the zero position)

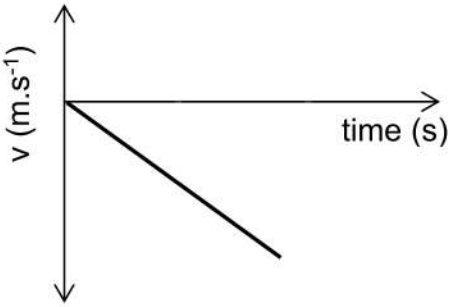


Since the object is DROPPED, the velocity at "A" is 0 m·s^{-1}.

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



Velocity – Time Graph



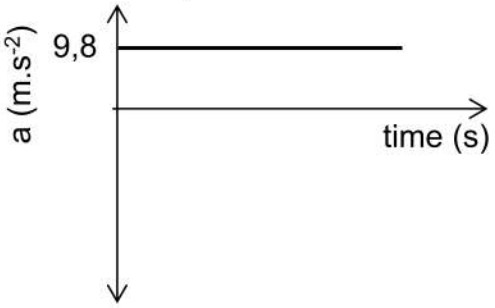
NOTE: If and object is thrown downwards from some height above the ground:

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

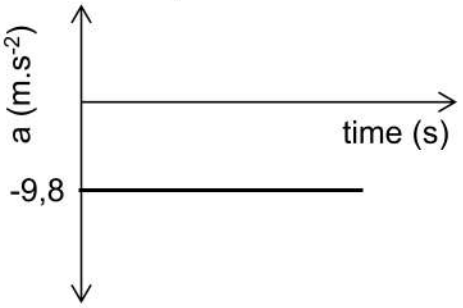
Acceleration – Time Graph

Constant Acceleration - Horizontal lines

Acceleration – Time Graph
(Downwards Positive)
$a = 9,8\ m \cdot s^{-2}$

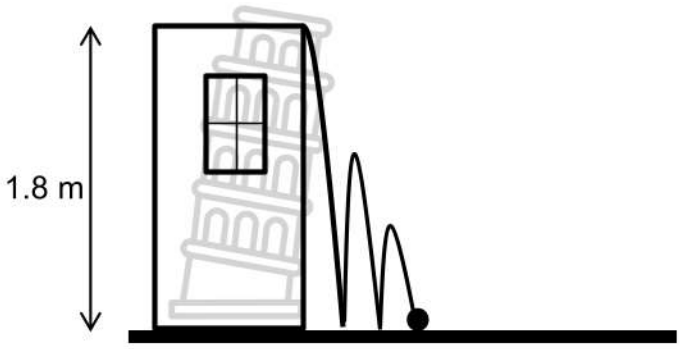


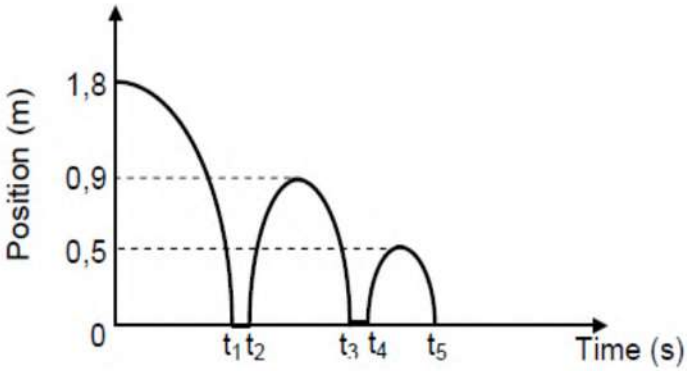
Acceleration – Time Graph
(Upwards Positive)
$a = -9,8\ m \cdot s^{-2}$



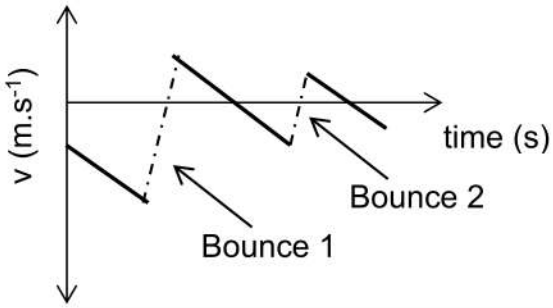
Scenario 4 – Bouncing Ball

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 the velocity-time graph)
- The lines must be drawn parallel.

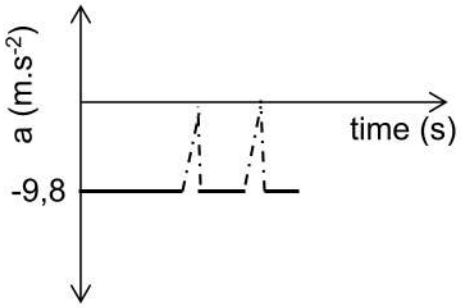
Note

(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.

Acceleration-Time Graph (bouncing ball)



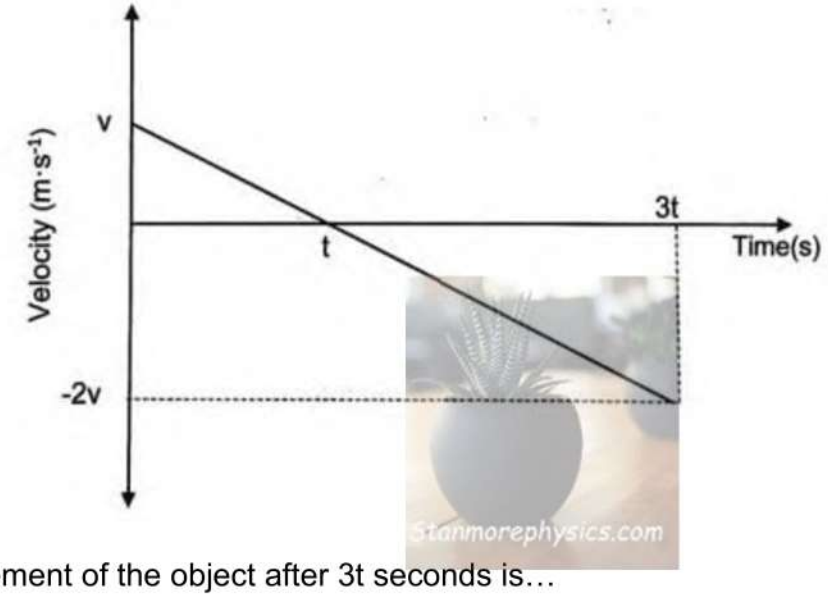
MULTIPLE CHOICE QUESTIONS
QUESTION 1

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)

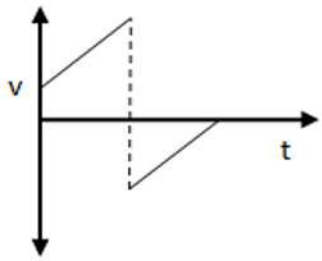
1.3 Ball **A** of mass **m** is projected vertically upwards from the ground with an initial velocity **v**. It rises to a maximum height **h** above the ground.
Ball **B** of mass **½m** is now projected vertically upwards from the ground with an initial velocity of **2v**. Ignore the effects of air 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)

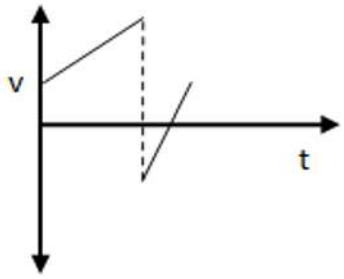
1.4 An object is thrown vertically downwards towards the ground from height h, with a velocity v. The object strikes the ground and bounces upwards. It is caught when it reaches its maximum height after the bounce.

Which of the following graphs for velocity versus time best represents the motion of the object?

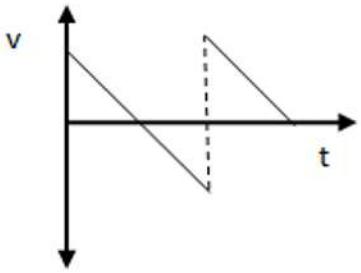
A



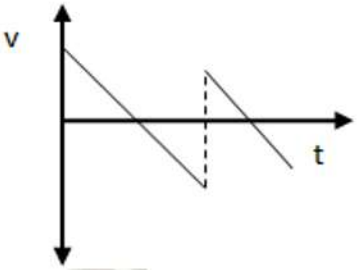
B



C

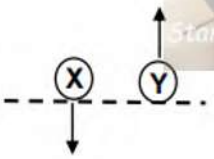


D



(2)

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



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?

	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	$v_X < v_Y$	$E_{kX} < E_{kY}$

(2)

1.6 A girl throws a ball upwards.

Which ONE of the following combinations give the DIRECTIONS of the ball's velocity, acceleration, and the net force that the ball experiences as it travels upwards just after leaving the girl's hand?

	Velocity	Acceleration	Net Force
A	Upward	Downward	Downward
B	Upward	Upward	Upward
C	Downward	Downward	Downward
D	Upward	Downward	Upward

(2)

1.7 A ball is dropped from a height *h* and hits the ground with a speed *v*. The speed of the ball at the moment when it reaches half its initial height is…

A v

B $\frac{v}{\sqrt{2}}$

C $\frac{v}{2}$

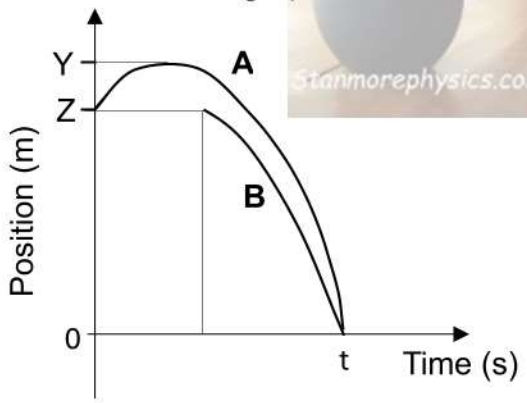
D $\frac{v}{4}$

(2)

[14]

QUESTION 2

Ball **A** is thrown vertically upwards at 12 $m \cdot s^{-1}$ from the top of a building. TWO seconds after ball **A** was thrown upwards, ball **B** is thrown vertically downwards at 5,4 $m \cdot s^{-1}$ from the top of the same building. Both balls, **A** and **B**, strike the ground at time **t** seconds. Ignore the effects of air friction. The position-time sketch graphs for both balls are shown below.



2.1 Using EQUATIONS OF MOTION ONLY, calculate the value of EACH of the following, as shown in the graphs:

2.1.1 t (5)

2.1.2 Z (3)

2.1.3 Y (4)

2.2 On the same set of axes, sketch the velocity-time graphs for ball A and ball B while they are in free fall. Label the graphs A and B for ball A and ball B respectively. Clearly indicate the following on the graphs:

The initial velocity of each ball

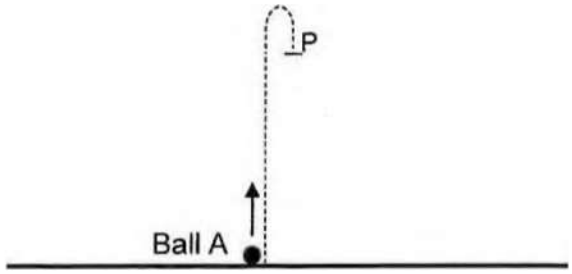
The time at which each ball is thrown

The time at which the balls strike the ground (4)

[16]

QUESTION 3

Ball A is projected vertically upwards at a velocity of 20 m•s^{-1} from the ground. On its way down, it passes point P with a speed of 6,87 m•s^{-1}. Ignore the effects of friction.



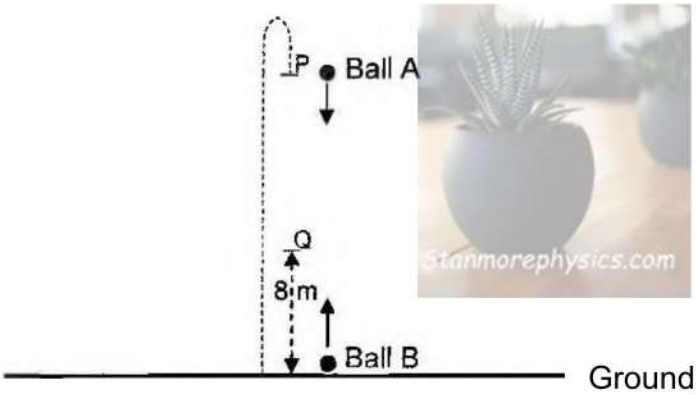
3.1 Define the term *free fall*. (2)

3.2 Using EQUATIONS OF MOTIONS ONLY, calculate the:

3.2.1 Time taken for ball A to reach point P on its way down (3)

3.2.2 The height of point P above the ground (3)

When ball A reaches point P, ball B is projected vertically upwards from the ground. The balls pass each other at point Q which is 8 m above the ground.



3.3 Calculate the speed at which ball B was projected. (5)

3.4 On the same set of axes, sketch the position versus time graph for ball A and ball B from the time ball A was projected until both reach point Q. Take the ground as the zero position. Label the graph for ball A and ball B as A and B respectively.

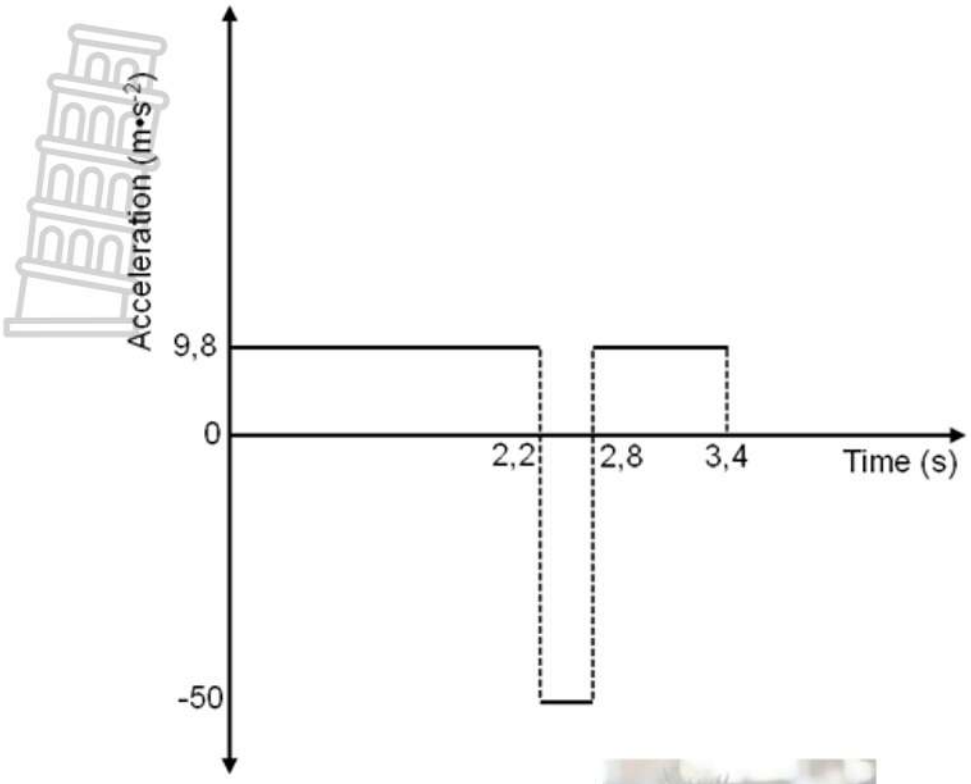
Indicate the following numerical values on the graph:

- Time taken for ball A to reach point P on its way down
- Height of point P
- Height of point Q (5)

[18]

QUESTION 4

The acceleration-versus-time sketch graph below illustrates the motion of an object dropped FROM REST from a point P above the ground.



4.1 Define a *projectile*. (3)

4.2 Describe the motion of the object from zero seconds until 3,4 s (3)

4.3 Calculate :

4.3.1 The velocity at 2,2 seconds. (3)

4.3.2 The height from which the object was dropped. (3)

4.3.3 The velocity of the object at 3,4 seconds. (5)

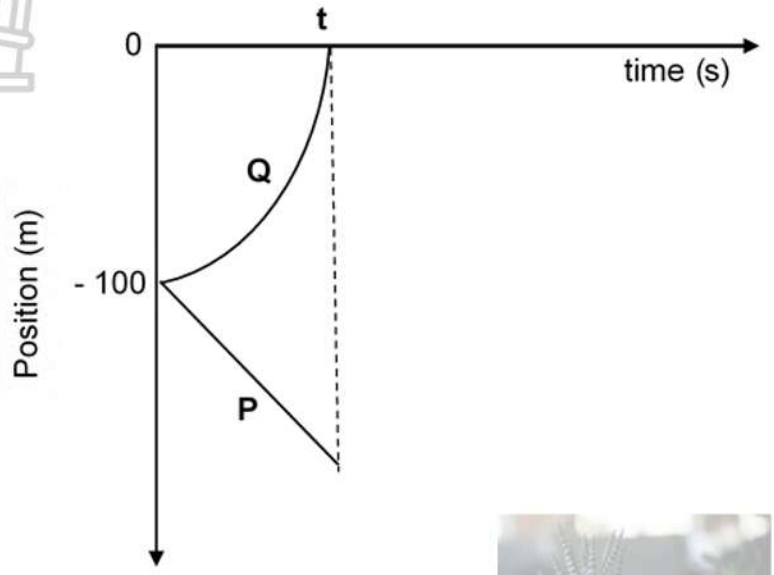
4.4 Sketch a corresponding velocity-versus-time graph for the motion of the object. Clearly show the numerical values for:

- Velocity at 2,2 s
- Velocity at 2,8 s
- Velocity at 3,4 s (5)

[21]

QUESTION 5

A hot-air balloon is moving vertically upward at a CONSTANT velocity. When the balloon is 100 m above the ground, a ball is thrown vertically downward from the balloon with a velocity EQUAL TO the velocity of the balloon. The position-time graphs below, where DOWNWARD IS TAKEN AS POSITIVE, represent the motion of the hot-air balloon and the ball. Take the ground as the zero position.



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

5.2 Which one of the graphs above, **P** or **Q**, represents the motion of:

5.2.1 The hot-air balloon? (1)

5.2.2 The ball? (1)

5.3 Write down the magnitude of the ball's velocity immediately after it is thrown (1)

5.4 Calculate:

5.4.1 The value of **t**, shown on the graph. (4)

5.4.2 The magnitude of the velocity with which the ball hits the ground. (3)

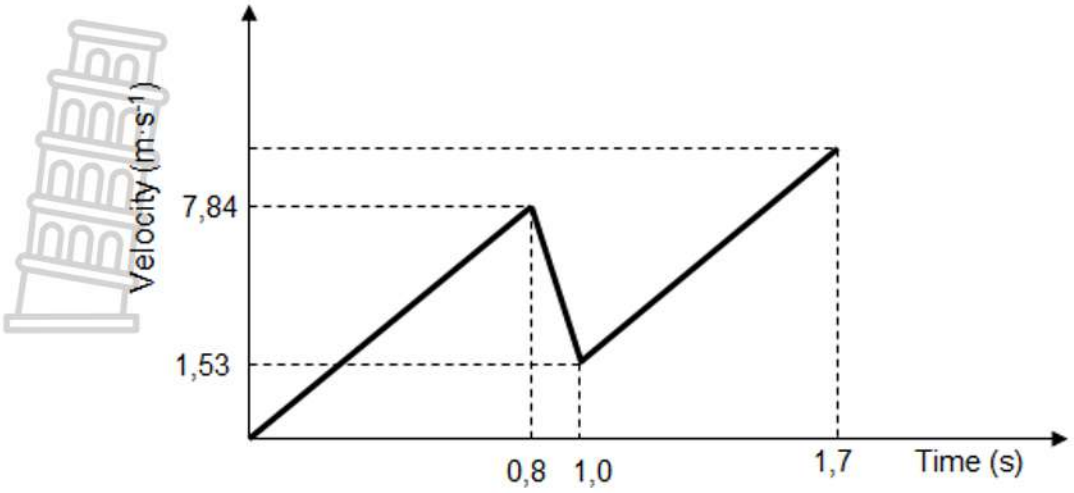
5.5 Three seconds after the ball was thrown, the distance between the hot-air balloon and the ball was 62,1 m.

Calculate the velocity of the hot-air balloon. (5)

[17]

QUESTION 6

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.



6.1 Define the term *projectile*. (2)

6.2 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)

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

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

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

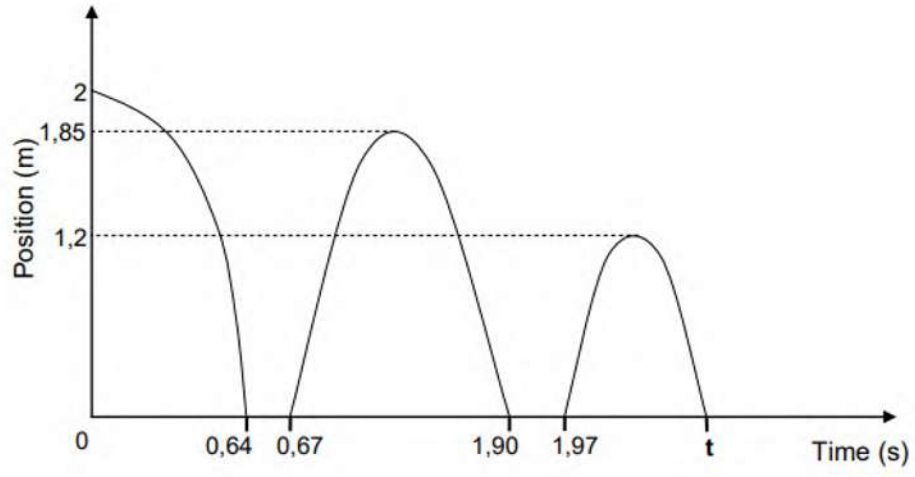
6.6 How does the magnitude of the force exerted by the ball on the glass roof compare to that of the force exerted by the glass roof on the ball? Choose from GREATER THAN, LESS THAN or EQUAL TO. (1)

[15]

QUESTION 7

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.



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

7.2 Use the graph and determine the:

7.2.1 Time that the ball is in contact with the floor before the first bounce (2)
7.2.2 Time it takes the ball to reach its maximum height after the first bounce (2)
7.2.3 The speed at which the ball leaves the floor at the first bounce (3)
7.2.4 Time **t** indicated on the graph (6)
[14]

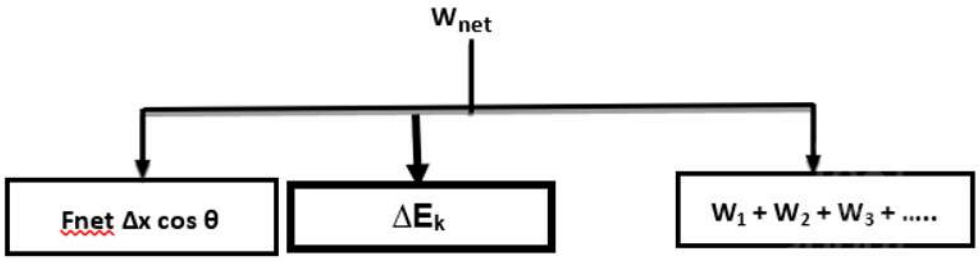
WORK, ENERGY AND POWER

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 $\theta = 180^0$)

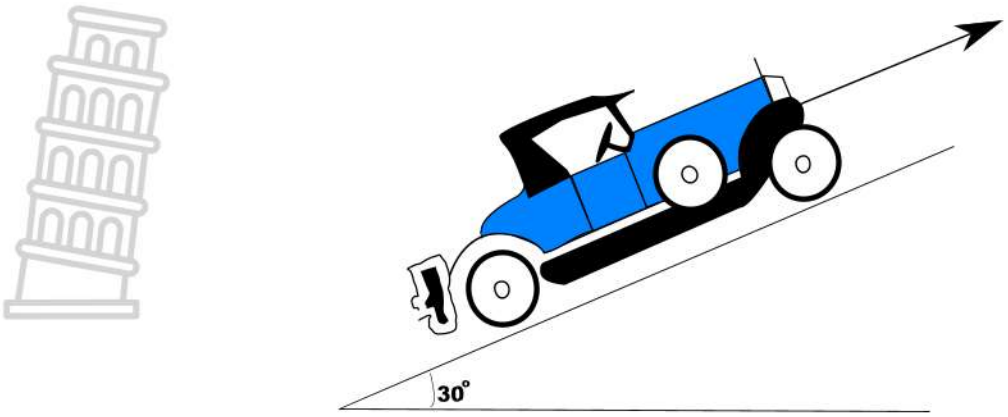
ZERO WORK	POSITIVE WORK	NEGATIVE WORK
The net work done on an object that is moving at constant velocity is zero. No work is done when a force is exerted on the object, but the object does not move. No work is done by forces acting perpendicular to the surface. ($\theta = 90^o$)	Occurs when an object moves in the direction of the force. It occurs when $\theta = 0^o$ θ lies between = 0^o & 90^o 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})

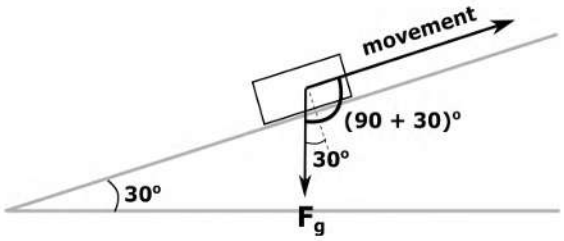
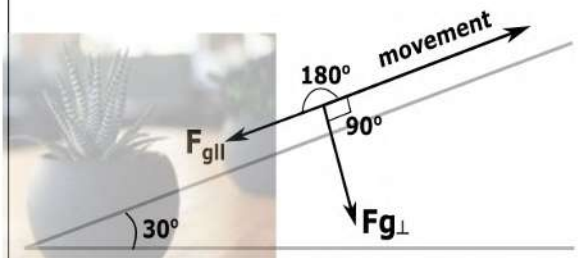
It is the total work done by all the forces acting on an object.
Use any one of the methods given below.



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.

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.

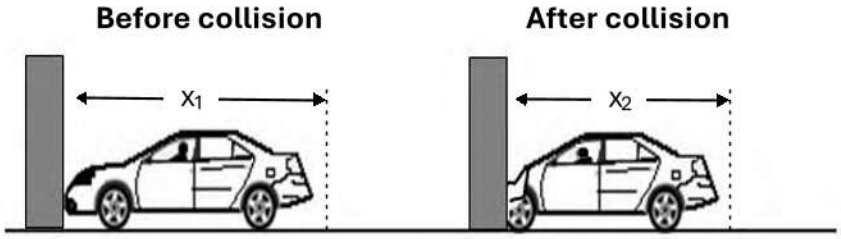
Work-energy theorem	Principle of Conservation of Mechanical Energy	Work done by non-conservative forces
• $W_{net} = \Delta K$ • This one considers all forces acting on the object (conservative and non-conservative forces)	• The total mechanical energy in an isolated system remains constant. • A **system 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.

WORKED EXAMPLE 1

QUESTION 1

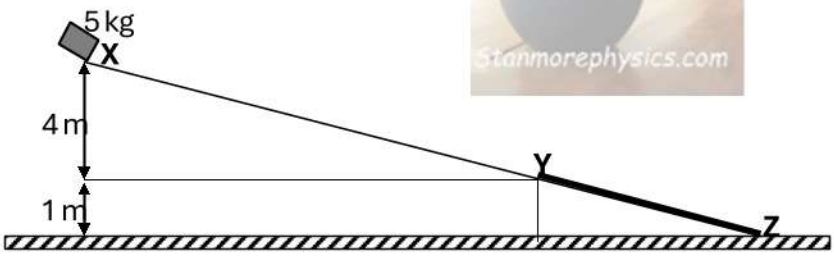
In order to measure the net force involved during a collision, a car is allowed to collide head-on with a flat, rigid barrier. The resulting crumple distance is measured. The crumple distance is the length by which the car becomes shorter in coming to rest.

In one of the tests, a car of mass 1 200 kg strikes the barrier at a speed of 20 m·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.



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·s^{-1}.

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

SOLUTION

1.1 $W_{net} = \Delta E_k$✓

$F_{net}\Delta x\cos\theta = \frac{1}{2} m(v_f^2 - v_i^2)$

$F_{net}(1{,}02)\cos 180°$✓ $= \frac{1}{2}(1\ 200)(0 - 20^2)$✓

$F_{net} = 235\ 294{,}12$ N✓ (4)

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

(4)

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

$(mgh + ½ mv^2)_X = (mgh + ½ mv^2)_Y$

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

$v = 8,85 \text{ m·s}^{-1}$ ✓

1.2.2 $W_{net} = \Delta K$ ✓

$W_w + W_f = ½m(v_f^2 - v_i^2)$

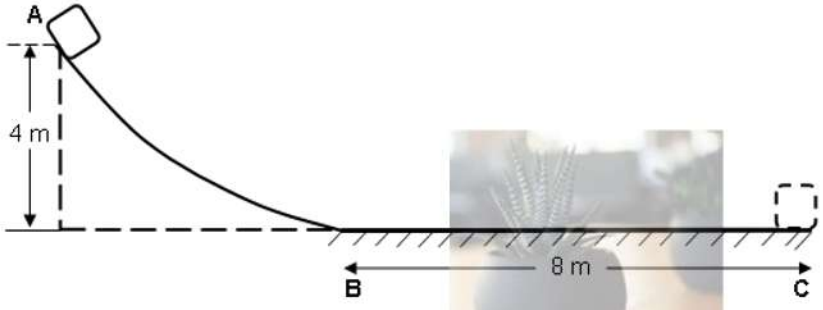
$mg\Delta y\cos 0° + f\Delta x\cos 180° = ½ m(v_f^2 - v_i^2)$

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

$\Delta x = 20,48$ 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.

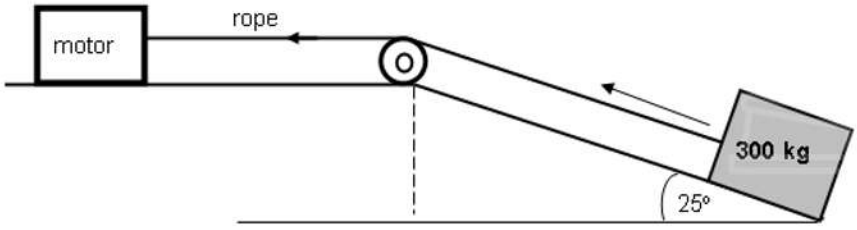


2.1.1 State the principle of conservation of mechanical energy in words. (2)

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)

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

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 $(E_p + E_k)_A = (E_p + E_k)_B$ ✓

$(mgh + ½ mv^2)_A = (mgh + ½ mv^2)_B$

$(10)(9,8)(4)$ ✓$+ 0 = 0 + ½ (10) v_f^2$ ✓

$v_f = 8,85 \text{ m·s}^{-1}$

$W_{net} = \Delta K$

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

$f(8)\cos 180^\circ$✓ $= ½ (10)(0 - 8,85^2)$ ✓

$f = 48,95$ N✓ (6)

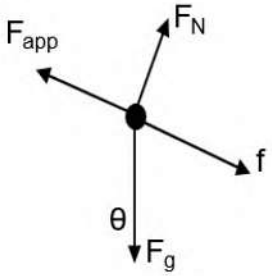
2.2.1 $f_k = \mu_k N$✓

$= \mu_k mg\cos\theta$ ✓

$= (0,19)(300)(9,8)\cos 25^\circ$✓

$= 506,26$ N (3)

2.2.2



$F_{net} = 0$

$F_A + (-F\sin\theta) + (-f) = 0$ ✓

$F_A - (300)(9.8)\sin 25^\circ$ ✓ $- 506.26$ ✓ $= 0$

$F_A = 1748.76$ N

$P_{ave} = Fv_{ave}$ ✓

$= 1748.76 \times 0.5$ ✓

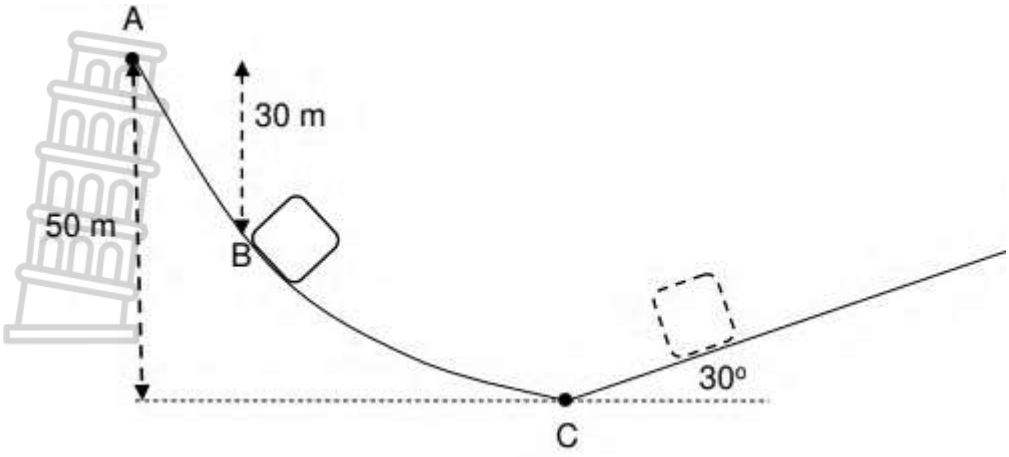
$= 874.38$ W ✓

(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.



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

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

$v_f = 19,80 \ m \cdot s^{-1}$✓ (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

$W_{net} = W_G + W_f$

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

$\Delta x = 28,41$ m

$h = (28,41)(\sin 30^o)$✓

$h = 14,21$ m✓ (6)

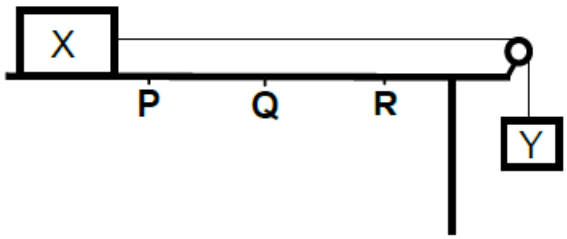
3.4.2 Smaller than✓

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

[15]

QUESTION 1: MULTIPLE CHOICE QUESTIONS

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**.



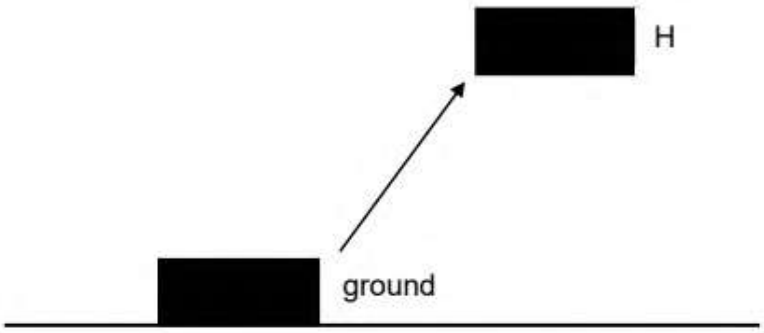
When block X reaches point **Q**, the string is cut and block X continues to move towards point **R**. Ignore the effect of air friction.
Consider the following statements:
(i) The work done by the frictional force acting on block X is greater when the block moves from point **P** to point **Q** than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

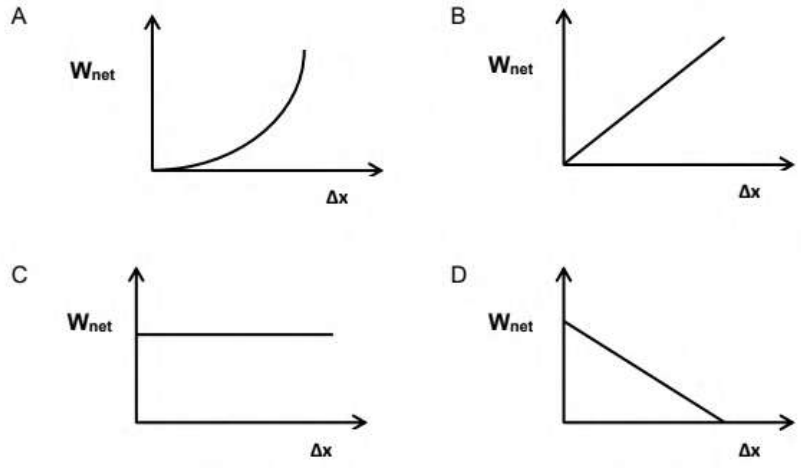
1.3 A mass is lifted from rest on the ground to point H as shown below.



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?

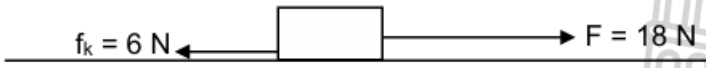
A P + K
B P – K
C K – P
D P x K (2)

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)

1.5 A block moves along a rough horizontal surface while a horizontal force F of magnitude 18 N and a constant kinetic frictional force of magnitude 6 N act on it.



Which ONE of the following combinations of ACCELERATION and NET WORK DONE ON THE BLOCK is CORRECT?

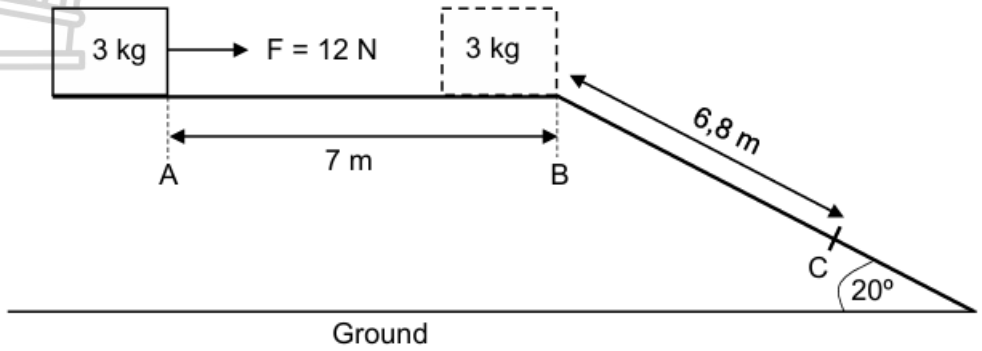
	ACCELERATION	**NET WORK DONE ON THE BLOCK**
A	Constant	Increases
B	Increases	Constant
C	Increases	Increases
D	Constant	Constant

(2)

STRUCTURED QUESTIONS

QUESTION 2

A crate of mass 3 kg is at rest at point A on a frictionless horizontal surface. A constant horizontal force F of 12 N acts on the crate and moves it from point A to point B. The crate then moves down a rough plane, inclined at 20° to the horizontal. The distance from point A to point B is 7 m and from point B to point C is 6,8 m, as shown in the diagram below.



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

2.2 Using ENERGY PRINCIPLES ONLY, calculate the kinetic energy of the crate at point B. (3)

Force F is removed when the crate reaches point B. The crate then experiences a constant frictional force of 21 N as it moves down the incline.

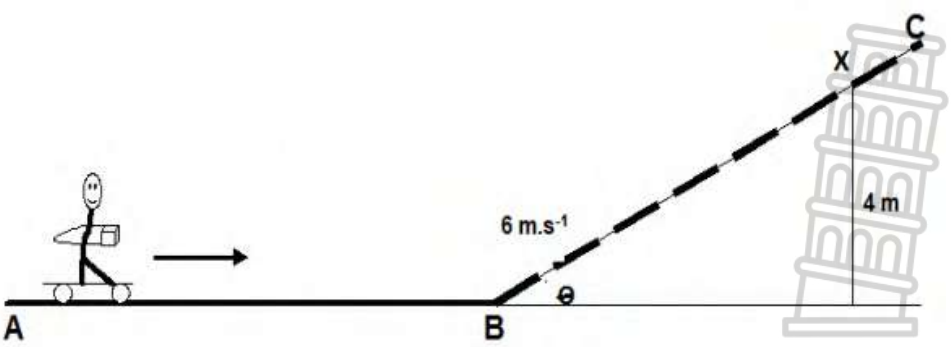
2.3 Draw a free-body diagram showing ALL the forces acting on the crate as it moves down the incline. (3)

2.4 Using ENERGY PRINCIPLES ONLY, determine whether the crate will pass point C. (5)

[13]

QUESTION 3

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.



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

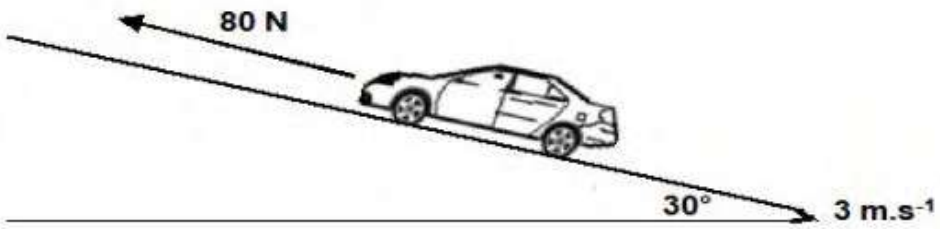
3.2 Name and define in words the Law of physics that was applied in QUESTION 3.1. (3)

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.

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

3.4 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 $m \cdot s^{-1}$



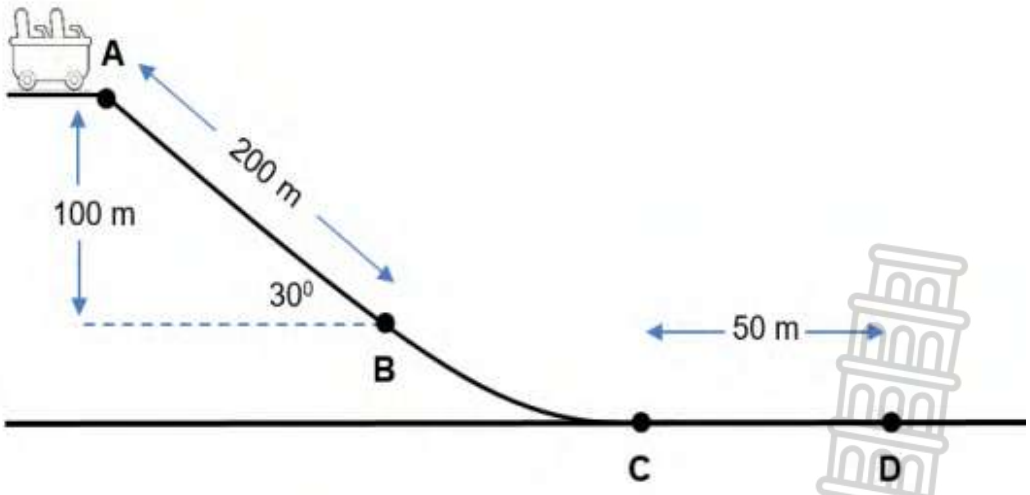
Use energy principles to calculate the speed of the car after it has travelled 5 m up the inclined plane. (6)

[15]

QUESTION 4

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.



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

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

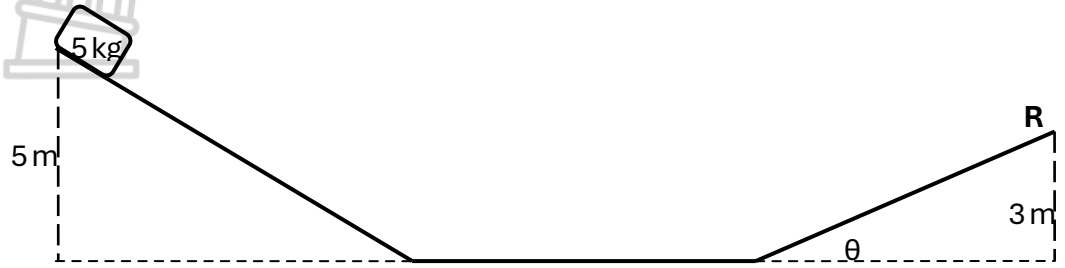
4.3 Calculate the net work done on the roller-coaster as it moves from A to B. (5)

4.4 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 5

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.

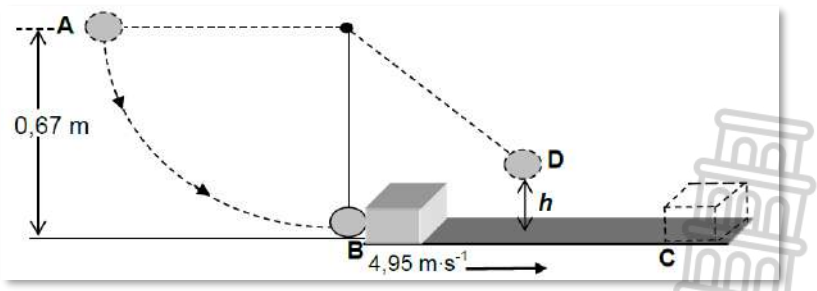
5.1 Using ENERGY PRINCIPLES only, calculate the speed of the block at point **P**. (4)

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

[11]

QUESTION 6

6.1 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.



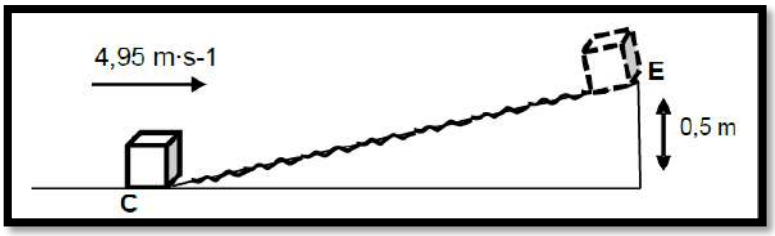
6.1.1 Explain what is meant by *isolated system*. (2)

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

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

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

6.2 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.



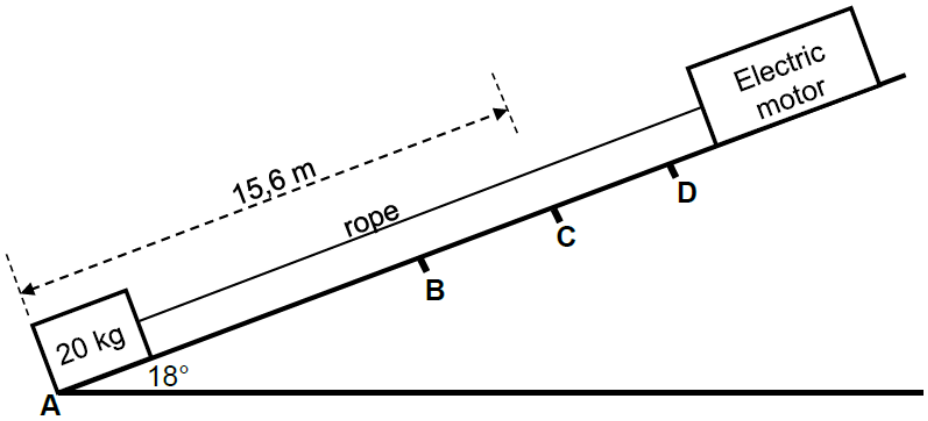
6.2.1 State *work-energy theorem* in words. (2)

6.2.2 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 7

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 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.

7.1 Define a non-conservative force. (2)

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

7.3 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.

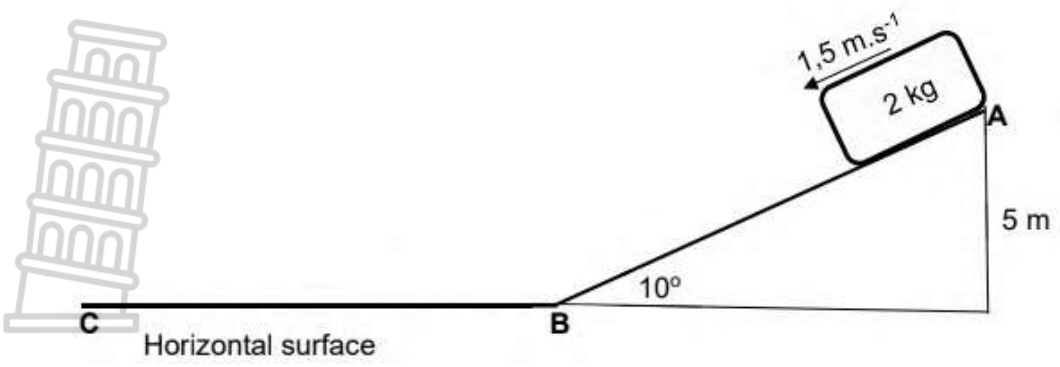
7.4 Draw a labelled free-body diagram for the crate as it slides down the plane past point **B**. (3)

7.5 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 8

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 10^{o} to the horizontal surface.



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.

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

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

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

8.4 Use ENERGY PRINCIPLES to calculate the:

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

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

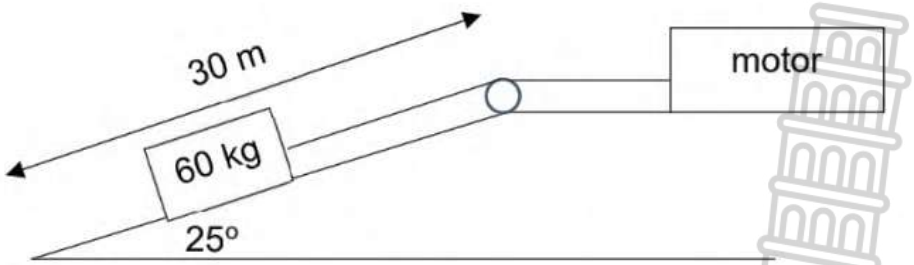
[17]

QUESTION 9

A motor is used to pull a crate of mass 60 kg up a 30 m rough slope. The motor is connected to the crate with an inextensible rope of negligible mass running over a frictionless pulley. The slope is at an angle of 25° to the horizontal.

The crate starts from rest and reaches a speed of 7,5 $m \cdot s^{-1}$ at the top of the slope.

The crate experiences a constant frictional force of 16,2 N.



9.1 Define the term a non-conservative force. (2)

9.2 Use the WORK-ENERGY THEOREM to calculate the average power that the motor must provide to pull the crate up in 2 minutes. (7)

9.3 Will the work done by the motor INCREASE, DECREASE or REMAIN THE SAME if the crate is lowered down the same slope at the same initial and final velocities? Explain the answer. (3)

[12]

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.

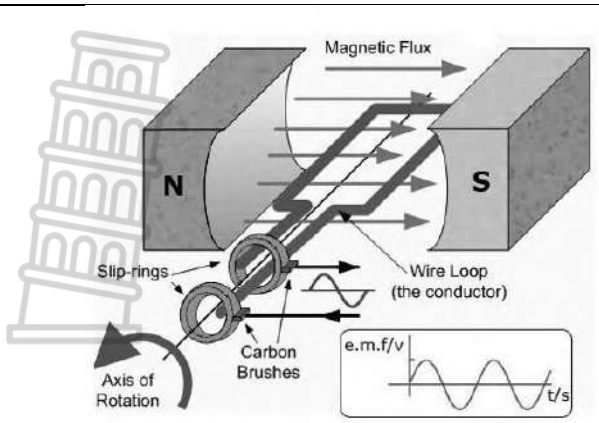
Alternating current

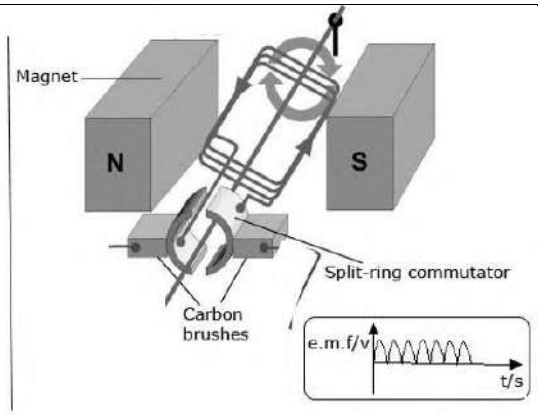
State the advantages of alternating current over direct current.
Sketch graphs of voltage versus time and current versus time for an AC circuit.
Define the term rms for an alternating voltage/current.
The rms potential difference is the AC potential difference which dissipates/produces the same amount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

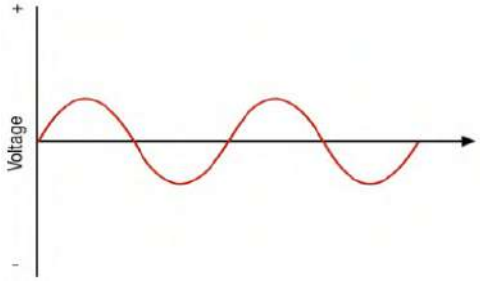
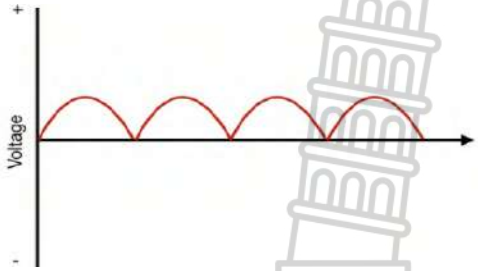
1 GENERATORS

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	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.	**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.
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?

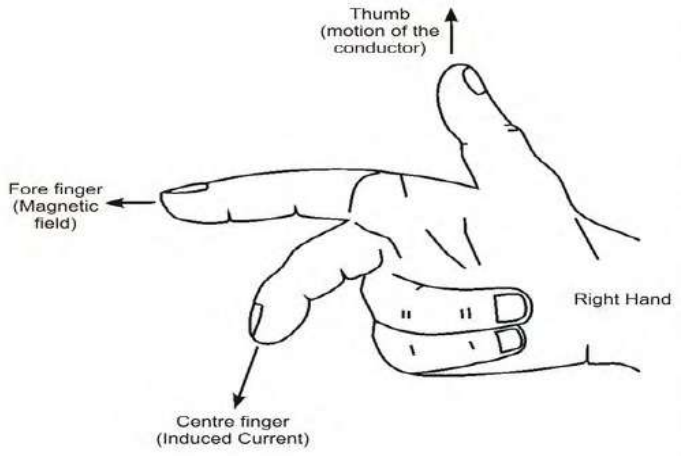
Fleming's Right-hand rule:

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

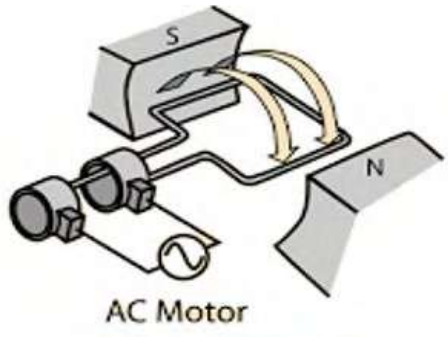


2 MOTORS

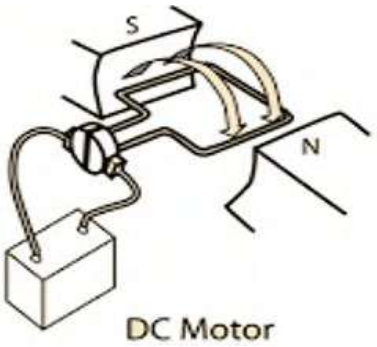
Energy conversion: Electrical energy to mechanical energy.
Principle: Motor effect.
Motor effect: A current carrying conductor placed in a magnetic field experiences a force.

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:

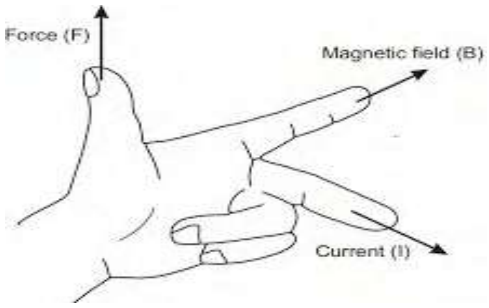
Fleming Left-hand rule:

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



Differences between AC and DC machines

AC machines have slip rings

DC machines have a split ring commutator

ALTERNATING CURRENT

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

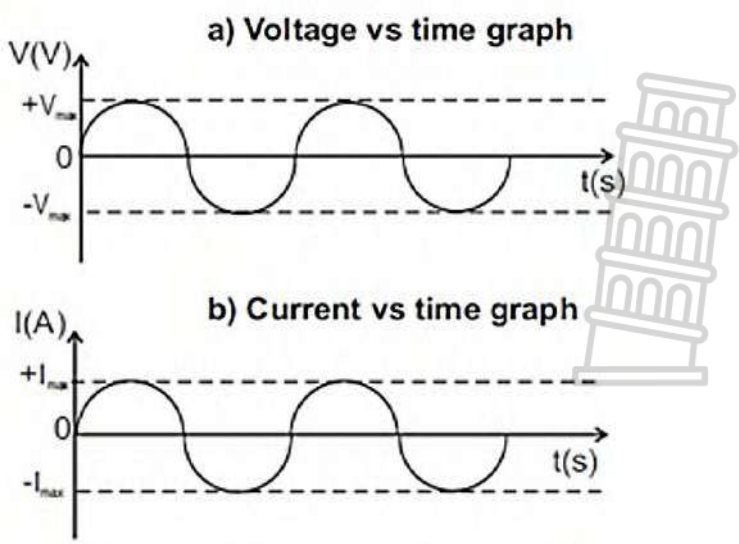
Advantages of alternating current over direct current

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)

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

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

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

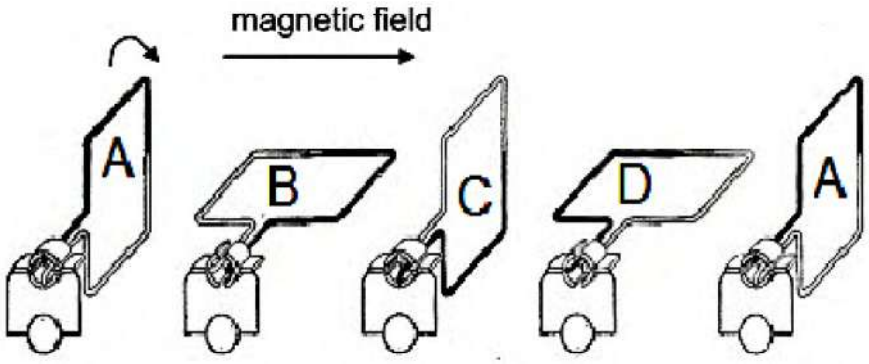
$P_{ave} = V_{rms} \times I_{rms}$

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

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

WORKED EXAMPLE 1

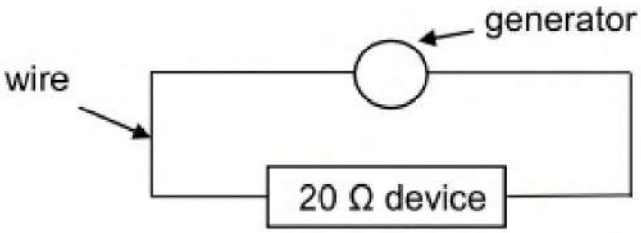
1.1 The diagram shows different positions (**ABCDA**) of the coil in a DC generator for a complete revolution. The coil is rotated clockwise at a constant speed in a uniform magnetic field. The direction of the magnetic field is shown in the diagram.



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)

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)

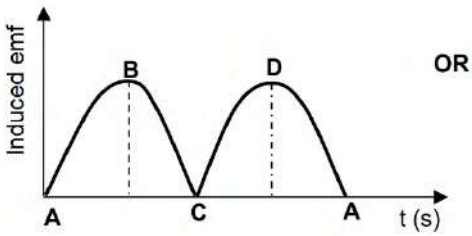
1.2.2 Calculate the average power delivered to the device. (5)

SOLUTIONS

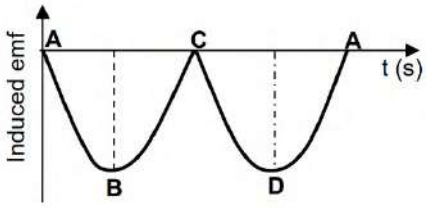
1.1

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 **OPTION 1**

$I_{rms} = \frac{V_{rms}}{R}$ ✓

$= \frac{25}{20.5}$ ✓

$= 1.22\ A$

$P_{av} = I_{rms}^2 R$ ✓ $= (1.22)^2(20)$✓ $= 29.77W$ ✓	$W = I_{rms}^2 R\Delta t$ $= (1.22)^2 0.5(1)$ $= 0.74J$ $P_{av} = \frac{V_{rms}^2}{R}$✓ $= \frac{(25)^2}{20.5}$✓ $= 30{,}49W$ *Actual energy delivered per second (power)* $(30.49 - 0.74)$ $= 29.75W$✓	$P_{av} = I_{rms}^2 R$ $= (1.22)^2(0.5)$ $= 0.74W$ $P_{av} = \frac{V_{rms}^2}{R}$✓ $= \frac{(25)^2}{20.5}$✓ $= 30{,}49W$ *Actual energy delivered per second (power)* $= (30.49 - 0.74)$ $= 29.75W$✓

(5)

OPTION 2

$V_{rms} = \frac{20}{20.5} \times 25$✓ $= 24{,}39V$ $P_{av} = \frac{V_{rms}^2}{R}$✓ $= \frac{(24.39)^2}{20}$✓ $= 29.74W$✓

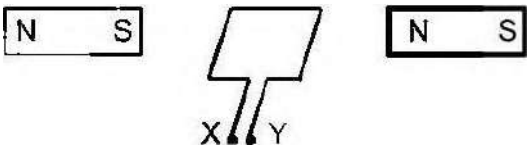
ACTIVITIES

MULTIPLE CHOICE QUESTION

1.1 How does the commutator in a DC motor ensure that the coil rotates continuously in ONE direction?

A By reducing friction
B By converting AC to DC
C By reversing the direction of the current in the coil
D By maintaining electrical contact between the external and the internal circuits (2)

1.2 The diagram below shows a coil in a magnetic field.



When the coil is part of a DC motor, which ONE of the following must be connected to X and Y?

A Split ring (commutator)
B Slip rings
C AC supply
D Soft iron core (2)

1.3 Which ONE of the following is the function of the split-ring commutator in an electric motor?

The split-ring commutator ...

A rotates the coil.
B delivers current from the coil to the external circuit.
C ensures that the coil rotates continuously in one direction.
D ensures that the current in the external circuit changes direction. (2)

1.4 Which of the energy conversions below takes place when an AC generator is in operation?

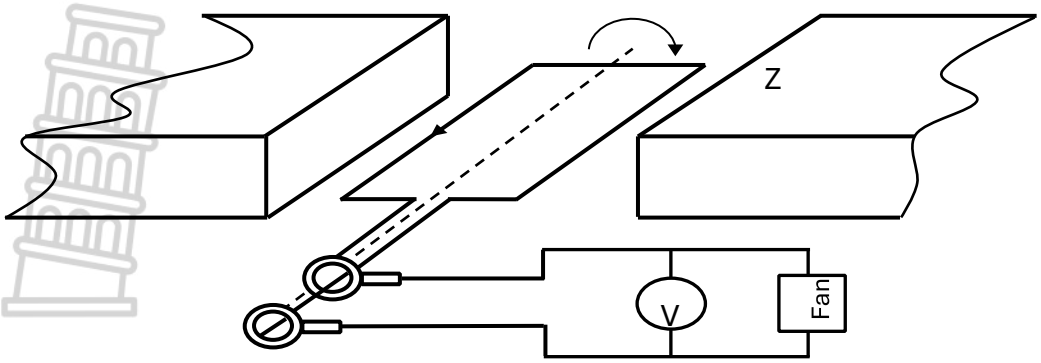
A Potential to electrical
B Mechanical to electrical
C Electrical to mechanical
D Heat to mechanical (2)

[8]

STRUCTURED QUESTIONS

QUESTION 2

An AC generator operates a fan. The directions of the rotation of the coil and the induced
current are shown in the simplified diagram below.

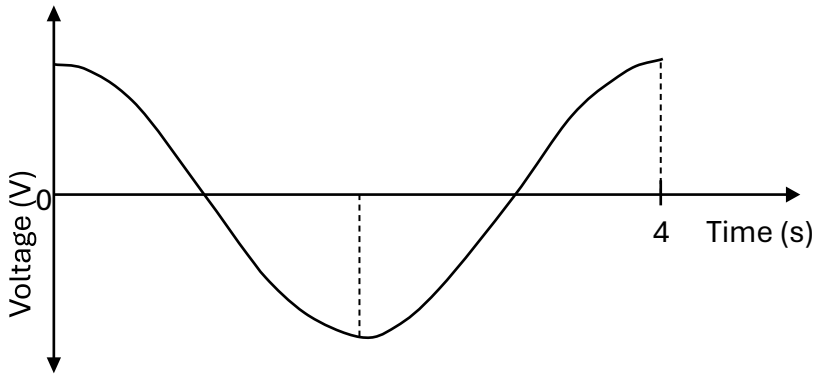


2.1 Define the term *rms potential difference.* (2)

2.2 What is the polarity of the magnet at Z? (2)

2.3 The resistance of the fan is 60 Ω and the maximum potential difference produced by the generator is 311,11 V. Calculate the cost of operating the fan for 1,5 hours if the cost of electricity is R3,33 per kWh. (5)

The voltage versus time graph for this generator is given below.



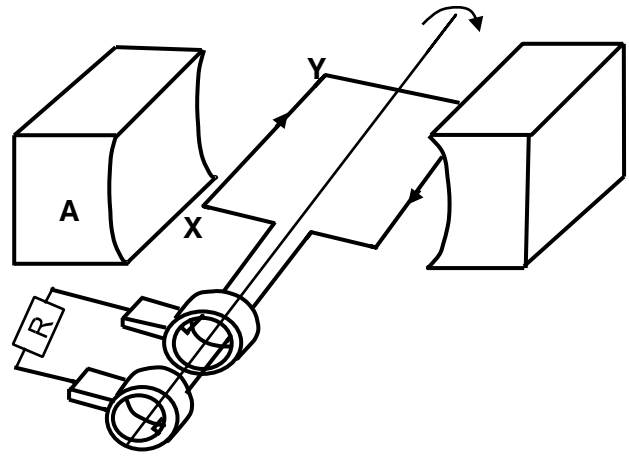
2.4 Redraw this graph in the ANSWER BOOK and label it as A. On the same set of axes, draw the graph for ONE rotation of the coil when the speed of rotation is doubled. Label this as graph B. (3)

2.5 State ONE way in which this generator can be changed to a DC generator. (1)

[13]

QUESTION 3

3.1 The diagram below represents a simplified version of an AC generator. The induced current flows from X to Y in the coil when the coil is rotated clockwise, as shown in the diagram below.



3.1.1 What is the polarity of A? Choose from NORTH or SOUTH. (2)

3.1.2 State ONE way in which the induced emf of this generator can be increased. (1)

3.1.3 Sketch a graph of induced current versus time for ONE complete rotation (3)
of the coil from the horizontal position, as shown in the diagram above.

3.2 An AC generator produces a maximum output voltage of 340 V. A 1 200 W electric kettle operates optimally when it is connected to this generator.

3.2.1 Define the term *root mean square current*. (2)

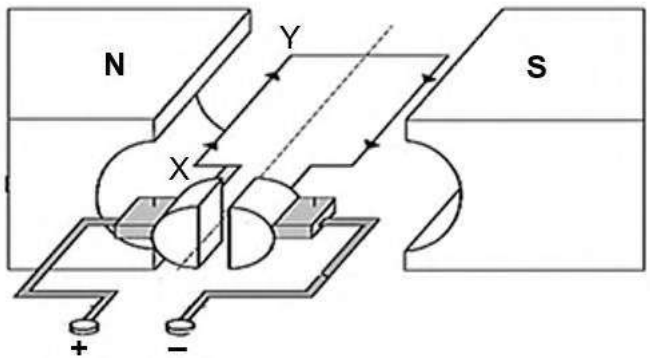
3.2.2 Calculate the root mean square current passing through the kettle. (4)

3.2.3 Calculate the resistance of the kettle. (3)

[15]

QUESTION 4

A simplified representation of a DC motor is shown in the diagram below. The current in the coil is in the direction X to Y.



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

4.2 In which direction will the coil rotate?
Write down only CLOCKWISE or ANTI-CLOCKWISE. (2)

4.3 Write down the energy conversion which takes place while the motor is working. (1)

4.4 An AC generator, producing a maximum voltage of 311,12 V, is connected to an lectric heater of resistance 30 Ω.
Calculate the:

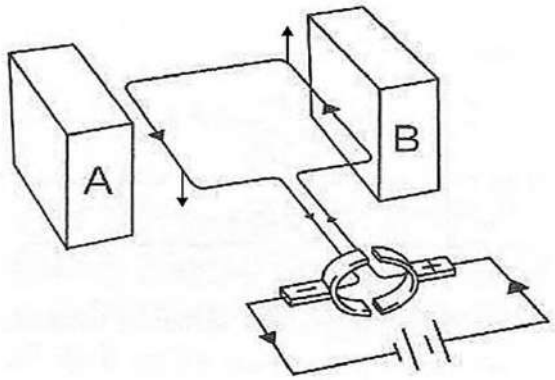
4.4.1 Root mean square (rms) value of the voltage (3)

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

[11]

QUESTION 5

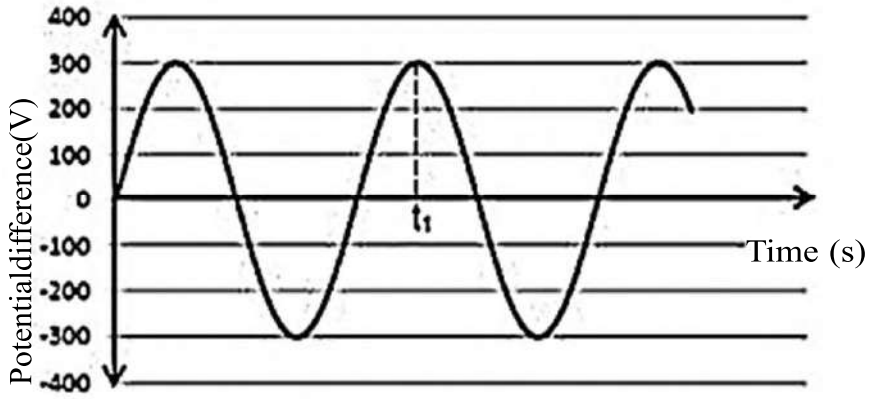
5.1 The simplified sketch below represents the structure of the motor of a cordless drill.



5.1.1 Name the electrical component in the above motor that ensures that the coil rotates in one direction only. (2)

5.1.2 Identify the polarity of magnets A and B if the current flows in the coil as indicated on the sketch and the coil rotates in an ANTICLOCKWISE direction. (2)

5.2 mum current output of another drill, operating on ALTERNATING current, is 10,6A. of potential difference output of the drill against time is shown below.



5.2.1 Define *rms current.* (2)

5.2.2 Calculate the rms current that the drill draws when operating. (3)

5.2.3 Hence, calculate the average power generated by the drill. (3)

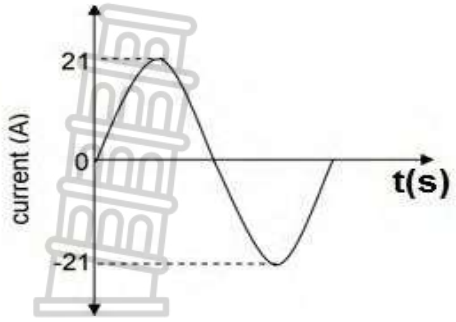
5.2.4 Is the power generated by the drill at t_1 a MAXIMUM or MINIMUM? (1)

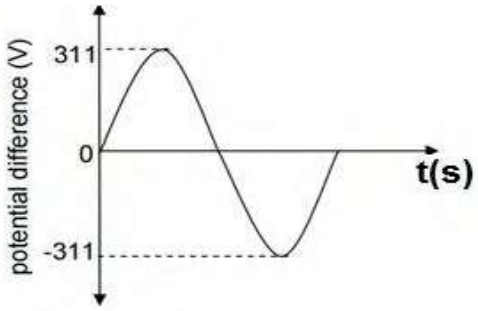
5.2.5 Provide TWO reasons why alternating current is preferred over direct current over long-distance transmission. (2)

[15]

QUESTION 6

Graphs of the current and potential difference outputs of an AC generator are shown below.





6.1 Define the term *root mean square value (rms)* of an AC voltage. (2)

6.2 Write down the energy conversion that takes place in an AC generator. (1)

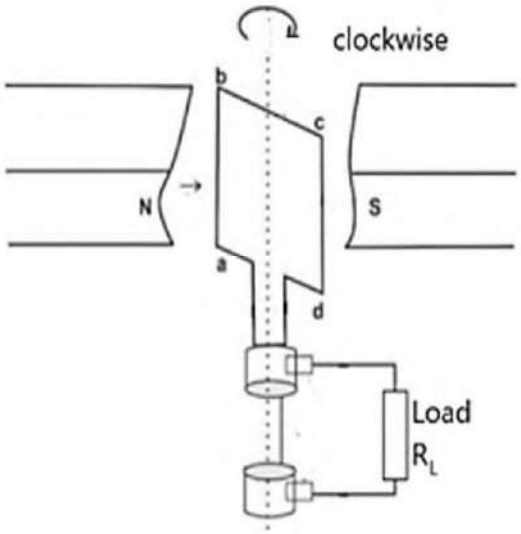
6.3 Give ONE reason why AC voltage is preferred to DC voltage for everyday use. (1)

6.4 Calculate the average power output of this generator. (6)

[10]

QUESTION 7

Study the diagram of a simple generator below and answer the questions that follow.

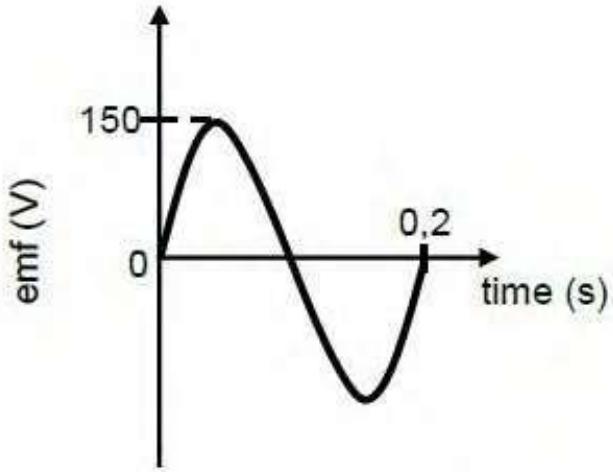


7.1 Is this an AC or a DC generator? Give a reason for the answer. (2)

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

7.3 In which direction will the induced current flow? State only from **a to b** or from **b to a.** (1)

The diagram below shows the emf time graph for one complete rotation of the coil.



7.4 Calculate the resistance of the load, R_L, if the value of I_{rms} is 4,55 A when the V_{max} is 150 V. (4)

7.5 Load RL is now replaced with a bulb with a power consumption of 400 W. Assume that the bub is 100% effective and calculate the light energy emitted by the bulb in 3 minutes. (3)

7.6 The speed of rotation of the coil is now DOUBLED.

7.6.1 Redraw the above diagram in your ANSWER BOOK. On the same set of axes, indicate the old and the new pattern obtained. Label the new pattern B. (2)

7.6.2 With what factor will the energy emitted change if the speed of rotation of the coil is doubled (two times faster)? Explain the answer. (4)

[17]

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

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.

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 operates 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

Cell potential

The cell potential is calculated using the formula:

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

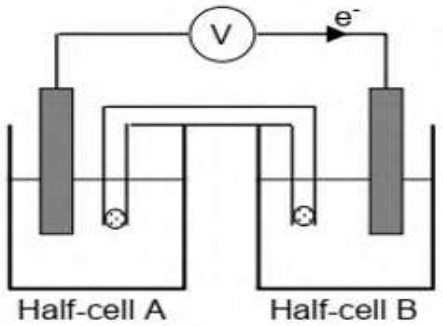
Or: $\mathbf{E^{\theta}_{Cell} = E^{\theta}_{Reduction} - E^{\theta}_{Oxidation}}$

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

WORKED EXAMPLES

QUESTION 1

The galvanic cell represented in the diagram below consists of a Magnesium (Mg) electrode dipped into a $Mg(NO_3)_2$ solution, and a Lead (Pb) electrode dipped into a $Pb(NO_3)_2$ solution.



1.1 State TWO standard conditions under which this cell operates. (2)

1.2 Write down the half-reaction that takes place in half-cell A. (2)

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

1.4 Calculate the emf of this cell. (4)

1.5 How will each of the following changes influence the value of the cell's emf calculated in QUESTION 1.4? Write down the only INCREASES, DECREASES or REMAINS THE SAME.

1.5.1 An increase in $[Mg^{2+}(aq)]$ (1)

1.5.2 An increase in $[Pb^{2+}(aq)]$ (1)

1.6 In which direction, from half-cell **A to B** or from half-cell **B to A**, do cations move within the salt bridge to maintain electrical neutrality? Explain how you arrived at your answer. (4)

[17]

SOLUTIONS

1.1 Temperature 298K / 25^0C ✓

Concentration of an electrolytes 1mol.dm^{-3} ✓ (2)

1.2 $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$ ✓✓ (2)

1.3 $Mg \mid Mg^{2+}(1mol.dm^{-3}) \parallel Pb^{2+}(aq)\ (1mol.dm^{-3}) \mid Pb(s)$ ✓✓✓ (3)

1.4 $E^{\theta}_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$ ✓ = -0,13 - (- 2, 36) ✓✓ = 2,23 V ✓ (4)

1.5.1 Decreases ✓ (1)

1.5.2 Increases ✓ (1)

1.6 Half-cell A to half-cell B ✓

Pb^{2+} ions are reduced at the cathode in half- cell B ✓

Concentration of positive ions decreases in half-cell B. ✓

To prevent build-up of negative ions in half –cell B, for electrical neutrality, positive ions migrate through the salt bridge toward half-cell B. ✓ (4)

[17]

QUESTION 2

The cell notation of a standard galvanic (voltaic) cell containing an unknown metal electrode **X** is shown below.

$$X(s) \mid X^{3+}(1mol.dm^{-3}) \parallel Pb^{2+}(1mol.dm^{-3}) \mid Pb(s)$$

2.1 Name the component of the cell represented by the double vertical lines (||) in the above cell notation. (1)

2.2 State the two standard conditions that are applicable to the Pb^{2+}| Pb half-cell. (2)

2.3 Identify the oxidizing agent in the above cell. (1)

2.4 The initial reading on a voltmeter connected across the electrodes of the above cell is 1,53 V. Identify metal **X** by calculating the standard reduction potential of the unknown metal **X.** (5)

2.5 Write down the balanced equations for the net (overall) reaction taking place in this cell. Omit the spectator ions. (3)

2.6 How will the initial voltmeter reading be affected if the concentrated if the concentration of the electrolyte in the **X (s) | X^{3+} (aq)** half-cell is increased? Write down only INCREASES, DECREASES or REMAIN THE SAME. (2)

2.7 Write down the value of the reading on the voltmeter when the cell reaction has reached equilibrium. (2)

[16]

SOLUTIONS

2.1 Salt bridge ✓ (1)

2.2 Concentration of the electrolyte 1mol.dm^{-3}✓; Temperature 25^0C / 273K ✓ (1)

2.3 Pb^{2+} ✓ (lead (||) ions) (1)

2.4 $E^{\theta}_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$ ✓

1.53 = (- 0,13) - E^{θ}_{anode} ✓✓

E^{θ}_{anode}= - 1,66 V ✓; therefore the unknown metal X is Al ✓ (5)

2.5 $2Al + 3Pb^{2+} \rightarrow 2Al^{3+} + 3Pb$ ✓✓✓ (3)

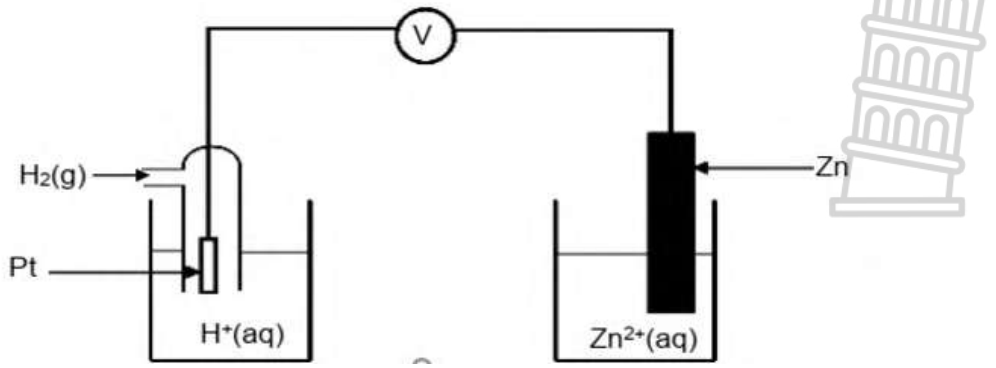
2.6 Decreases ✓ (2)

2.7 0V ✓✓ (2)

[16]

QUESTION 3

The discovery of electrochemical cells has revolutionised our way of life. The diagram represents an electrochemical cell.



3.1 Name the type of electrochemical cell that converts chemical energy to electrical energy. (1)

3.2 If the electrochemical cell is set up as illustrated in the diagram above, there will be no reading on the voltmeter. Give a reason for this observation. (1)

3.3 Write down the value of the standard emf of the electrochemical cell when it is functioning, after fixing the issue in question 3.2. (1)

3.4 Write down the voltmeter reading when the net cell reaction in the above electrochemical cell reaches equilibrium. (1)

3.5 Write down the equation for the reaction that occurs at an anode. (2)

3.6 Another electrochemical cell is set up under standard conditions by replacing the standard hydrogen half-cell with a standard magnesium half-cell.

3.6.1 Which electrode will undergo a decrease in mass? Give a reason for your answer. (2)

3.6.2 Calculate the initial emf of this electrochemical cell at standard conditions. (4)

3.6.3 After a while the emf of this electrochemical cell decreases. Explain this observation by referring to the concentration of the electrolytes. (2)

[14]

SOLUTIONS

3.1 Galvanic / voltaic cell ✓ (1)

3.2 Incomplete circuit / No salt bridge ✓ (1)

3.3 0,76V ✓ (1)

3.4 Zero ✓ (1)

3.5 $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^{-}$ ✓✓ (2)

3.6.1 Mg ✓

Mg is oxidised ✓ (Mg is the reducing agent) (2)

3.6.2 $E^{\theta}_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$ ✓ = -0,76✓ - (-2,36) ✓ = + 1,6 V ✓ (4)

3.6.3 As the cell functions, the concentration of zinc ions decreases ✓ The reverse reaction starts opposing the forward reaction causing the emf to decrease relative to standard conditions. ✓ (2)

[14]

ACTIVITY

QUESTION 1: MULTIPLE-CHOICE

MCQ's

QUESTION 1

1.1 The oxidation number of Chromium (Cr) in Potassium dichromate $K_2Cr_2O_7$ is:

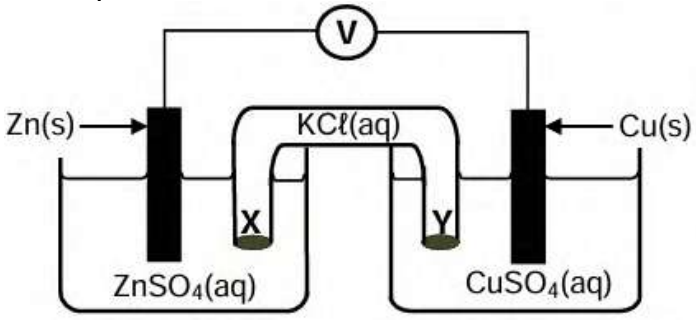
A +2
B +3
C +6
D +9 (2)

1.2 Which one of the following reactions in NOT spontaneous under standard conditions?

A $Pb + Sn^{2+} \rightarrow Pb^{2+} + Sn$

B $Cu + 2Fe^{3+} \rightarrow Cu^{2+} + 2Fe^{2+}$
C $3Sn + 2Fe^{3+} \rightarrow 3Sn^{2+} + 2Fe$
D $Pb + Sn^{4+} \rightarrow Pb^{2+} + Sn^{2+}$ (2)

1.3 The diagram below represents a voltaic cell.



Which ONE of the following correctly describes the movement of ions in the salt bridge?

	TYPE OF IONS	DIRECTION OF MOVEMENT
A	$Cℓ^-(aq)$	Y to X
B	$SO_4^{2-}(aq)$	X to Y
C	$Cu^{2+}(aq)$	Y to X
D	$K^+(aq)$	Y to X

(2)

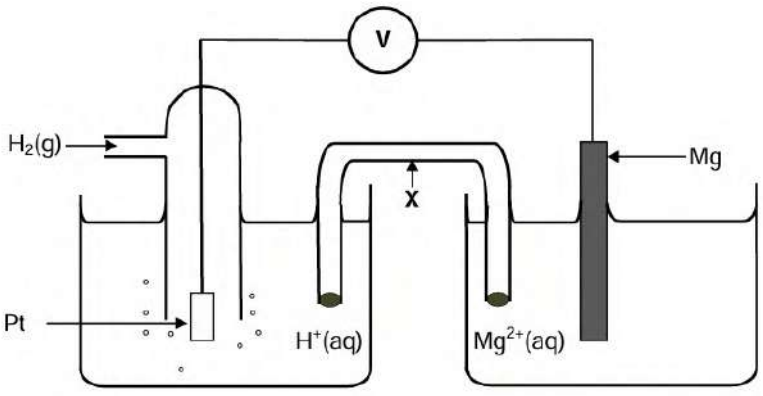
1.4 Which ONE of the following metals will reduce $Cd^{2+}(aq)$ to Cd(s), but will NOT reduce $Mn^{2+}(aq)$ to Mn(s)?
A Zn
B Ag
C Ni
D Mg (2)

1.5 In a galvanic (voltaic) cell, electrons move from the ...
A anode to the cathode through the salt bridge.
B anode to the cathode in the external circuit.
C cathode to the anode through the salt bridge.
D cathode to the anode in the external circuit. (2)

[10]

QUESTION 2

The electrochemical cell represented below consists of a hydrogen half-cell and a magnes cell at standard conditions.



The reading on the voltmeter is 2,36 V

2.1 Apart from concentration, write down TWO other conditions needed for the hydrogen half-cell to function at standard conditions. (2)

2.2 Write down the name of the item of apparatus labelled **X**. (1)

2.3 Is magnesium the ANODE or CATHODE in the cell above?
Refer to the relative strengths of reducing agents to explain the answer. (4)

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

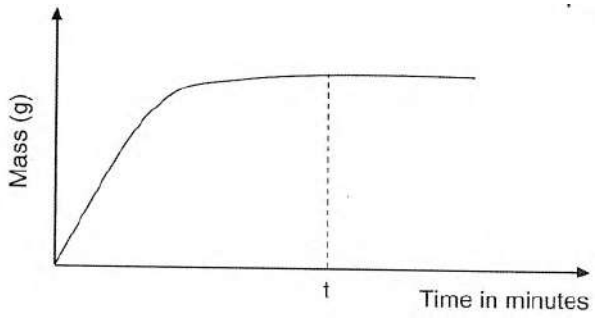
2.5 Calculate the standard reduction potential of the magnesium half-cell. Show ALL your working. (4)

2.6 Write down the balanced NET (overall) cell reaction that takes place in this cell. No spectator ions are required. (3)

[17]

QUESTION 3

A standard galvanic cell is set up using a zinc and an unknown metal, **X**. The graph below shows the change in mass of the metal, **X** whilst the cell is in operation.



3.1 Define the term *electrolyte*. (2)

3.2 Write down the half reaction that takes place at the anode of this cell. (2)

3.3 The initial emf of this cell under standard conditions is 0,63 V.

3.3.1 Write down TWO standard conditions required for the initial emf to be 0,63 V (2)

3.3.2 Identify the metal **X**, by calculating the standard reduction potential of **X**. (5)

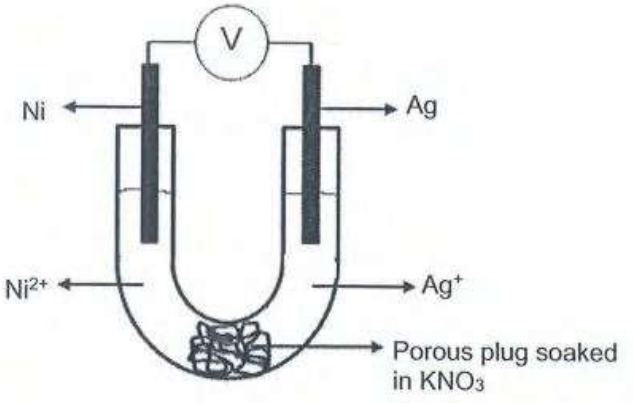
3.4 Write down the cell notation for this cell. (3)

3.5 Write down the value of the emf at time t, shown on the graph. (1)

[15]

QUESTION 4

The diagram below represents a galvanic cell labelled A.



4.1 State TWO standard conditions under which this cell functions. (2)

4.2 Write down TWO functions of the porous plug. (2)

4.3 In which direction (from **Ni to Ag** or from **Ag to Ni**) do electrons flow in the external circuit? (1)

4.4 Write down the balanced equation for the overall (net) reaction for this cell. (3)

4.5 If 0,4 moles of electrons flow to the cathode, what will be the decrease in mass of the anode be? (3)

4.6 A second galvanic cell **B** is constructed using Mg(s) | $Mg(NO_3)_2$(aq) and Ag(s) | $AgNO_3$(aq) half-cells. Without any calculations, determine which ONE of the TWO galvanic cells (A or B) will result in the highest initial potential difference when it is operational under standard conditions.
Explain your answer by referring to the relative strengths of the reducing agent. (4)

[15]

QUESTION 5

A learner has the following reagents to construct an operational GALVANIC CELL under standard conditions: Pb, $Pb(NO)_2$, Ag, $AgNO_3$, and $FeCl_3$.

5.1 Define the term *Electrolyte*. (2)

5.2 Using ONLY the reagents given above, write down the cell notation of the operational galvanic cell. (3)

5.3 Write down the NAME or FORMULA of a substance that can be used in the salt bridge. (2)

5.4 Calculate the EMF of the above cell. (4)

[11]

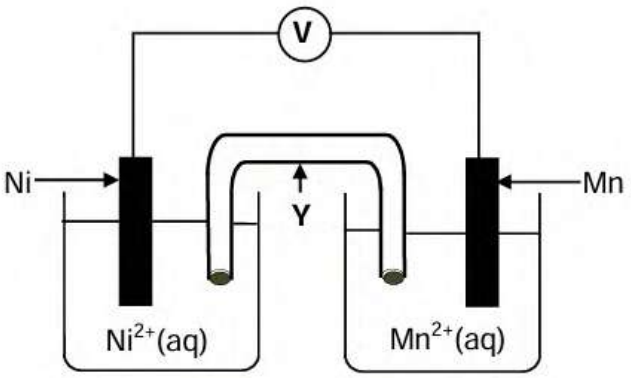
QUESTION 6

6.1 A piece of zinc (Zn) is placed in a test tube containing an acidified permanganate solution, MnO_4^-(aq). After some time, it is found that a redox reaction has taken place. Use the Table of Standard Reduction Potentials to answer the following questions:

6.1.1 Write down the NAME or FORMULA of the reducing agent. (1)

6.1.2 Refer to the relative strengths of the OXIDISING AGENTS to explain why a redox reaction has taken place. (3)

6.2 A standard electrochemical cell is set up as shown below.



6.2.1 Write down TWO functions of component Y. (2)

6.2.2 In which direction will electrons flow in the external circuit? Choose from 'Ni to Mn' OR 'Mn to Ni'. (2)

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

6.2.4 Write down the balanced equation for the net cell reaction taking place. (3)

6.2.5 The concentration of $Ni^{2+}(aq)$ is now increased.
Will the reading on the voltmeter INCREASE, DECREASE or REMAIN THE SAME? (1)

6.2.6 Explain your answer by using Le Chatelier's principle. (3)

[19]

QUESTION 7

The following reaction takes place in a galvanic cell under standard conditions.

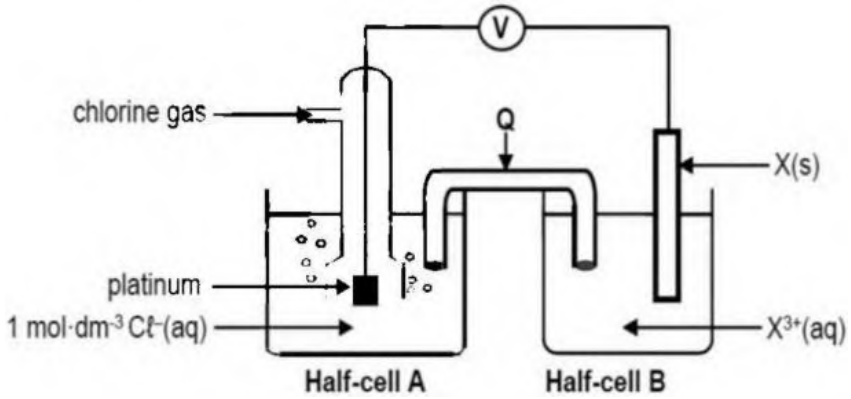
$$Mg(s) + X^{3+}(aq) \rightarrow Mg^{2+}(aq) + X(s)$$

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

7.2 Write down the half-reaction taking place at the ANODE. (2)

7.3 Explain in terms of CHANGES IN OXIDATION NUMBERS why $X^{3+}(aq)$ is the oxidising agent. (1)

The Mg half-cell is replaced with a Chlorine half-cell as shown in the diagram below.
The electrochemical cell below also functions under standard conditions.



7.4 Give a reason why platinum is used as the electrode in half-cell A. (1)

7.5 Besides concentration, state TWO other standard conditions for the above electrochemical cell. (2)

7.6 Write down the cell notation for the above electrochemical cell. (3)

7.7 The initial emf of this cell is 2,10 V. Using a suitable calculation, determine the NAME or FORMULA of metal **X**. (5)

7.8 What will be the effect on the cell potential when a small amount of silver nitrate solution, $AgNO_3(aq)$, is added to half-cell A?
Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

7.9 Explain your answer in 7.8.
(HINT: Silver chloride is an insoluble salt). (3)

[19]

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.

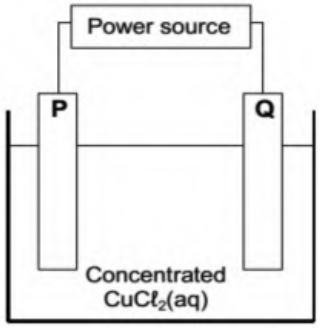
Some of the applications of electrolytic cells include;

- Electrolysis of concentrated solution of Sodium chloride (Brine).
- Decomposition of copper II chloride.
- Electroplating.
- Purification (Electro-refining) of copper.

WORKED EXAMPLES

QUESTION 1

The simplified diagram below represents an electrochemical cell used to refine copper.
One of the electrodes consists of impure copper.



1.1 What type of power source, AC or DC, is used to drive the reaction in this cell? (1)

1.2 When an electric current passes through the $CuCl_2$ (aq), the mass of electrode **P** increases. Is electrode P the **cathode** or the **anode**?
Write down the relevant half-reaction to support your answer. (3)

1.3 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)

1.4 Electrodes P and Q are now replaced by carbon electrodes.
1.4.1 What will be observed at electrode Q? (2)

1.4.2 How will the concentration of the electrolyte change as the reaction proceeds?
Choose from INCREASES, DECREASES or REMAINS THE SAME.

(2)
[11]

SOLUTIONS

1.1 DC ✓ (1)

1.2 Cathode ✓
$Cu^{2+}(aq) + 2e^- \rightarrow Cu$ ✓✓ (3)

1.3 Cu^{2+} is a stronger oxidising agent ✓ than Zn^{2+} ions ✓; therefore Zn^{2+} ions will not be reduced (to Zn). ✓ (3)

1.4.1 (Chlorine) gas/ bubbles is/ are formed. ✓✓ (2)

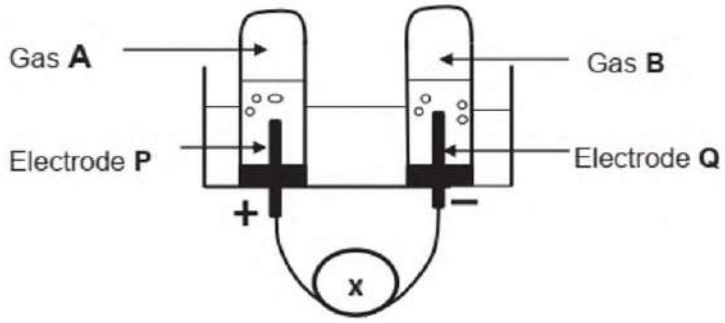
1.4.2 Decreases ✓✓ (2)

[11]

QUESTION 2

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:

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



2.1 Write down the:

2.1.1 NAME of component X (1)

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

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

2.1.4 FORMULA of the reducing agent (1)

2.2 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?

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

Explain the answer. (2)

2.3 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]

SOLUTIONS

2.1.1 Battery ✓ or Power source (1)

2.1.2 Chlorine ✓ (1)

2.1.3 $2H_2O\ (l) + 2e^- \rightarrow H_2(g) + 2OH^-\ (aq)$ ✓✓ (2)

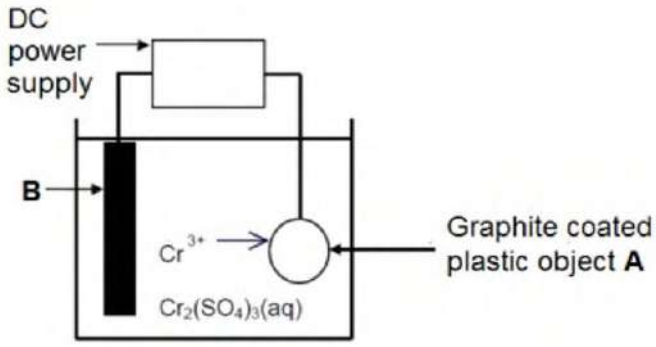
2.1.4 Cl^- ✓ (or NaCl) (1)

2.2 $[H_3O^+] > 1x10^{-7}$ ✓
Solution is alkaline ✓ (2)

2.3 Cu^{2+} is a stronger oxidizing agent ✓than Na^+ and will be reduced✓ to Cu ✓ (3)
[10]

QUESTION 3

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.



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

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

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

3.4 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)

SOLUTIONS

3.1 Oxidation is a loss of electrons ✓✓ (2)

3.2 A ✓ Cr^{3+} ions moves Towards A ✓
Or Reduction is taking place
Or Oxidation is taking place at B, B is positive, so A must be negative. (2)

3.3 $Cr^{3+}\ (aq) + 3e^- \rightarrow Cr(s)$ ✓✓ (2)

3.4 Cr is a stronger reducing agent than Ag (Silver) ✓✓
Or Ag^+ is a stronger oxidizing agent. (2)
[8]

ACTIVITY

QUESTION 1: MULTIPLE-CHOICE

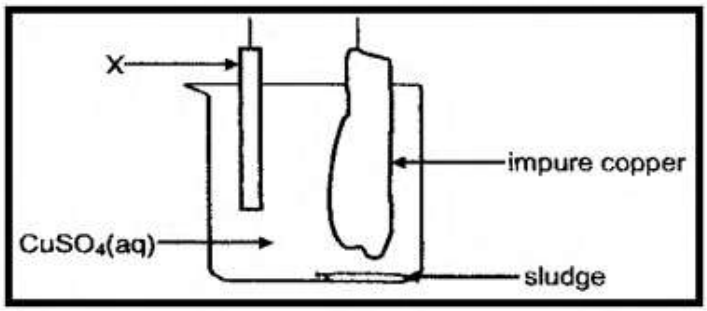
1.1 Consider the following balanced equation of a chemical reaction:

$$2NaC\ell\,(aq) + 2H_2O\,(l) \rightarrow C\ell_2\,(g) + H_2\,(g) + 2NaOH\,(aq)$$

Which ONE of the following statements about the reaction is correct?

A galvanic cell and absorbs energy.
B galvanic cell and releases energy.
C electrolytic cell and absorbs energy.
D electrolytic cell and releases energy. (2)

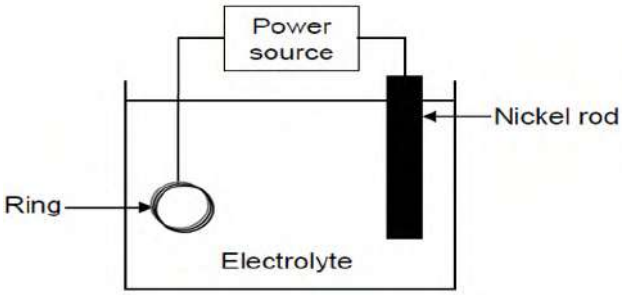
1.2 The diagram below represents a part of an electrochemical cell used for refining copper. The impure copper contains silver metal and zinc metal.



Which ONE of the following half-reactions will take place at electrode X?

A $Ag^+ + e^- \rightarrow Ag$
B $Cu \rightarrow Cu^{2+} + 2e^-$
C $Cu^{2+} + 2e^- \rightarrow Cu$
D $Zn^{2+} + 2e^- \rightarrow Zn$ (2)

1.3 A group of grade 12 learners want to electroplate a copper ring with nickel. They use the experimental set-up shown in the simplified diagram below.



Which ONE of the following is CORRECT?

	ANODE	CATHODE	ELECTROLYTE
A	Copper ring	Nickel rod	$CuSO_4$
B	Nickel ring	Copper ring	$CuSO_4$
C	Copper ring	Nickel rod	$NiSO_4$
D	Nickel rod	Copper ring	$NiSO_4$

(2)

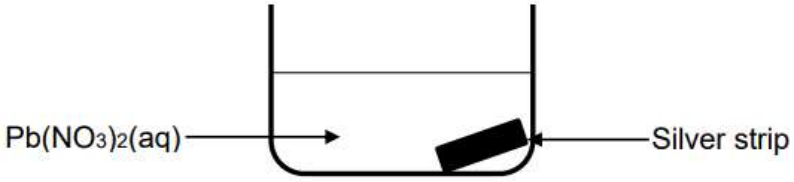
1.4 Which ONE of the following statements regarding an electrolytic cell is CORRECT?

A An electric current causes a chemical change to occur.
B Reduction occurs at the anode.
C A spontaneous chemical reaction produces an electric current.
D Electrons flow to the electrode where oxidation occurs. (2)

[8]

QUESTION 2

2.1 A strip of silver is added to a 1 mol·dm^{-3} solution of $Pb(NO_3)_2$ at 25 °C.



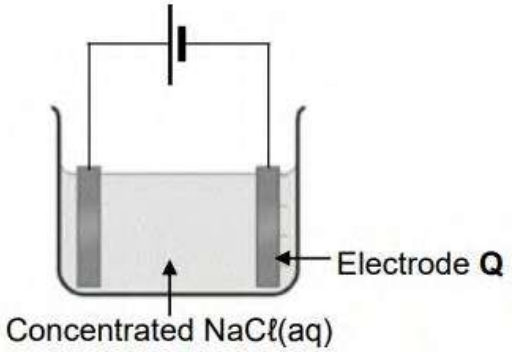
Consider the reaction below.

$$2Ag(s) + Pb^{2+}(aq) \rightarrow 2Ag^{+}(s) + Pb(s)$$

2.1.1 Define the term Electrolyte. (2)

2.1.2 By means of a calculation, determine whether this reaction is SPONTANEOUS or NON-SPONTANEOUS. (5)

2.2 The simplified diagram below represents an electrolytic cell. The electrodes are made of carbon.



2.2.1 Write down the PREDOMINANT oxidation half-reaction that takes place in this cell. (2)

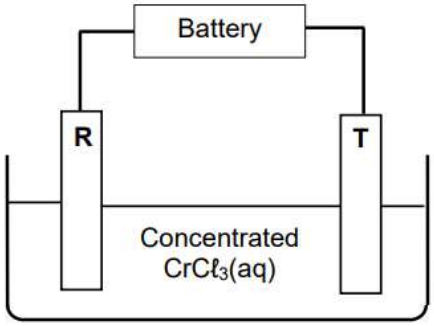
2.2.2 Write down the NAMES or FORMULAE of the products formed at electrode **Q**. (2)

2.2.3 Explain the answer to QUESTION 2.2.2 by referring to the relative strengths of the oxidising agents involved. (2)

[13]

QUESTION 3

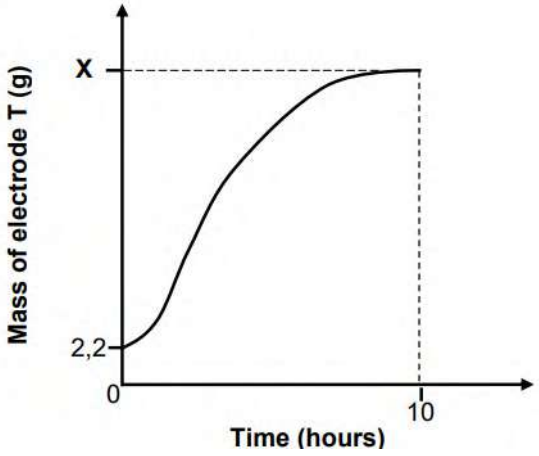
The diagram below represents a simplified cell used for the electrolysis of CONCENTRATED chromium (III) chloride, $CrCℓ_3(aq)$. Electrodes R and T are made of carbon.



The net cell reaction is: $2CrC\ell_3(aq) \rightarrow 2Cr(s) + 3C\ell_2(g)$

3.1 Define the term electrolysis. (2)

3.2 The graph below, NOT drawn to scale, represents the changes in the mass of electrode T during electrolysis.



3.2.1 Write down the half-reaction that takes place at electrode T. (2)

A current of 2,5 A passes through the cell for 10 hours.

Calculate the:

3.2.2 Total charge that flows through the cell during this time (3)

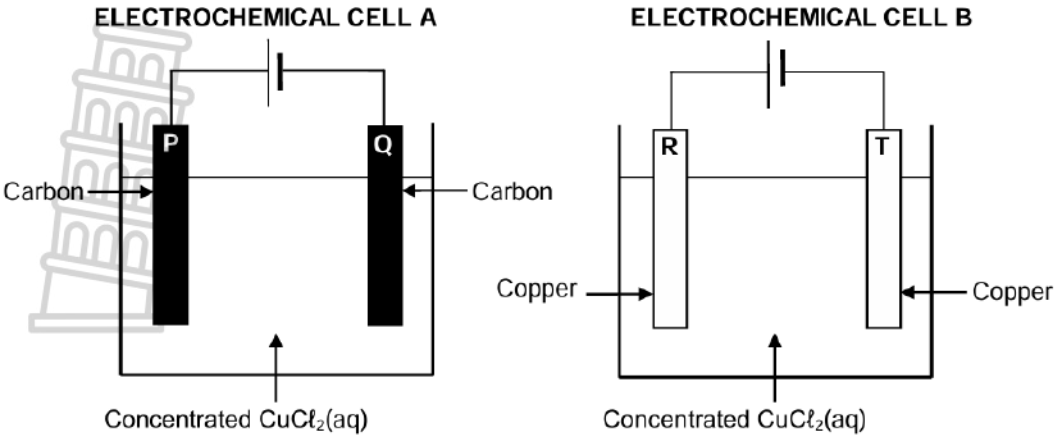
3.2.3 Value of X as shown on the graph (6)

[13]

QUESTION 4

The simplified diagrams below represent two electrochemical cells, A and B.

A concentrated copper (II) chloride solution is used as an electrolyte in both cells.



4.1 Are A and B ELECTROLYTIC or GALVANIC cells? (1)

4.2 Which of the electrodes (P, Q, R or T) will show a mass increase? Write down a half reaction to motivate the answer. (4)

4.3 Write down the NAME or FORMULA of the product formed at:

4.3.1 Electrode **P** (1)

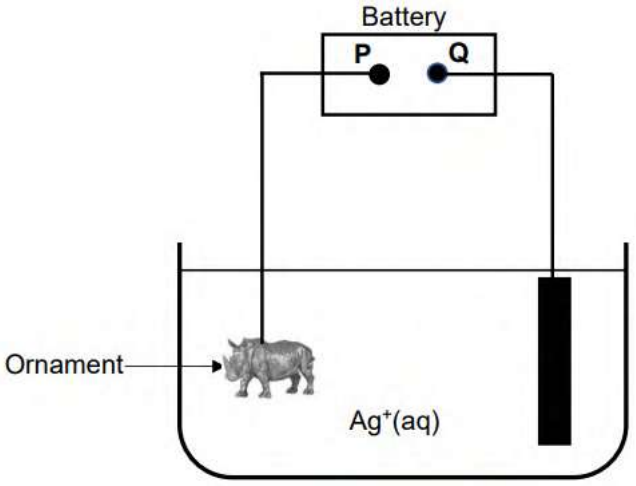
4.3.2 Electrode **R** (1)

4.4 Fully explain the answer to QUESTION 4.3.2 by referring to the relative strengths of the reducing agents involved. (3)

[10]

QUESTION 5

The simplified diagram below represents the cell used for electroplating ornaments with silver, Ag. P and Q are the two terminals of the battery.



5.1 State the energy conversion that takes place in this cell. (1)

5.2 Which terminal of the battery (P or Q) is negative? (1)

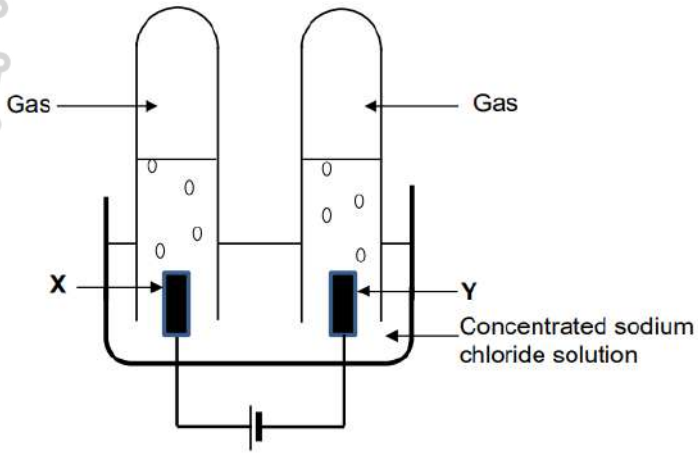
5.3 Write down the equation for the half-cell reaction that takes place at the cathode. (2)

5.4 Calculate the current needed to electroplate the ornament with 3,25 g of silver in 30 minutes. (5)

QUESTION 6

The simplified diagram below represents an electrolytic cell used to demonstrate the electrolysis of a concentrated sodium chloride solution, NaCℓ(aq).

X and **Y** are carbon electrodes.



6.1 Define the term *electrolysis*. (2)

6.2 Write down the reduction half-reaction for this cell. (2)

6.3 What is the direction of the electron flow in the external circuit? Choose from **X to Y** or **Y to X**. (1)

6.4 Calculate the number of electrons transferred through the external circuit when 300 cm^3 of gas is collected at electrode **X**.
Take the molar gas volume as 24 $dm^3 \cdot mol^{-1}$. (4)

[9]

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)
- 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 $\Sigma E_{ki} = \Sigma E_{kf}$ (Total kinetic Energy before = total kinetic Energy after).
- If the collision is Inelastic $\therefore \Sigma E_{ki} \neq \Sigma E_{kf}$ (Total kinetic Energy before ≠ Total kinetic Energy after).

$\Sigma E_{ki} = \frac{1}{2}m_Av_i^2 + \frac{1}{2}m_Bv_i^2$
(total kinetic energy before)
S.I unit: Joule(J)

$\Sigma E_{kf} = \frac{1}{2}m_Av_f^2 + \frac{1}{2}m_Bv_f^2$
(total kinetic energy after)
S.I unit :Joule(J)

WORKED EXAMPLES

1. A cricket ball of mass 500g is bowled towards a batsman at a speed of 40m.s^{-1}. The batsman misses the ball and the wicket keeper catches the ball.
   1.1 Calculate the average force exerted by the wicket keeper on the ball, if he stops the ball in 0,8s. (4)
   1.2 Use the equation $F_{net} = \frac{\Delta p}{\Delta t}$ to explain why the wicket keeper should pull his hands back when catching a fast-moving ball. (3)
2. A wooden trolley of mass 2,7 kg moves to the left with a constant velocity of 3 m·s^{-1}. A bullet of mass 0,03 kg is fired horizontally from the left towards the trolley. (See DIAGRAM 1.)
   The bullet strikes the trolley and comes to rest inside the trolley in 0,02 s. The average net force exerted by the trolley on the bullet during this time is 591 N. The bullet-trolley combination now moves to the right. (See DIAGRAM 2.)

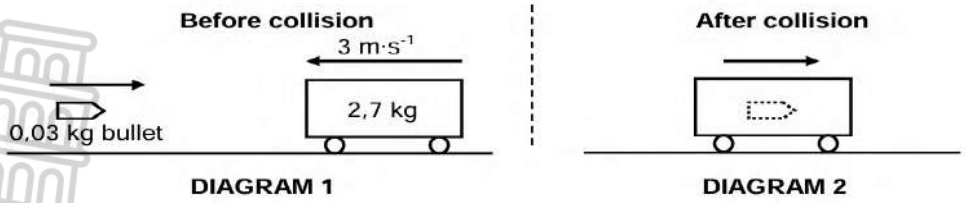


DIAGRAM 1 DIAGRAM 2

Ignore all frictional and rotational effects.

2.1 Write down the magnitude and direction of the average net force that the bullet exerts on the trolley. (1)

2.2 Calculate the magnitude of the velocity with which the bullet strikes the trolley. (4)

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

2.4 Calculate the magnitude of the velocity of the bullet-trolley combination after the collision. (4)

[11]

SOLUTIONS

1.1 $F_{net} . \Delta t = \Delta p$ ✓

$F_{net}(0,8)$✓$= 0,5(0 - 40)$ ✓

$F_{net} = -25$ N

$F_{net} = 25$ N ✓ (4)

1.2 As the wicket keeper pulls his hand back, the contact time increases✓, the net force decreases✓ and the change in momentum decreases.✓ (3)

2.1 591 N to the right/original direction of bullet/Accept East ✓ (1)

2.2 $F_{net} \Delta t = \Delta p$

$= m(v_f - v_i)$

$(591)(0,02) = 2,7[v_f - (-3)]$

$v_f = 1,38 \text{ m·s}^{-1}$

$\Sigma p_i = \Sigma p_f$ ✓

$m_b v_{bi} + m_t v_{ti} = (m_b + m_t)v_f$

$(0,03)v_{bi} + (2,7)(-3)$✓$= (0,03+2,7)(1,38)$✓

$(0,03)v_{bi} = 11,86$

$v_i = 395,58 \text{ m·s}^{-1}$✓ (4)

2.3 The total (linear) momentum in an isolated system is conserved/remains constant.✓✓ (2)

2.4 RIGHT AS POSITIVE

$\sum p_i = \sum p_f$✓

$m_x v_{ix} + m_y v_{iy} = m_x vf_x + m_y v_{fy}$

$(0,03)(395,58) + (2,7)(-3)$✓ $= v_f(0,03 + 2,7)$✓

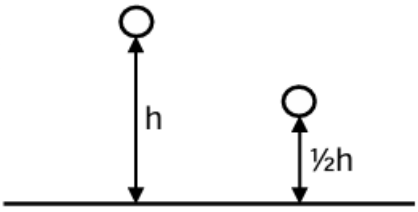
$v_f = 1,38 \text{ m·s}^{-1}$ ✓ (4)

[11]

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 A ball is dropped from height h and strikes the floor with momentum p. The ball is then dropped from height ½h.



Ignore the effects of air friction.
Which ONE of the following represents the momentum of the ball when it strikes the floor after being dropped from height ½h?

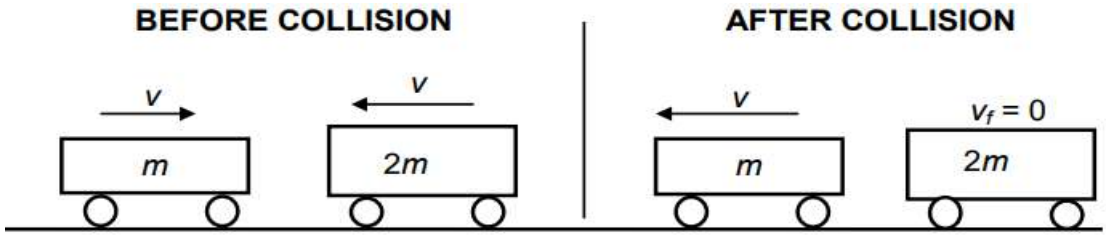
A p

B $\frac{1}{\sqrt{2}}$p

C $\frac{1}{2}$p

D 2p (2)

1.2 An object of mass *m* moving at velocity *v* collides head-on with an object of mass *2m* moving in the opposite direction at velocity *v*. Immediately after the collision the smaller mass moves at velocity *v* in the opposite direction and the larger mass is brought to rest. Refer to the diagram below.



Ignore the effects of friction. Which ONE of the following is CORRECT?

	Momentum	Kinetic energy
A	Conserved	Conserved
B	Not conserved	Conserved
C	Conserved	Not conserved
D	Not conserved	Not conserved

(2)

1.3 If the momentum of an object is doubled, then its kinetic energy is…

A Halved.

B Doubled.

C Three times greater.

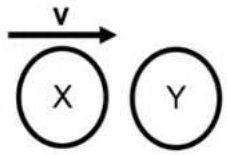
D Four time greater. (2)

1.4 A person drops a glass bottle onto a concrete floor from a certain height and the bottle breaks. The person then drops a second, identical glass bottle from the same height onto a thick, woollen carpet, but the bottle does not break.
Which ONE of the following is CORRECT for the second bottle compared to the first bottle for the same momentum change?

	AVERAGE FORCE ON SECOND BOTTLE	TIME OF CONTACT WITH CARPET
A	Larger	Smaller
B	Smaller	Smaller
C	Larger	Larger
D	Smaller	Larger

(2)

1.5 A ball X, travelling to the right at a speed v, collides with a stationary ball Y of equal mass. The collision is perfectly elastic,



Which statement correctly describes the motion of the ball X and ball Y immediately after the collision?

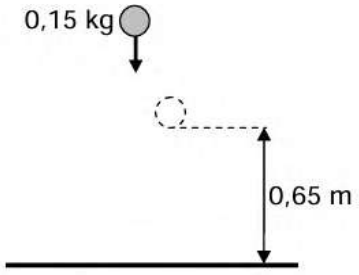
A X comes to rest and Y travels at speed v.
B X and Y both travel in the same direction at speed 1v ,
C X moves to the left at speed v and Y remains stationary.
D X moves to the left at speed $\frac{1}{2}$v and Y moves to the right at speed $\frac{1}{2}$v (2)

[10]

STRUCTURED QUESTIONS
QUESTION 2

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 $m \cdot s^{-1}$. The ball bounces straight upwards at a velocity of 3,62 $m \cdot s^{-1}$ to a height of 0,65 m, as shown in the diagram below. The effects of air friction may be ignored.



2.1 Define the term *impulse* in words. (2)

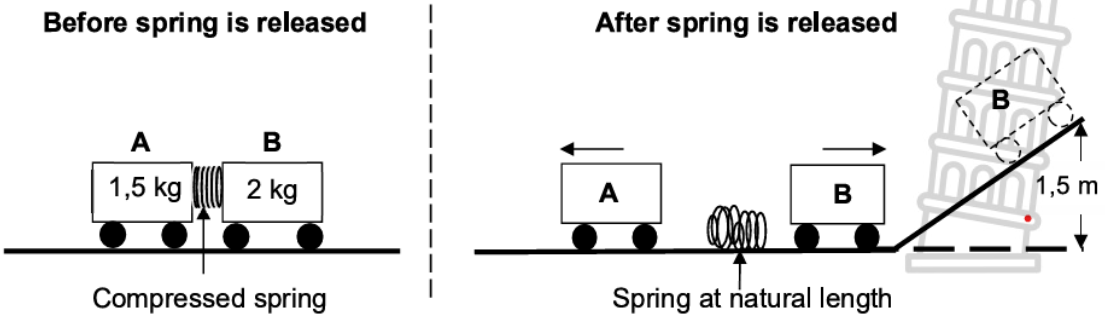
2.2 Calculate the magnitude of the impulse of the net force applied to the ball during its collision with the floor. (3)

2.3 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]

QUESTION 3

Two trolleys A and B of masses 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 fall 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 height of 1,5 m as shown in the diagram below



Ignore the rotational effects of the wheel

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)

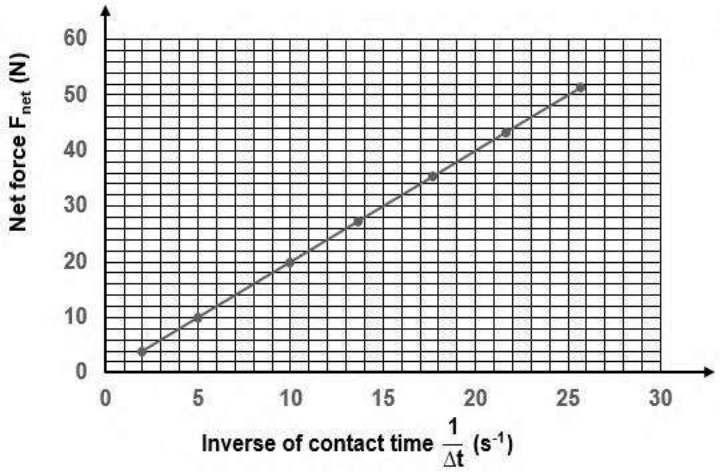
3.3 For t seconds that the spring takes to return to its natural length;

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]

QUESTION 4

The learners investigate the relationship between the net average force exerted on a tennis ball during a bounce and the inverse of the contact time. A tennis ball of mass 0,06 kg is dropped from rest from a height of 6 m above the floor. The learners record the contact times and plots a graph of the net force versus the inverse of contact time, as shown in the graph below.

Ignore the effects of air friction.

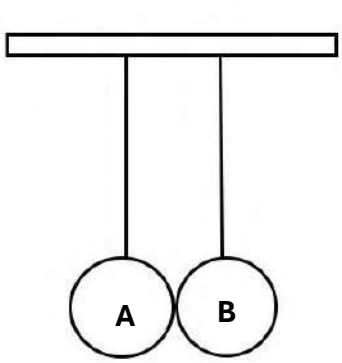


4.1 Define the term *impulse*. (2)
4.2 Calculate the impulse of the tennis ball. The tennis ball strikes the floor at a velocity of 10,84 $m \cdot s^{-1}$ and it remains in contact with the floor for 0,1 s. (3)
4.3 Calculate the bouncing velocity of the tennis ball. A rubber mat is placed on the floor, and the same tennis ball is dropped from the same height. (3)
4.4 How will the net force on the tennis ball by the floor be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)
4.5 Explain the answer to QUESTION 4.4. (2)
[11]

QUESTION 5

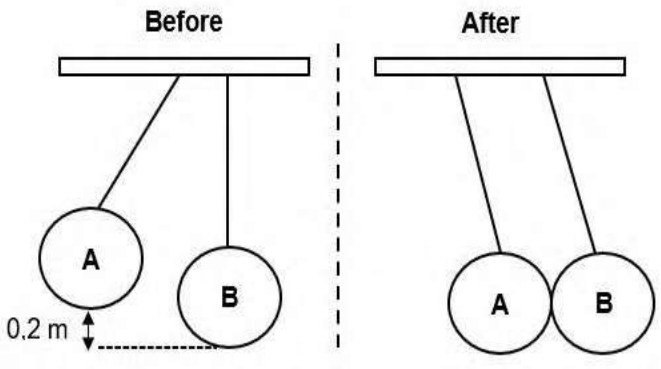
Two small plastic balls, **A** and **B**, at rest, are suspended vertically from the ceiling by identical light inextensible strings.

Ball **A** has a mass of 0,4 kg and ball **B** has a mass of 0,6 kg.



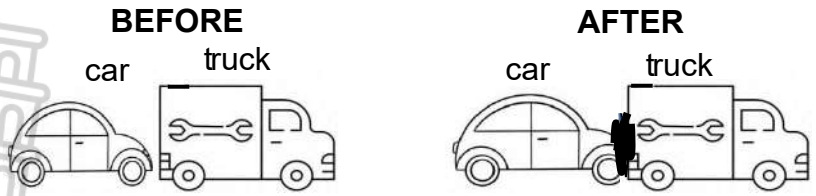
Ball **A** is pulled horizontally to the left, so that its centre of mass is raised 0,2 m above its original equilibrium position. It is then released from rest. Ball **A** swings downwards and collides with ball **B**, which was initially at rest. The two balls swing together after collision.

Ignore the effects of air resistance and assume no energy is lost during collision.



5.1	State the principle of conservation of linear momentum in words.	(2)
5.2	Calculate the velocity of ball **A** just before it collides with ball **B**.	(4)
5.3	Calculate the velocity of ball **B** immediately after the collision.	(4)
5.4	Is the collision between ball **A** and ball **B** ELASTIC of INELASTIC?	(1)
		[11]

QUESTION 6	
A car of mass 1 200 kg moving at a speed of 25 $m \cdot s^{-1}$ in the eastern direction, crashes into the back of a truck of mass 6 000 kg moving in the same direction at 15 $m \cdot s^{-1}$. The velocity of the car after the collision is 16 $m \cdot s^{-1}$ to the east. Ignore all frictional and rotational effects.	

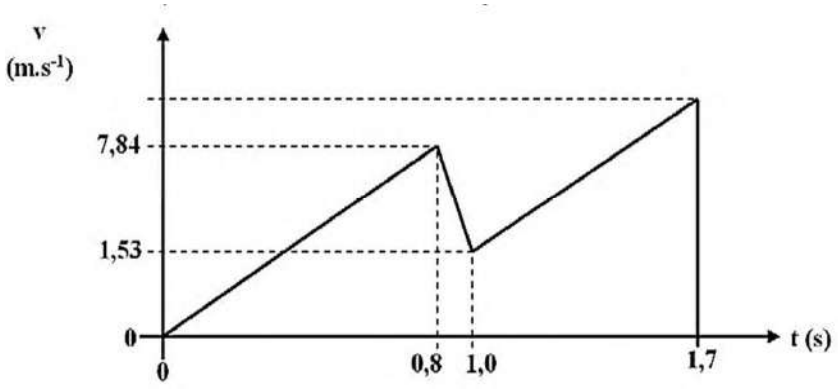


6.1 Write the *principle of conservation of linear momentum* in words. (2)
6.2 Calculate the velocity of the truck after the collision. (4)
6.3 Calculate the mechanical energy lost during the car-truck collision. (5)
6.4 Explain why mechanical energy is lost. (2)
[13]

QUESTION 7

A learner is testing the strength of a piece of glass by dropping a steel ball of mass 5 kg from a height of 3 m onto the glass.

The velocity-time graph below represents the motion of the steel ball from the moment the learner drops the ball until it reaches the ground.

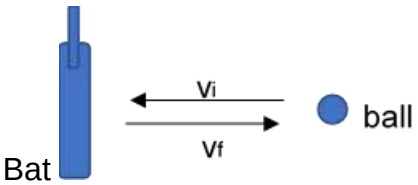


7.1 Define the term *momentum.* (2)
7.2 Calculate the net force exerted by the glass on the steel ball. (4)
7.3 Is this an ELASTIC or INELASTIC collision? Refer to the data in the graph and the relevant principles to explain the answer. (4)
7.4 The glass does not break when the learner drops a soft rubber ball of similar mass from the same height onto the glass. Use Physics principles to explain this phenomenon. (3)
[13]

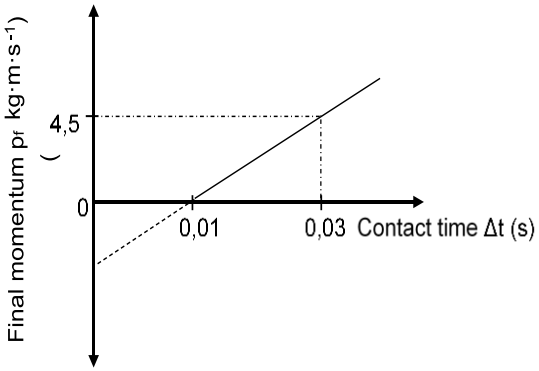
QUESTION 8

Cricketers at an academy conduct an experiment to determine the relationship between the contact time and the final momentum of a ball for a constant average net force.

A cricket ball of mass 150 g is thrown horizontally with a certain initial velocity and is struck by a bat so that the ball moves in the opposite direction, as shown in the diagram below. The average net force acting on the ball is horizontal.



The experiment is repeated using the same ball. The average net force and the initial velocity of the ball are kept constant. The contact time between the bat and the ball is changed EACH time. The results obtained are shown in the sketch graph below.



8.1 Define the term *impulse*. (2)

8.2 Calculate the:

8.2.1 Average net force acting on the ball (3)

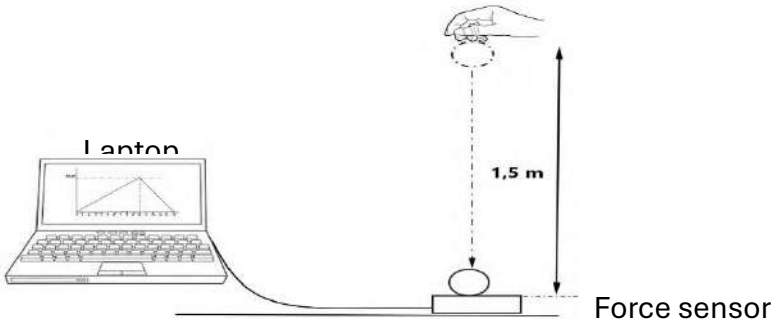
8.2.2 Magnitude of the initial velocity of the ball (4)

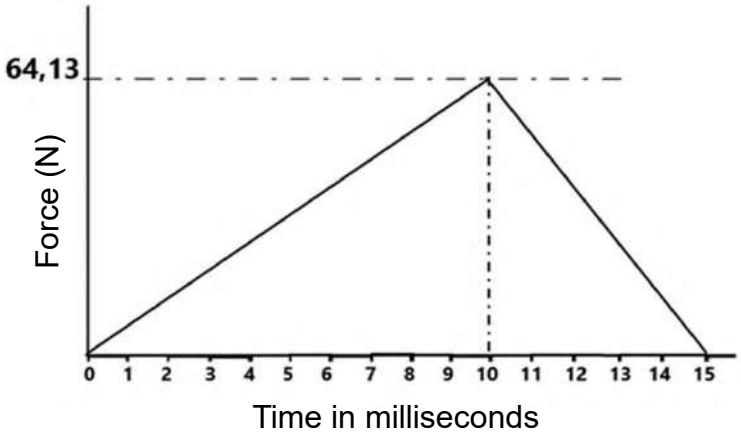
8.3 Redraw the graph in the ANSWER BOOK and label it as A. On the same set of axes, draw the graph that will be obtained when a ball with a bigger mass is used, without changing the initial velocity and average net force. Label this as B. (2)

[11]

QUESTION 9

When a ball hits and bounces off a surface, it exerts a force on that surface. Grade 12 learners investigated how this force varies over time as the ball hits a force sensor and bounces off. A 50 g soft ball was dropped from a height of 1,5 m vertically above a force sensor connected to a laptop as shown on the diagram.





9.1 Define the term *impulse*. (2)

9.2 Use the information on the graph to determine the magnitude of the impulse as (2)

9.3 State the magnitude and the direction of the change in the momentum of the ball. (2)

9.4 If the velocity of the ball just before it hits the force sensor is 5,42 $m \cdot s^{-1}$ (4)

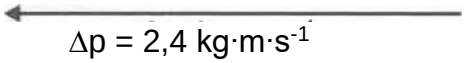
9.5 The ball is now replaced with a hard ball of the same size and mass. Will the force on the force sensor INCREASE, DECREASE OR REMAIN THE SAME? Explain the answer. (3)

[13]

QUESTION 10

Ball **A** and ball **B** move towards each other along a horizontal surface. Ball **B** has a mass of 0,3 kg and an initial speed of 15 $m \cdot s^{-1}$. The balls collide. The vector shown below represents the change in momentum of ball **A**.

Ignore the effects of friction.



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

10.2 What was the initial direction of ball **A**? Choose from LEFT or RIGHT. (2)

10.3 Calculate the velocity of ball **B** after the collision. (5)

[9]

QUESTION 11

A girl with a mass of 53 kg, and a boy, with a mass of 68 kg, are participating in a figure skating contest. The boy is skating forward at a velocity of 7 $m \cdot s^{-1}$ and the girl is skating in the opposite direction at a velocity of 5 $m \cdot s^{-1}$, right before he picks her up, and they skate forward together.

Ignore the effects of friction and the rotational effects of the skates.

11.1 State the *Principle of Conservation of Linear Momentum*. (2)

11.2 Calculate the combined velocity of the boy and the girl as he picks her up, and they skate forward together. (5)

11.3 When the boy puts the girl down, and she lands on the ice, she bends her knees.

11.3.1 Because of this action, the force that she experiences when she lands will…

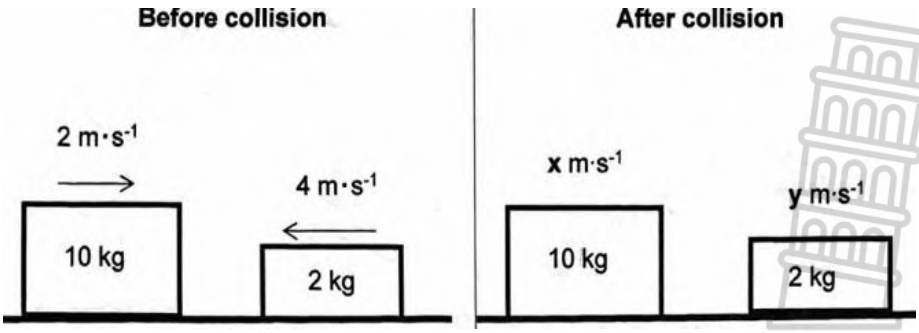
Choose from INCREASE, DECREASE or STAYS THE SAME. (1)

11.3.2 Explain your answer to QUESTION 11.3.1. (2)

[10]

QUESTION 12

A 10 kg block travelling at 2 $m \cdot s^{-1}$ to the right collides with a 2 kg block travelling at 4$m \cdot s^{-1}$ to the left as shown in diagram below. The collision is ELASTIC. After the collision the 10 kg block has a velocity X $m \cdot s^{-1}$ and the 2 kg block has a velocity of Y $m \cdot s^{-1}$. Ignore the effects of friction. Type equation here.



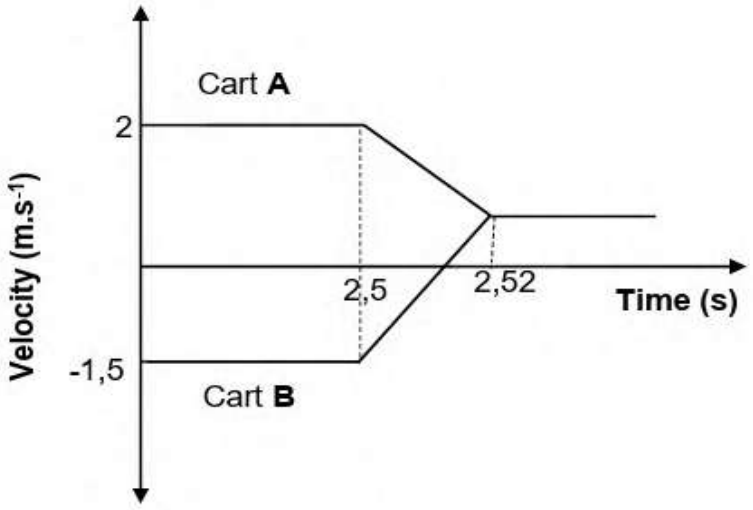
12.1 Explain what is meant by elastic collision? (2)

12.2 Determine the velocity of each block after collision. (7)

[9]

QUESTION 13

The graph below represents the motion of two toy carts, A and B, of mass 1 kg and 2 kg, respectively. Cart A is traveling eastwards.



13.1 Define the term *linear momentum* in words. (2)

13.2 Write down the initial speed of each cart. (2)

13.3 Calculate the:

13.3.1 Velocity of the carts after the collision (4)

13.3.2 Net force that the carts A exert on cart B (4)

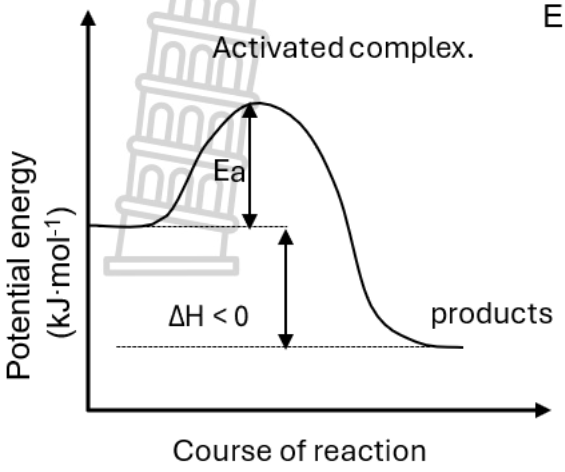
13.4 What is the acceleration of the carts after the collision? (1)

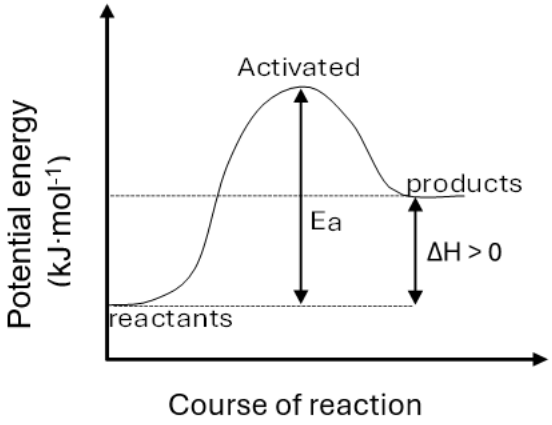
13.5 Use a relevant calculation to determine whether the collision is ELASTIC or (5)

[18]

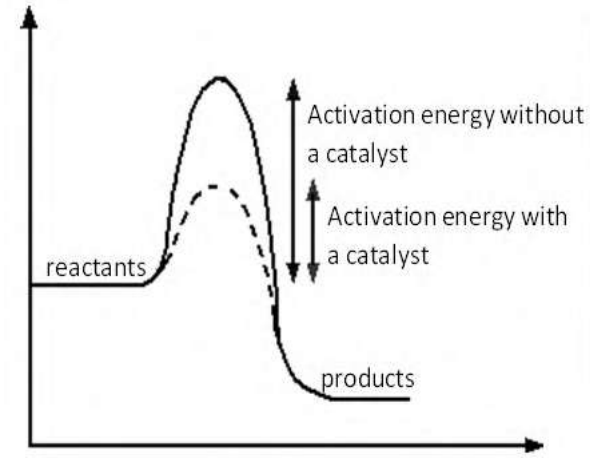
REACTION RATES AND ENERGY IN CHEMICAL REACTIONS

ENERGY PROFILES





Effect of catalyst



Catalyst

Increases reaction rate without undergoing a permanent change.

Mechanism of catalyst: Increase reaction rate by loweringthe total activation energy

REACTION RATE: Is Change in concentration of reactants or products per unit time.

FACTORS AFFECTING REACTION RATES

1. The nature of reactants – type of atoms and molecules
2. Concentration – higher concentration, faster rate
3. Surface Area – greater surface area, faster rate
4. Temperature – higher temperature, faster rate
5. Catalyst – increases reaction rate without undergoing a permanent change.

PRACTICAL SKILLS

Independent variable: The variable that is changed/manipulated during an investigation e.g. an increase in temperature. (It is the input.)

Dependent variable: The variable that changes due to a change in the independent variable e.g., reaction rate changes due to a change in temperature. (It is the output.)

Controlled variable: The variable(s) that is / are kept constant e.g. concentration and surface areaare kept constant to measure the effect of temperature on reaction rate.

Investigative question: A question about the relationship between the dependent and independent variables. Must have both the independent and dependent variable and is a question about the relationship between them. Example: What is the relationship between temperature and reaction rate?

Hypothesis: A prediction on the answer to the investigative question prior to the investigation must have both the independent and dependent variable and predict the relationship between them. Example: When temperature increases, reaction rate will decrease. OR When temperature increases, reaction rate will increase.

Conclusion: The conclusion is drawn after the investigation and answers the investigative question. Must have both the independent and dependent variable and state the relationship between them. Example: When temperature increases, the reaction rate increases.

Calculating the rate

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

Unit of reaction rate: Any unit of the above quantities per second

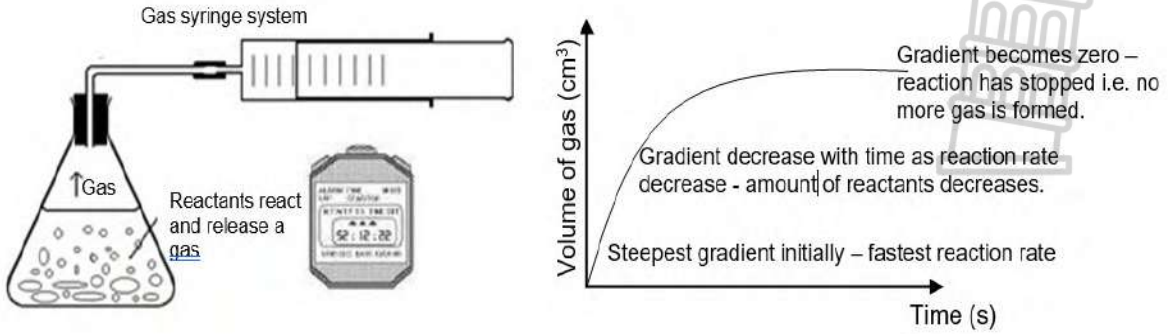
Examples: $mol \cdot dm^{-3} \cdot s^{-1}$ OR $g \cdot s^{-1}$ OR $dm^{-3} \cdot s^{-1}$ OR $mol \cdot s^{-1}$

MEASURING REACTION RATE

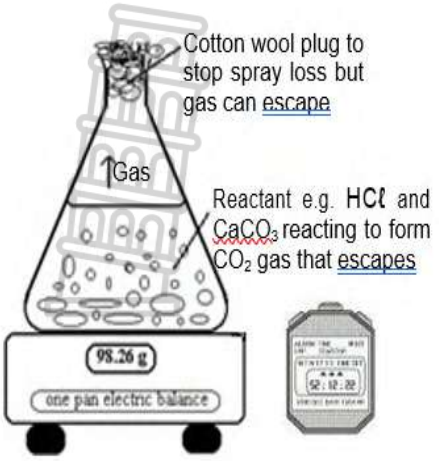
If we do an experiment to establish the speed (rate) of a reaction under different conditions, we can measure how fast the reaction is proceeding in several different ways:

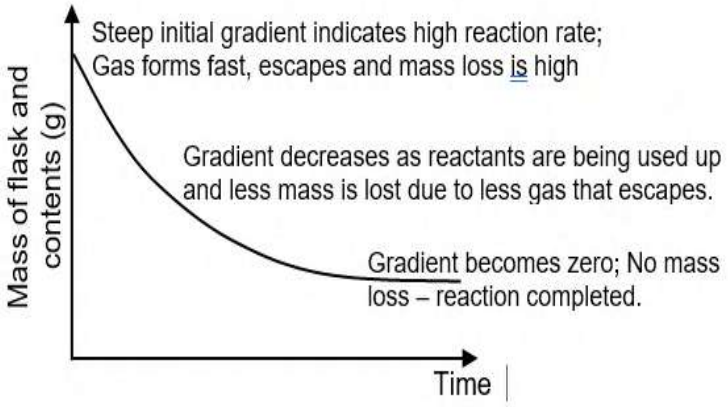
- gas volume produced.
- volume of solid formed
- mass changes
- how reactants disappear or products appear
- colour changes (colour cards or spectrophotometers)
- concentration of ions (conductivity)

MEASURING VOLUME OF GAS RELEASED PER TIME



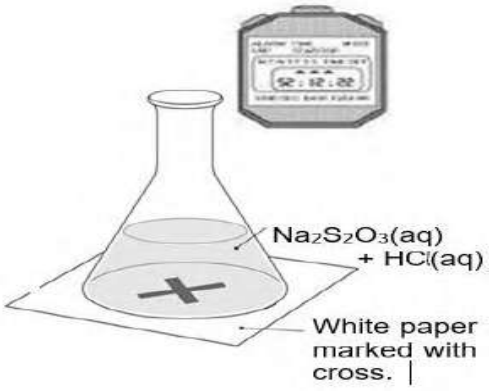
MEASURING LOSS IN MASS OF REACTANTS PER TIME

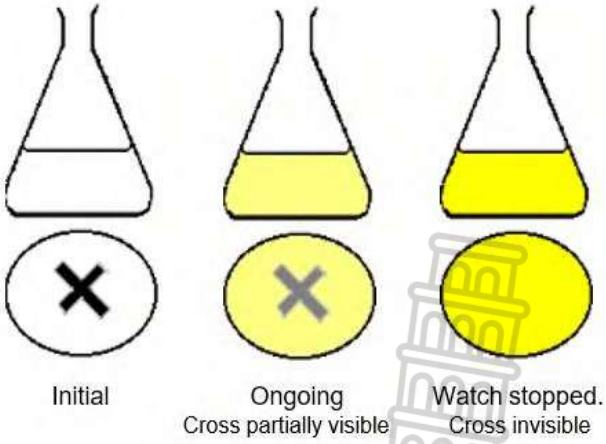




MEASURING THE TIME FOR THE FORMATION ON AN AMOUNT OF PRECIPITATE

- When sodium thiosulphate ($Na_2S_2O_3$) reacts with HCℓ, a yellow precipitate ofSulphur is formed.
- The time how long it takes a certain amount of Sulphur to form, is measured.
- The reaction is observed from the top through a conical flask, viewing ablack cross (X) on white paper.
- The X is eventually obscured by the Sulphur precipitate and the time noted.
- The reaction can be repeated at:
    - **Different temperatures** (same concentration of $Na_2S_2O_3$ and HCℓ), to measure the effect of temperature on rate
    - **Different concentrations** of $Na_2S_2O_3$ at the same temperature tomeasure the effect of concentration on reaction rate.





For the cross to become invisible, the same amount of precipitate (Sulphur) is formed in each experiment and therefore the mass of S Formed is the same and represented by 1

Reaction rate is calculated as $\frac{1}{time}$

THE COLLISION THEORY

The collision theory explains the factors influencing reaction rate.

The collision theory states that for a chemical reaction to occur, the reacting particles must collide

with one another. The rate of the reaction depends on the frequency of collisions i.e. the number of collisions per unit time. The theory also tells us that reacting particles often collide without reacting.

For collisions to be successful or effective, reacting particles must:

- Collide with sufficient kinetic energy
- Have the correct orientation

FACTORS THAT AFFECT THE RATE OF REACTION

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 because:

- An increase in temperature increases the average kinetic energy of the particles.
- More particles with enough kinetic energy
- More effective collisions per unit time (correct orientation).
- The reaction rate increases.

Concentration

Concentration is the number moles of solute per unit volume of solvent

When the concentration of a substance is increased, the rate of reaction also increases. When the concentration of a substance is decreased, the rate of reaction also decreases. This is because:

- 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. (correct orientation).
- 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 because:

- 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 because:

- 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. E.g. Simple and complex molecules, strong and weak acids, pure and impure substances.

Catalyst

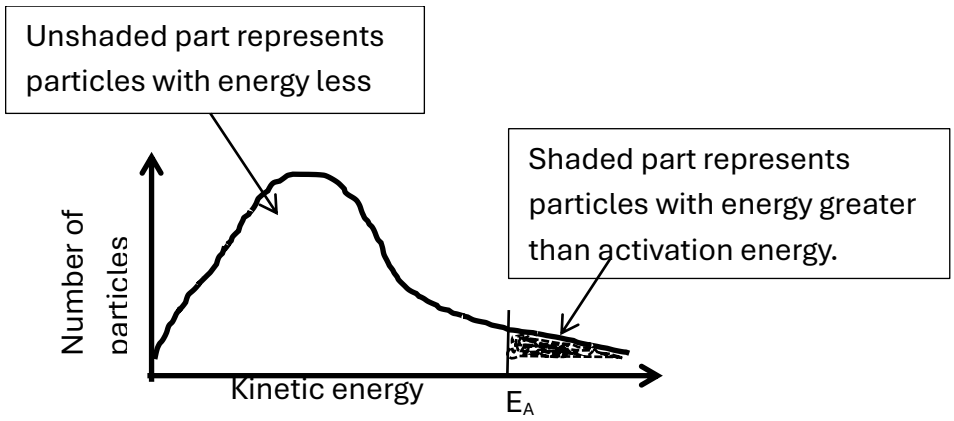
A **catalyst** is a substance that increases the rate of chemical reaction without itself undergoing any permanent change

When a catalyst is added, the rate of a chemical reaction increases. This is because:

- 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.



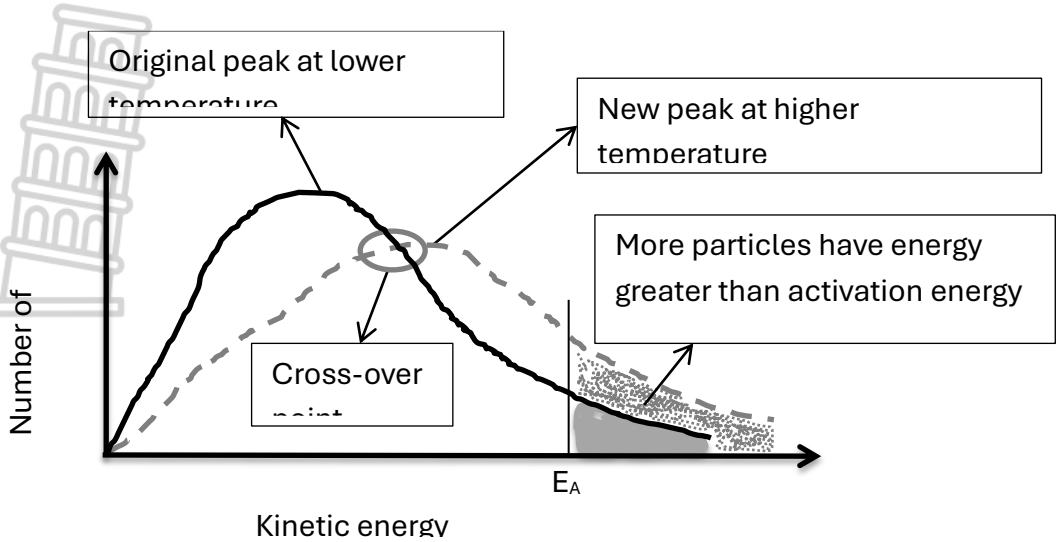
The Maxwell-Boltzmann distribution curve is affected by changes in **temperature**, **Concentration** and **catalyst.**

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.



WORKED EXAMPLES
QUESTIONS 1

1.1 Magnesium ribbon of mass 2 g reacts with excess hydrochloric acid of concentration 0,1 mol·dm^{-3} at 20 °C below:

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow Mgcl_{2(aq)} + H_{2(aq)}$$

Which ONE of the following changes will NOT increase the initial rate of the reaction?

A. Using 2 g of powdered magnesium

B. Increasing the temperature of HCl to 30 °C

C. Using a longer piece of the magnesium ribbon

D. Doubling the volume of the hydrochloric acid used (2)

1.2 The average rate of the formation of CO_2 in the following balanced reaction is 0,5 mol.min^{-1}

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_2 + H_2O$$

The average rate of consumption (disappearance) of HCℓ for this same reaction is:

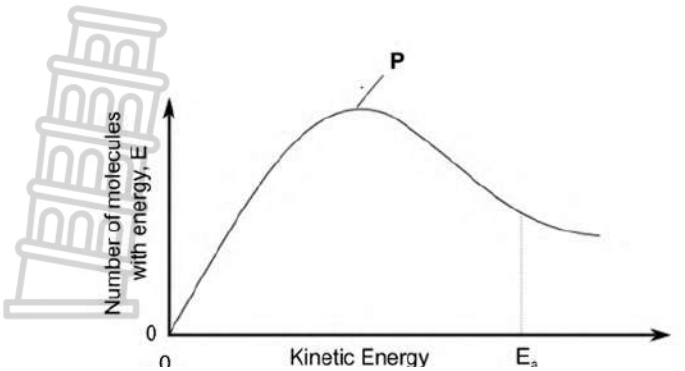
A. 2 mol .min^{-1}

B. 1 mol .min^{-1}

C. 0,5 mol .min^{-1}

D. 0,25 mol .min^{-1} (2)

1.3 The diagram below shows the Maxwell-Boltzmann distribution curve for one mole of a gas**. P** represents the peak of the distribution curve. The gas takes part in a reaction with an activation energy, Ea.



Which statement CORRECTLY describes the effect of an increase in temperature?

A. Peak P will be higher and fewer molecules will have an average kinetic energy > EA.

B. Peak P will be higher and more molecules will have an average kinetic energy > EA.

C. Peak P will be lower and fewer molecules will have an average kinetic energy > EA.

D. Peak P will be lower and more molecules will have an average kinetic energy > EA. (2)

SOLUTIONS

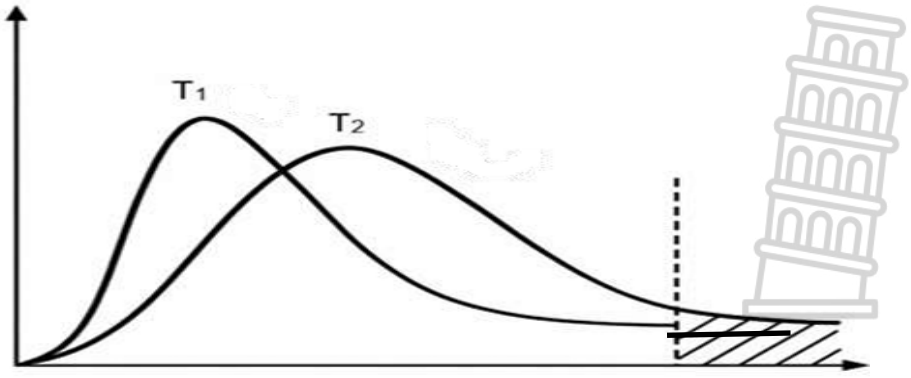
1.1 D✓✓

1.2 B✓✓

1.3 D✓✓

QUESTION 2

The graph below represents the Maxwell-Boltzmann distribution of molecular energies for a gas at two different temperatures, T_1 and T_1



2.1 Label the following:

2.1.1 y-axis (1)

2.1.2 shaded area (1)

2.1.3 dotted vertical line (1)

2.2 Which curve, T_1 or T_2, represents the gas at a higher temperature? Give a reason for the answer. (2)

2.3 A catalyst is added to the reaction. How will the position of the dotted vertical line change? Choose from **SHIFT TO THE LEFT** or **SHIFT TO THE RIGHT**? Give a reason for the answer. (2)

2.4 Explain why the total area under the curves remains the same even when the temperature is increased and a catalyst is added. (3)

[10]

SOLUTIONS

QUESTION 2

2.1.1 Number of (given) particles.✓ (1)

2.1.2 Particles with sufficient kinetic energy✓ (1)

2.1.3 Activation energy✓ (1)

2.2 T2✓more particles with sufficient kinetic energy✓ (1)

2.3 Shift to left ✓ catalyst decreases activation energy ✓ (1)

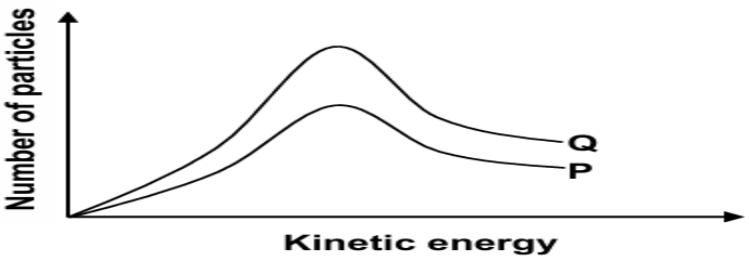
2.4 (3)

- Increasing temperature, only increases the average speed/kinetic energy of particles✓
- Catalyst provides an alternative path of lower activation energy/ catalyst only increases the rate of reaction.✓
- Both increasing temperature and adding a catalyst have no effect on the number of particles✓ (area under the curve)

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 The Maxwell-Boltzmann energy distribution curve P for CO_2 gas under certain conditions. Curve Q was obtained after a change was made.



Which ONE of the following represents the change made to obtain curve Q?

A. Increase in temperature

B. Addition of a catalyst

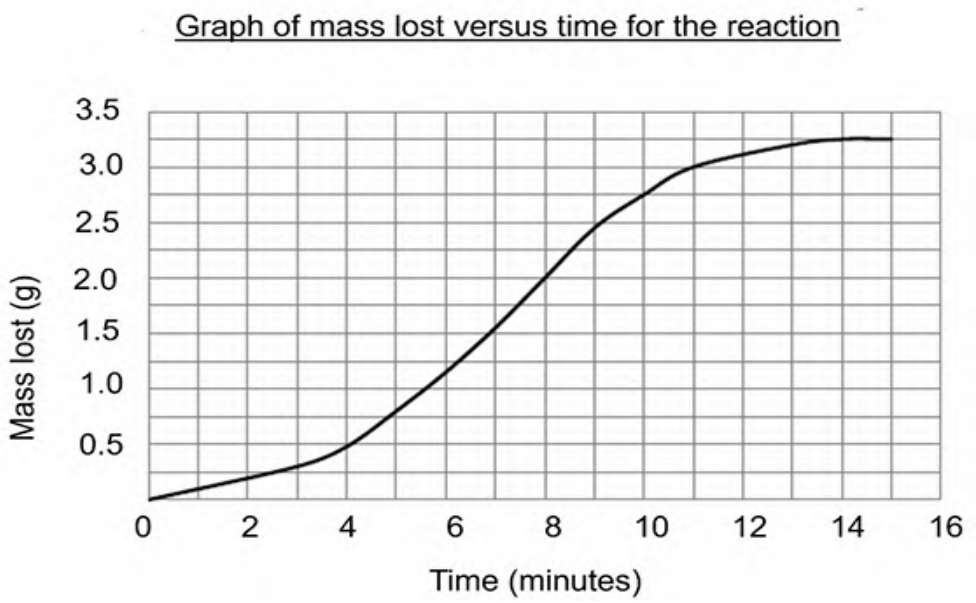
C. Increase in concentration

D. Increase in surface area of CO_2 (2)

QUESTION 2

Large lumps of calcium carbonate (CaCO3) with a total mass of 12 g are placed in an open flask. 200cm^3 hydrochloric acid (HCℓ) of concentration 3 $mol.dm^{-3}$ is added to completely cover the lumps. The mass of the flask is determined every two minutes. The balanced chemical equation for the reaction taking place in the flask is:

$$CaCO_{3(s)}+2HCl_{(aq)}\rightarrow CaCl2_{(aq)}+CO_2+H_2O$$



2.1 Calculate the number of moles of CaCO3 in a 12 g sample. (3)

2.2 Which reactant is in EXCESS? Show all calculations. (4)

2.3 How does the rate of reaction at 4 minutes compare to the rate of reaction at 8 minutes? Choose **GREATER THAN, EQUAL TO or SMALLER THAN.** (1)

2.4 Use the Collision Theory to fully explain the answer to QUESTION 2.3. (3)

2.5 What is the final mass of CO_2 produced. (1)

2.6 Determine the percentage yield of CO_2 (5)

2.7 This reaction is now repeated using 12 g of **POWDERED** $CaCO_3$ and the HCℓ unchanged. What effect (if any) will this have on:

2.7.1 The gradient of the graph. (1)

2.7.2 The final mass of CO2 produced. (1)

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QUESTION 3

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

$$Na_2S_2O_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + SO_{2(g)} + S_{(s)} + H_2O_{(l)}$$

Five experiments, A to E, are conducted during this investigation. In each experiment, 5 cm^3 of 0,15 mol $.dm^{-3}$ HCℓ was added to 25 cm^3 of $Na_2S_2O_3$ SOLUTIONS. The results obtained are shown in the table below.

Experiment	Volume of $Na_2S_2O_3$ (aq) (cm^3)	Concentration of $Na_2S_2O_3$ ($mol \cdot dm^{-3}$)	Volume of HCℓ (cm^3)	Concentration of HCℓ ($mol \cdot dm^{-3}$)	Rate (s^{-1})
A	25	0,01	5	0,15	0,005
B	25	0,02	5	0,15	0,009
C	25	0,04	5	0,15	0,022
D	25	0,08	5	0,15	0,042
E	25	0,10	5	0,15	0,050

3.1 Define the term reaction rate. (2)

3.2 Write down the INDEPENDENT variable for this investigation. (1)

3.3 Use the COLLISION THEORY to explain the effect of an increase in concentration on reaction rate. (3)

3.4 Consider experiment E.

3.4.1 Prove by calculation that HCℓ is the LIMITING REAGENT. (4)

3.4.2 Calculate the number of SULPHUR ATOMS in the precipitate produced when the reaction goes to completion. (4)

[14]

QUESTION 4

Learners perform three investigations (**A**, **B** and **C**) to study three factors which affect the rate of chemical reactions. They use the reaction between solid calcium carbonate ($CaCO_3$) and excess hydrochloric acid (HCℓ) solution, represented by the balanced equation below, in all three investigations.

$$CaCO_3(s) + 2HCℓ(aq) \rightarrow CaCℓ_2(aq) + H_2O(ℓ) + CO_2(g)$$

EXCESS HYDROCHLORIC ACID is used and the calcium carbonate is COMPLETELY COVERED in all the investigations

4.1 INVESTIGATION A: The learners conduct two experiments using the conditions as shown in the table below.

	Mass of $CaCO_3$ (g)	State of $CaCO_3$	Concentration of HCℓ ($mol \cdot dm^{-3}$)	Temperature of HCℓ (°C)
Experiment 1	2	powder	0,2	25
Experiment 2	2	lumps	0,2	25

4.1.1 Identify the independent variable in this investigation. (1)

4.1.2 Write down a hypothesis for this investigation. (2)

4.1.3 Is it fair to compare results obtained in **Experiment 1** with that in **Experiment 2**? Give a reason for the answer. (2)

4.1.4 The reactions in **Experiments 1** and **2** both run to completion. How will the yield of $CO_2(g)$ in **Experiment 1** compare to that in **Experiment 2**? Write down only LARGER THAN, SMALLER THAN or EQUAL TO and give a reason for the answer. (3)

4.2 INVESTIGATION B: The learners conduct two experiments using the conditions as shown in the table below.

	Mass of $CaCO_3$ (g)	State of $CaCO_3$	Concentration of HCℓ ($mol \cdot dm^{-3}$)	Temperature of HCℓ (°C)
Experiment 3	2	lumps	0,2	25
Experiment 4	2	lumps	1,0	25

4.2.1 Identify the independent variable in this investigation. (1)

4.2.2 Write down a investigative question for this investigation. (2)

4.2.3 Is it fair to compare results obtained in **Experiment 3** with that in **Experiment 4**? Give a reason for the answer (3)

4.2.4 The reactions in **Experiments 3** and **4** both run to completion. How will the yield of $CO_2(g)$ in **Experiment 3** compare to that in **Experiment 4**? Write down only LARGER THAN, SMALLER THAN or EQUAL TO and give a reason for the answer. (2)

4.3 INVESTIGATION C:The learners conduct two experiments using the conditions as shown in the table below.

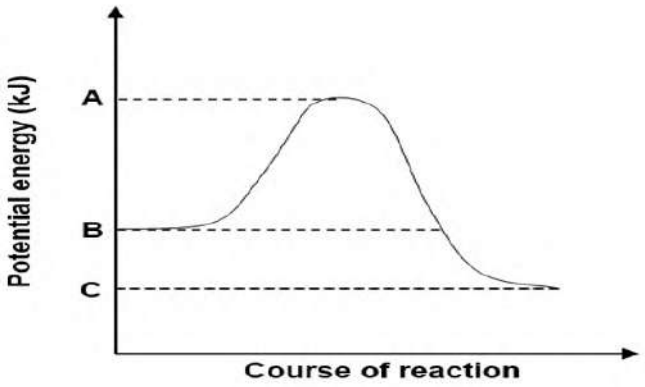
	Mass of $CaCO_3$ (g)	State of $CaCO_3$	Concentration of HCℓ ($mol \cdot dm^{-3}$)	Temperature of HCℓ (°C)
Experiment 5	4	powder	0,2	25
Experiment 6	4	powder	0,2	35

4.3.1 How does the average kinetic energy of the particles in the reaction in **Experiment 5** compare to that in **Experiment 6**? Write down only HIGHER THAN, LOWER THAN or EQUAL TO. (1)

4.3.2 On the same set of axes, draw sketch graphs of the number of molecules versus the kinetic energy (Maxwell-Boltzmann distribution curves) for each of **Experiment 5** and **Experiment 6**

- Label axes
- Clearly label each graph as **Experiment 5** or **Experiment 6** (3)

4.4. The graph below shows changes in the potential energy for the reaction between calcium carbonate and hydrochloric acid.



4.4.1 Is this reaction endothermic or exothermic? Give a reason for the answer. (2)

4.4.2 Use the relevant energy values, **A**, **B** and **C**, to write down an expression for each of the following:

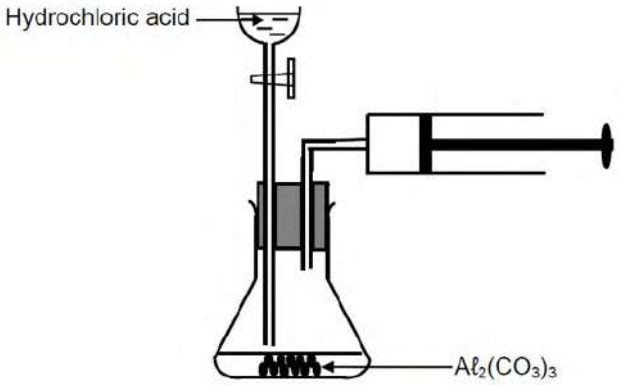
4.4.2.1 The energy of the activated complex (1)

4.4.2.2 ΔH for the forward reaction (1)

QUESTION 5

Two experiments, **I** and **II**, are conducted to investigate one of the factors that affects the rate of the reaction of aluminium carbonate, $A\ell_2(CO_3)_3$, with EXCESS hydrochloric acid, $HC\ell$. The balanced equation for the reaction is:

$A\ell_2(CO_3)_{3(S)} + 6HC\ell_{(aq)} \rightarrow 2A\ell C\ell_{3(aq)} + 3H_2O_{(l)} + 3CO_{2(g)}$



The reaction conditions used for each experiment are as follows:

Experiment I: 100 cm^3 of 1,5 $mol{\cdot}dm^{-3}$ $HC\ell(aq)$ reacts with 0,016 mol $A\ell_2(CO_3)_3$ granules at 25 °C

Experiment II: 50 cm^3 of 2 $mol{\cdot}dm^{-3}$ $HC\ell(aq)$ reacts with 0,016 mol $A\ell_2(CO_3)_3$ granules at 25 °C

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

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

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

5.4 The average rate of the reaction in **Experiment II** during the first 2,5 minutes is $4{,}4 \times 10^{-3} mol{\cdot}min^{-3}$ Calculate the number of moles of Aℓ2(CO3)3 that remains in the flask after 2,5 minutes. (3)

5.5 Calculate the maximum volume of CO2(g) that can be prepared at 25 °C in **Experiment I**. Take molar gas volume at 25 °C as 24 000 cm^3mol^{-1} (3)

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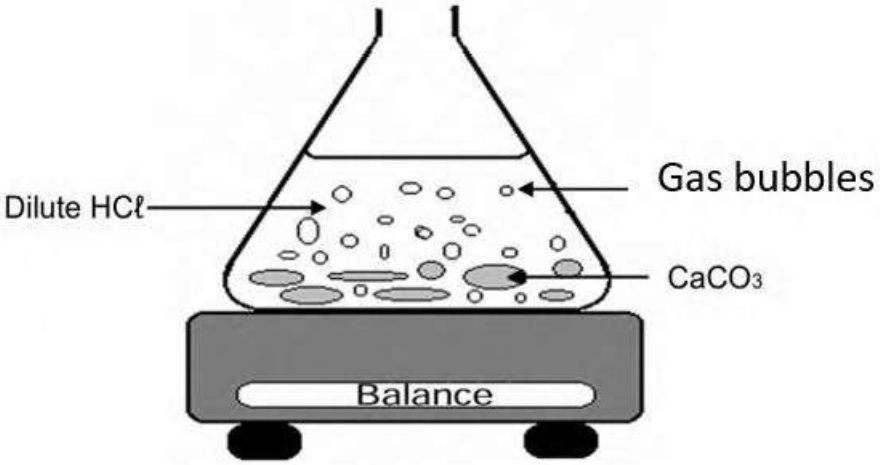
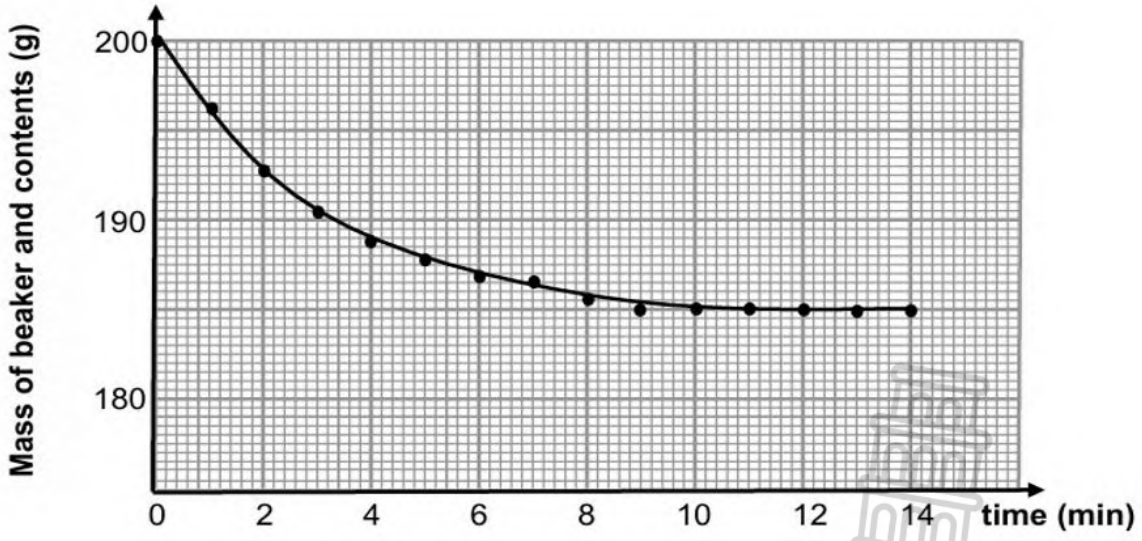
QUESTION 6

Calcium carbonate (CaCO3) chunks are added to EXCESS dilute hydrochloric acid (HCℓ) solution in an Erlenmeyer flask that is placed on an electronic scale, as shown below. The balanced equation for the reaction that takes place is:

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



The change in mass of the flask and its contents are recorded in 1-minute intervals. The results obtained are shown in the graph below.

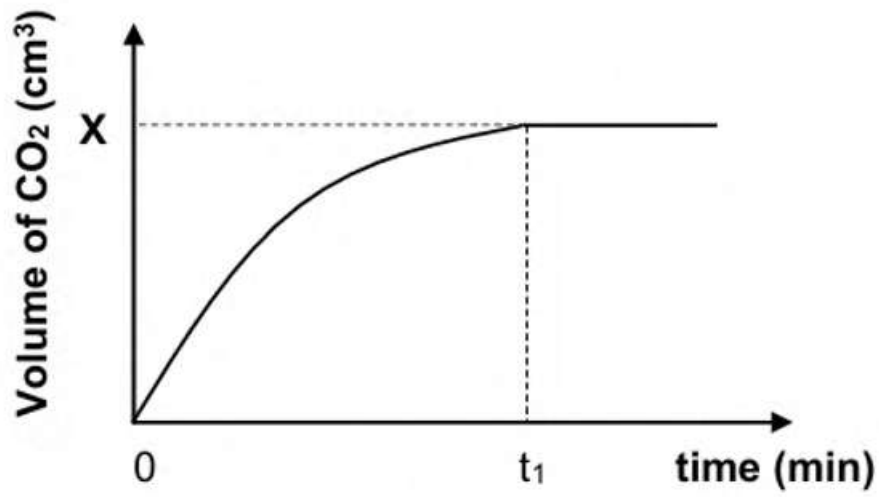


6.1 Is the reaction **EXOTHERMIC** or **ENDOTHERMIC**? Give a reason for the answer. (2)

6.2 Give a reason why the mass of the flask and its contents does not remain constant. (2)

6.3 Write down the reading on the scale balance on 4 minutes. (2)

6.4 The sketch graph below shows the change in volume of CO2 gas produced for this experiment.



6.4.1 Write down the value of t_1. (1)

6.4.2 How does the rate at which the amount CO_2 is produced compared to the rate at which the amount $CaCO_3$ is consumed? Choose from HIGHER THAN, SMALLER THAN or EQUAL TO. Give a reason for the answer. (3)

Calculate

6.4.3 Value of **X** Take the molar volume as 24 000 $cm^3 \cdot mol^{-1}$ (5)

6.4.4 Average rate in $g \cdot min^{-1}$ at which calcium carbonate was consumed after 11 minutes (4)

6.5 The experiment is repeated by increasing the temperature of the reaction mixture. The results of the two experiments are compared.

6.5.1 Write down a hypothesis for this comparison. (2)

6.5.2 How would reaction rate be affected by this change? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

6.5.3 Explain the answer to QUESTION 6.5.2 by referring to the collision theory. (3)

[23]

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.

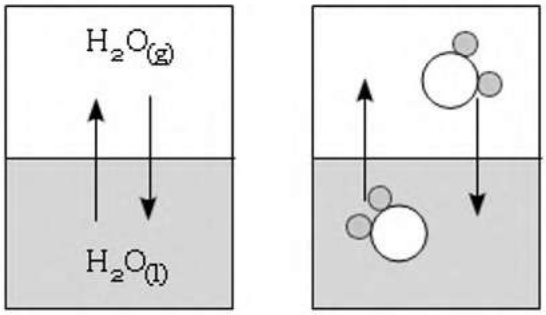


Figure 2: closed system

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

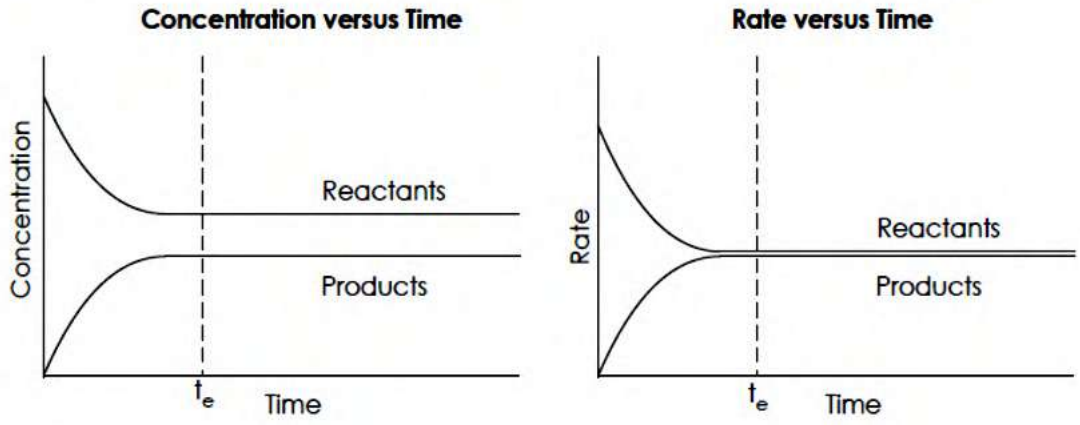
Concentration
Temperature
Pressure (gases only)

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

Le Chatelier's Principle (LCP): 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:



Graph A Graph B

At equilibrium, the concentrations of both the products and reactants remain 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 concentrated ionic solution is added to a system at equilibrium and the solution contains an ion that is already present in the equilibrium system (a common ion), then the reaction that uses up the common ion will be favoured.

For example:

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

By adding HCl (conc), the concentration of Cl^- ions increases. According to LCP, the reaction that uses the Cl^- ion is favoured. In this case the reverse reaction is favoured (i.e. the reverse reaction is faster than the forward reaction until a new equilibrium is established). Therefore, the formation of NaCl(s) is observed.

Worked Examples

1.1. Initially, 2,2 g of pure CO_2 (g) is sealed in an empty 5 dm^{-3} containers at 900 °C. Calculate the initial concentration of CO_2. (4)

1.2 Give a reason why equilibrium will not be established (1)

$CaCO_3(s)$ is now added to the 2,2 g $CO_2(g)$ in the container and after a while equilibrium is established at 900°C according to the following balanced equation:

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

The equilibrium constant for this reaction at 900°C is 0,0108.

1.3 Give a reason why this reaction will only reach equilibrium in a SEALED container. (1)

1.4 Calculate the minimum mass of $CaCO_3(s)$ that must be added to the container to achieve equilibrium. (7)

1.5 How will EACH of the following changes affect the amount of $CO_2(g)$? Choose from INCREASES, DECREASES or REMAINS THE SAME

1.5.1 More $CaCO_3(s)$ added at 900 °C. (1)

1.5.2 The pressure is increased. (1)

1.6 It is found that the equilibrium constant (Kc) for this reaction at 727 °C is 2,6 x 10^{-6}. Is the reaction EXOTHERMIC or ENDOTHERMIC? Fully explain the answer. (4)

Worked Example 1 solutions

1.1 $c = \frac{m}{MV}$ ✓ $= \frac{2.2}{44 \times 5}$ ✓✓ 0.01 mol.dm^{-3}✓ (4)

1.2 For equilibrium to be reached, a forward reaction and a reverse reaction are needed OR without CaO(s), the reverse reaction is not possible.✓ (1)

1.3 CO_2 is a gas and will escape if the container is not sealed.✓ (1)

1.4

$K_c = [CO_2]$✓

$= 0.0108$✓

	$CaCO_3$	CaO	CO_2
Initial (mol)	0	0	0.05
Change (mol)	0.004	x	0.004✓✓
Quantity at equilibrium			0.054✓
Equilibrium Concentration(mol.dm^{-3}			0.0108

$m(CaCO_3) = n\ M$

$= (0.004)(100)$✓

$= 0,4g$✓ (7)

1.5.1 Remains the same✓ (1)

1.5.2 Decreases✓ (1)

1.6 Endothermic ✓
• Kc decreases with decrease in temperature. ✓
• Therefore the concentration of products ✓decreases/The reverse reaction is favoured.
• A decrease in temperature favours the exothermic reaction.✓ (4)
[21]

Worked Example 2

2 Initially 60,8 g pure carbon dioxide, $CO_2(g)$, is reacted with carbon, C(s), in a sealed container of volume 3 dm^3. The reaction reaches equilibrium at temperature T according to the following balanced equation:

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$$

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

2.2 At equilibrium it is found that the concentration of the carbon dioxide is 0,054 $mol \cdot dm^{-3}$. Calculate the:

2.2.1. Equilibrium constant, Kc, for this reaction at temperature T (7)

2.2.2 Minimum mass of C(s) that must be present in the container to obtain this equilibrium (3)

2.3 How will EACH of the following changes affect the AMOUNT of CO(g) at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME.

2.3.1 More carbon is added to the container (1)

2.3.2 The pressure is increased by reducing the volume of the container at constant temperature. Use Le Chatelier's principle to explain the answer. (3)

2.4 The table below shows the mole percentages of CO2(g) and CO(g) in the container at different temperatures.

TEMPERATURE (°C)	**% CO2(g)**	**% CO(g)**
827	6.23	93.77
950	1.32	98.68
1050	0.37	99.63
1200	0.06	99.94

2.4.1 Is the reaction **EXOTHERMIC** or **ENDOTHERMIC?** Refer to the data in the table and explain the answer. (3)

2.4.2 Use the information in the table to determine temperature T. Show clearly how you arrived at the answer. (3)
[22]

Worked Example 2 Solutions

2.1 The stage in a chemical reaction when the rate of forward reaction equals the rate of reverse reaction. OR The stage in a chemical reaction when the concentrations of reactants and products remain constant.✓✓

(2)

2.2.1 $n(CO_2) = \frac{m}{M} = \frac{60,8}{44}$ ✓=1,382 mol

	CO_2	CO
Initial	1.382	0
Change (mol)	1.22✓	2.44✓
Equilibrium (mol)	0.162	2.44
Equilibrium Conc	0.054	0.813✓

$K_c = \frac{[CO]^2}{[CO_2]}$ ✓$= \frac{(0,813)^2}{0,054}$ ✓$= 12,24$✓

(7)

2.2.2 $n(C)_{reacted} = n(CO_2)_{reacted} = 1,22$ mol ✓

$m(C) = nM = 1,22(12)$ ✓$= 14,64$ g ✓ (3)

2.3.1 Remains the same ✓ (1)

2.3.2 Decreases ✓

- When pressure is increased) the reaction that leads to the smaller amount/ number of moles/volume of gas is favoured. ✓
- The reverse reaction is favoured. / More CO_2 is formed✓.

(3)

2.4.1 Endothermic✓

• When the temperature increases the mol/percentage CO(g) / product increases/forward reaction is favoured. ✓

• An increase in temperature favours the endothermic reaction. ✓ (3)

2.4.2

$n_{total\ eq} = 0,162 + 2,44$ ✓ $= 2,606$ mol

$\%CO_2 = \frac{0,162}{2,606} \times 100$ ✓

OR

$= 6,225\%$

$\therefore T = 827\ °C$ ✓

$\%CO = \frac{2,44}{2,606} \times 100$ ✓

$= 93,63\%$

(3)

[22]

Equilibrium Constant

Writing an expression for the equilibrium constant K_c

- For the reaction $aA + bB \rightleftharpoons cC\ (g) + dD\ (g)$, $K_c = \frac{[C]^2}{[A]^a}\frac{[D]^d}{[B]^b}$.
- Only gases (g) and solutions (aq) appear in the K_c expression- No solids (s) and pure liquids are included.
- Equilibrium constant does not have units.
- Large K_c values ($K_c > 1$) : Reactions in which the concentration of product is high in comparison to that of reactants.

- Small K_c values ($K_c < 1$): Reaction in which the concentration of products is low in comparison to that of reactants.
- Only a temperature change can change the K_c value.
- If the K_c value increases due to a change in temperature the forward reaction is favoured.
- If the K_c value decreases due to a change in temperature the reverse reaction is favoured.

Equilibrium graphs

Concentration time graphs

STUDY TIP 1:
Concentration, pressure and temperature changes made to a gaseous chemical equilibrium are identified as follows:

- Concentration Change: The graph of one of the substances spikes upward or downward.
- Pressure Change: The graph spikes upward or downward for each gas in the Equation.
- Temperature Change: The graph does not spike, but shows gradual upward and downward changes that are opposite for the forward and reverse reactions.

STUDY TIP 2:
Upward spiking and gradual upward changes show an increase in concentration as well as reaction rate. Downward spiking and gradual downward changes show a decrease in concentration as well as reaction rate.

STUDY TIP 3:
Pressure is increased by decreasing the volume of the container containing the reaction mixture. Conversely, pressure is decreased by increasing the volume of the closed container. Therefore pressure changes are really concentration changes.

STUDY TIP 4: Once the change is made, Le Chatelier's Principle can be used to explain the graph shape.

Examples

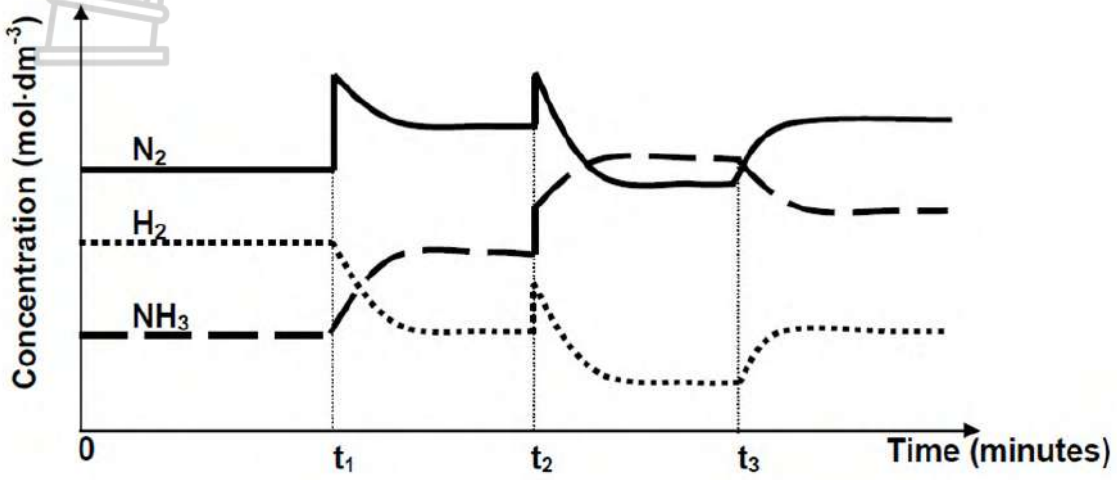
In the Haber Process, the reaction:

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

takes place in a closed container.

Changes are made to the reaction at times t_1, t_2 and t_3.

The graphs below show the situation.



1. What do the shapes of the graph lines between time 0 and t_1 indicate about the reaction? (1)
2. State the change that was made to the reaction at the following times and give a reason for each
   - 2.1 t_1 (2)
   - 2.2 t_2 (2)
   - 2.3 t_3 (2)
3. Use Le Chatelier's principle to explain the shapes of the graph lines between:
   - 3.1. t_1 and t_2 (3)
   - 3.2 t_2 and t_3 (3)

Solutions to worked examples

1. The reaction is in equilibrium✓ (1)

2.1 $[N_2]$ was increased. ✓

Reason: There is an upward spike only for N_2.✓ (2)

2.2 Pressure was increased.✓

There is an upward spike for N_2, H_2 and NH_3. ✓ (2)

2.3 Temperature was increased.✓

All changes in the graph line shapes are gradual. The changes are upward for the reverse reaction and downward for the forward reaction.✓

(2)

3.1 STEP 1: Change made: $[N_2]$ increases. ✓

STEP 2: According to Le Chatelier's Principle, the forward reaction is favoured (i.e. the reaction that reduces the $[N_2]$ is favoured).✓

STEP 3: Therefore, the [H_2] decreases and the [NH_3] increases until a new equilibrium is established.✓

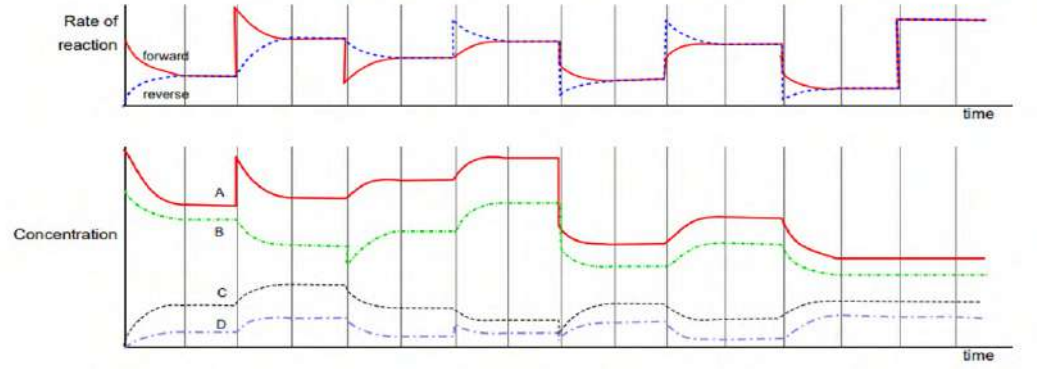
(3)

3.2 STEP 1: Change made: Pressure was increased. ✓
STEP 2: According to Le Chatelier's principle, the forward reaction is favoured (i.e. the reaction that produces less molecules is favoured✓
STEP 3: The [NH_3] increases, but the [N_2] and [H_2] decrease until a new equilibrium is established✓

(3)
[25]

$2A(g) + B(g) \rightleftarrows 3C(g) + D(g) \quad \Delta H < 0$ forwards exothermic

	A and B in a container	A added	B removed	D added	Volume doubled	Temperature increased	Temperature decreased	Catalyst added
Disturbance		[A]↑	[B]↓	[D]↑	P↓	T↑	T↓	Both reactions equally faster
Le Chatelier's principle: the system reacts to ...		[A]↓	[B]↑	[D]↓	P↑	T↓	T↑	
The ... reaction is favoured		forward	reverse	reverse	more mol gas forward	endothermic reverse	exothermic forward	
[C] will ...		↑	↓	↓	↑	↓	↑	
Kc ...		constant	constant	constant	constant	↓	↑	constant



ACTIVITIES

QUESTION ONE (MULTIPLE CHOICE QUESTIONS)

1.1. A catalyst will change the...

A Time taken for a reaction to reach equilibrium.
B Amount of product present at equilibrium.
C Amount of reactants present at equilibrium.
D The equilibrium constant for the reaction. (2)

1.2. Consider the following equilibrium constants for the same reaction at two different temperatures:
298K : Kc=0.03
318K: Kc =0.005
Which ONE of the following is CORRECT?

	HEAT OF THE REACTION	**YIELD OF PRODUCTS AS THE TEMPERATURES INCREASES**
A	$\Delta H > 0$	Increases
B	$\Delta H < 0$	Decreases

C	$\Delta H > 0$	Decreases
D	$\Delta H < 0$	Remains the same

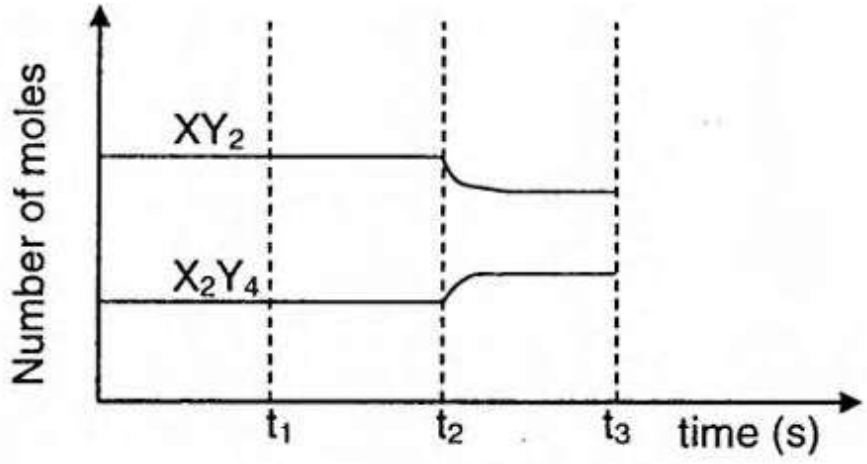
(2)

1.3. The reaction represented by the equation

$$X_2Y_4\ (g) \rightleftharpoons 2XY_2\ (g) \qquad \Delta H > 0$$

Is initially at equilibrium up to time t_2 for which the K_C value is 0,25. The equilibrium is disturbed at time t_2.

The situation is represented by the graph below.



Which one of the following BEST explains the change that occurred at time t_2?

A X_2Y_4 was added to the reaction mixture.
B The pressure increased without any change in temperature.
C The temperature was decreased.
D The temperature was increased. (2)

1.4 Consider the reaction:

$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

The equilibrium constant for this reaction at 25˚ C is 10^{-14}. At 60˚C the equilibrium constant for this reaction is 10^{-13}. From the above information one can conclude that this reaction at 60˚C…

A is an exothermic reaction.
B has a higher product yield than at 25°C.
C has a lower concentration of H_3O^+ ions than OH^- ions.
D does not change the concentration of theproducts. (2)

1.5 Cobalt chloride crystals are dissolved in a water/alcohol mixture to form a blue solution, represented by the following equation:

$$CoCl_4^{-2}(aq) + 6H_2O(\ell) \rightleftharpoons Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \qquad \Delta H<0$$

(blue) **(pink)**

A few drops of concentrated sulphuric acid is added to the above solution. What colour change is observed and what is the reason for the colour change?

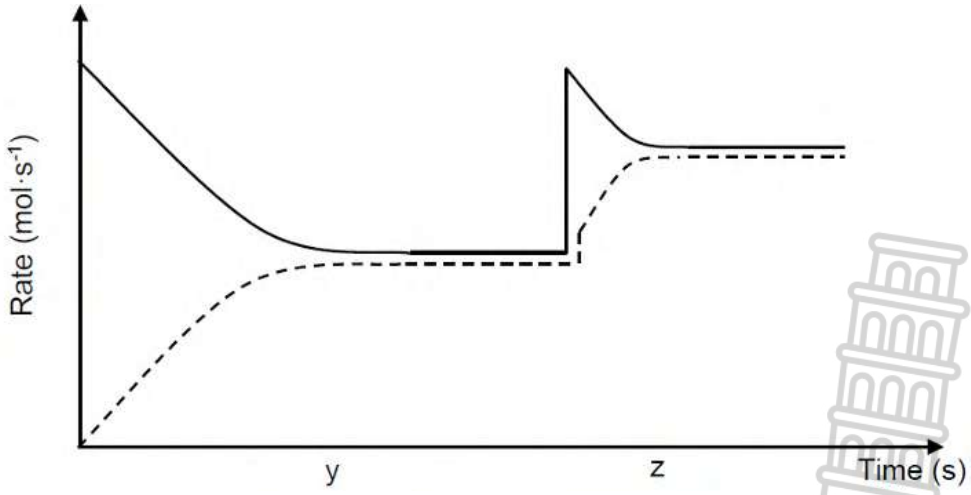
	COLOUR CHANGE	REASON
A	Pink to Blue	H_2O molecules are removed
B	Blue to Pink	Cl^- ions are added
C	Pink to Blue	Cl^- ions are added
D	Blue to Pink	H_2O molecules are added

(2)

1.6 The hypothetical compound AX_3 (g) decomposes in a closed container according to the following balanced equation:

$$2AX_3(g) \rightleftharpoons 2AX_2(g) + X_2(g)$$

Equilibrium is reached at temperature **T_1** after **y** seconds. The temperature is increased to **T_2** and a new equilibrium is established at this higher temperature after **z** seconds, as shown in the graph below.



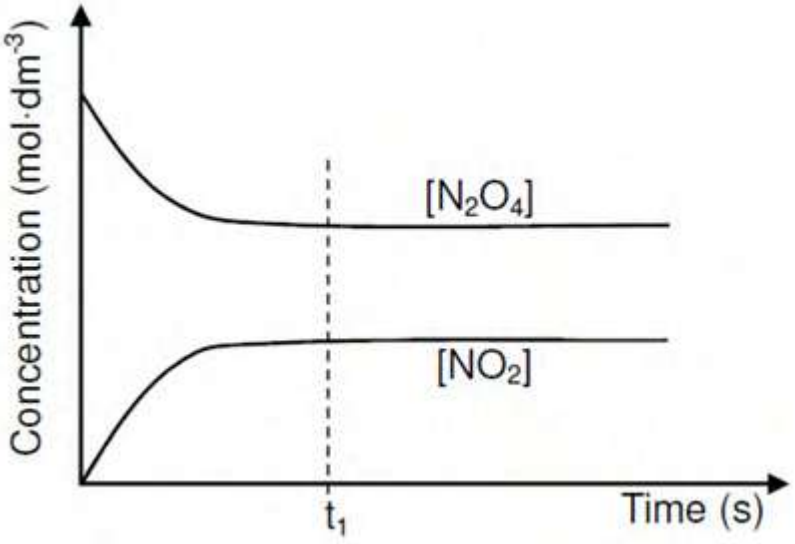
Which one of the following combinations is correct?

	The forward reaction is:	Kc at temperature T_1 is:
A	Endothermic	Smaller than K_c at **T_2**
B	Endothermic	Larger than K_c at **T_2**
C	Exothermic	Smaller than K_c at **T_2**
D	Exothermic	Larger than K_c at **T_2**

(2)

1.7 The graph below represents the decomposition of $N_2O_4(g)$ in a closed container according to the following balanced equation

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



Which one of the following correctly describes the situation at t_1?

A The N_2O_4 gas is used up.
B The NO_2 gas is used up.
C The rate of the forward reaction is equal to the rate of the reverse reaction.
D The concentration of the reactants and product are equal. (2)

1.8 Initially 2 mol of CO(g) and 2 mol $H_2(g)$ are sealed in a container. The reaction reaches equilibrium according to the following balanced equation

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

At equilibrium the amount of CH_3OH is

A 1 mol
B 2 mol
C Less than 1 mol
D Greater than 1 mol (2)

1.9 The addition of a catalyst to a reversible reaction at equilibrium increases the …

A equilibrium constant of the forward reaction.
B product at equilibrium.
C the rate of both the forward and the reverse reactions.
D rate of only the forward reaction.

(2)
[10]

QUESTION 2

2.1 Carbon dioxide reacts with carbon in a closed system to produce carbon monoxide, CO(g), according to the following balanced equation:

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

2.1.1 What does the double arrow indicate in the equation above?

(1)

2.1.2. Is the above reaction an EXOTHERMIC reaction or an ENDOTHERMIC reaction? Give a reason for the answer. (2)

Initially an unknown amount of carbon dioxide is exposed to hot carbon at 800 °C in a sealed 2 dm^3 container. The equilibrium constant, Kc, for the reaction at this temperature is 14. At equilibrium it is found that 168,00 g carbon monoxide is present.

2.1.3 How will the equilibrium concentration of the product compare to that of the reactants? Choose from LARGER THAN, SMALLER THAN or EQUAL TO. Give a reason for the answer.
(No calculation is required)

(2)

2.1.4 Calculate the initial amount (in moles) of $CO_2(g)$ used in the reaction.

(9)

2.2 State how EACH of the following will affect the yield of CO(g) at equilibrium. Choose from INCREASES, DECREASES or REMAINS THE SAME

2.2.1 More carbon is added at constant temperature. (1)
2.2.2 The pressure is increased. (1)
2.2.3 The temperature is increased. (1)

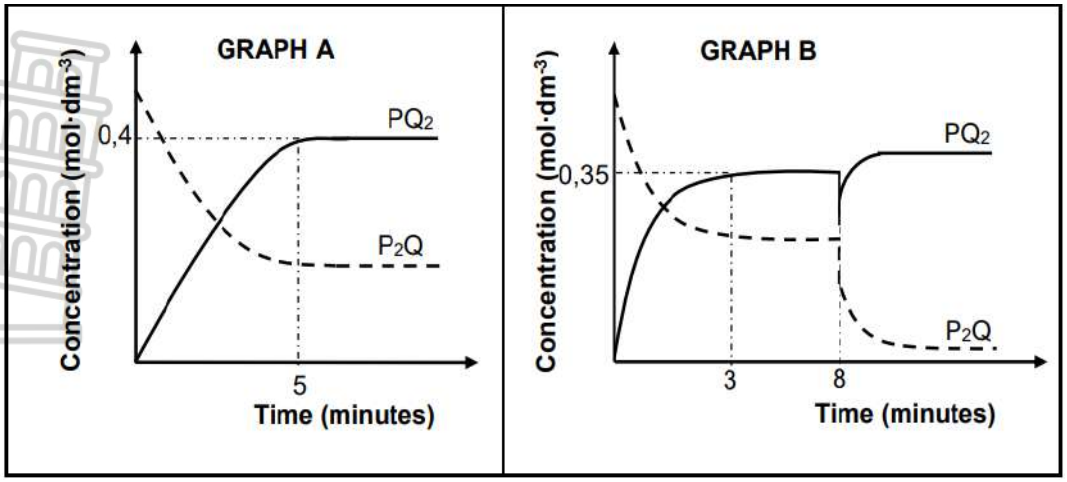
[17]

QUESTION 3

3 Consider the balanced equation for a hypothetical reaction that takes place in a 2 dm^3 sealed container.

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

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.



3.1 State Le Chatelier's Principle. (2)

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

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

3.4 Explain the answer to QUESTION 3.3. (2)

3.5. 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. (2)

3.6 The equilibrium constant, Kc, is 0,49 at 398 K (graph B). Calculate the initial number of moles of P_2Q. (8)

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

3.8 Explain by using Le Chatelier's principle how the system reacts to the change in QUESTION 3.7. (2)

[20]

QUESTION 4

4 Consider the balanced equation below for a hypothetical reaction that takes place in a sealed 2 dm^3 container at 300 K.

$$2P(g) + Q_2(g) \rightleftharpoons 2PQ(g)$$

4.1 Define the term chemical equilibrium. (2)

4.2 The amount of each substance present in the equilibrium mixture at 300 K is shown in the table below.

	AMOUNT (mol) AT EQUILIBRIUM
P	0.8
Q_2	0.8
PQ	3.2

The temperature of the container is now increased to 350 K. When a NEW equilibrium is established, it is found that 1.2 mol P(g) is present in the container.

4.2.1 Is the heat of the reaction (ΔH) POSITIVE or NEGATIVE? (1)

4.2.2 Use Le Chatelier's principle to explain the answer to QUESTION 4.2.1. (3)

4.2.3 Calculate the equilibrium constant at 350 K. (8)

4.2.4 How will the equilibrium constant calculated in QUESTION 17.2.3 be affected when the volume of the container is decreased at constant temperature? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

4.3 More $T_2(g)$ is now added to the reaction mixture at constant temperature. How will EACH of the following be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

4.3.1 The yield of PQ(g) (1)

4.3.2 Number of moles of P (g) (1)

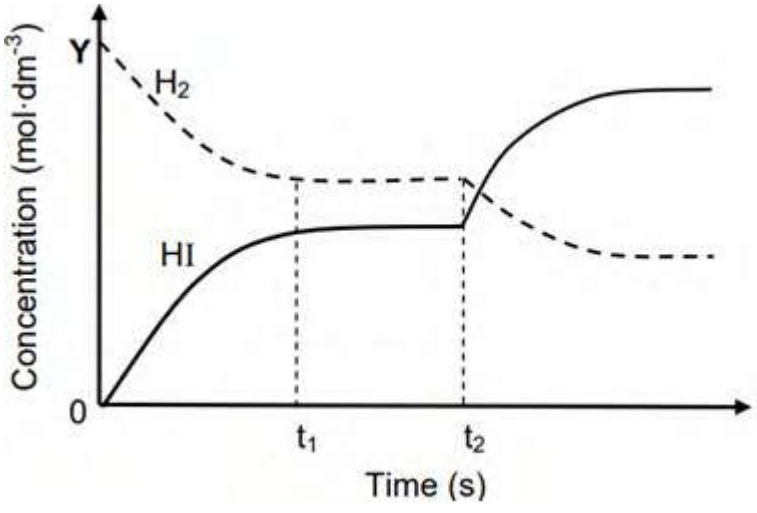
[18]

QUESTION 5

5 Initially, 4 moles $H_2(g)$ and 4 moles $I_2(g)$ are allowed to react in a sealed 2 dm^3 flask according to the following balanced equation:

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

The graph below shows the concentrations of $H_2(g)$ and HI(g) versus time during the reaction.



5.1.1 Write down the value of **Y**. (1)

5.1.2 State Le Chatelier's principle. (2)

5.1.3 Changes were made to the temperature of the flask at time t_2. Was the flask HEATED or COOLED? (1)

5.1.4 Fully explain the answer to QUESTION 5.1.3 (3)

5.2 The equation below represents the reversible reaction that takes place when $NO_2(g)$ is converted to $N_2O_4(g)$.

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

Initially, x mol of $NO_2(g)$ is sealed in a 1 dm^3 container at 350 K. When equilibrium is established at this temperature, 0,81 mol $N_2O_4(g)$ is present in the container.

5.2.1 Write down the meaning of the term reversible reaction. (1)

5.2.2 Show that the equilibrium constant for this reaction is given by:

$$\frac{0.81}{(x-1.62)^2}$$

0,79 moles of $N_2O_4(g)$ is now added to the equilibrium mixture. When the NEW equilibrium is established at 350 K, it is found that the amount of $NO_2(g)$ increased by 1,2 moles. (5)

5.2.3 Calculate the value of x. (6)

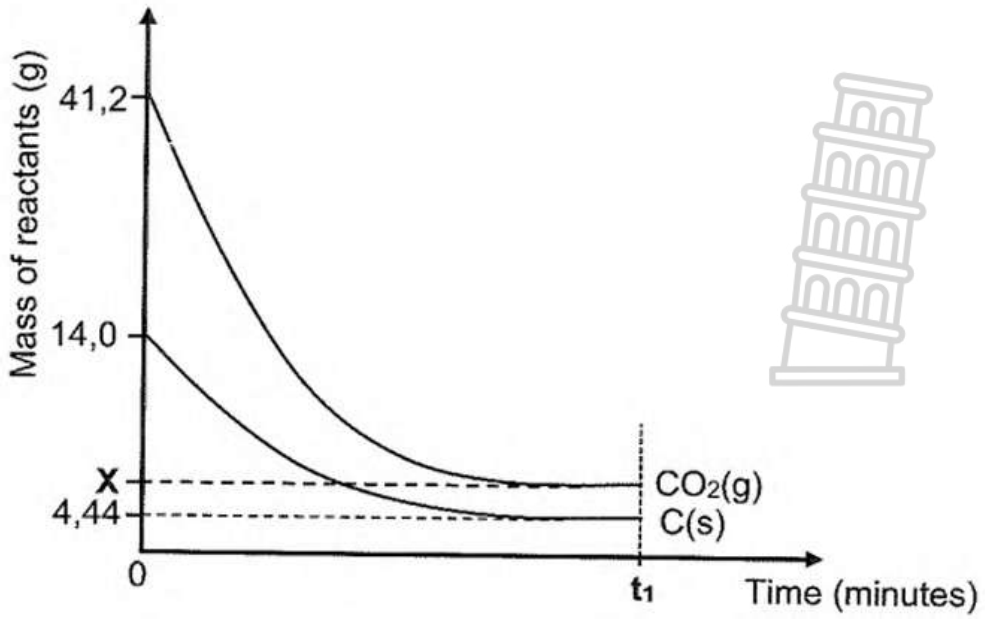
[18]

QUESTION 6

6 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.



6.1. 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.

6.1.1 A catalyst is added (1)

6.1.2 The volume of the container is increased at a constant temperature (1)

6.1.3 More powdered carbon is added (1)

6.2. Explain the answer to question 6.1.2 by referring to Le Chatlier's principle. (2)

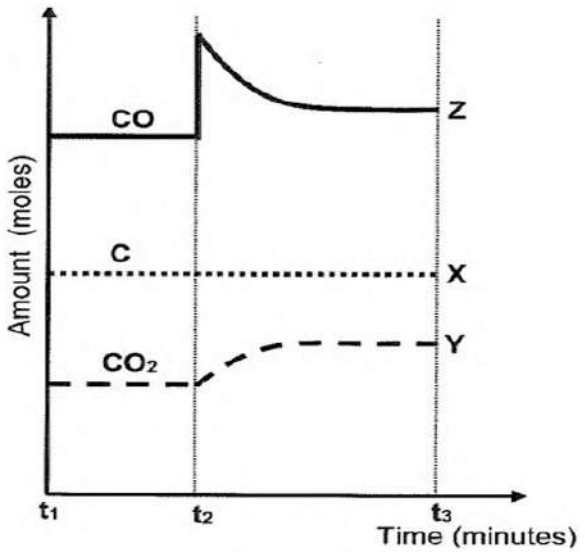
6.3 Calculate the value of X shown on the graph (6)

6.4 Calculate the equilibrium constant, Kc, at T °C. (5)

6.5 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.



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

6.6 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 7

Carbonyl bromide, $COBr_2$, decomposes into carbon monoxide and bromine according to the following balanced equation:

$$COBr_2(g) \rightleftharpoons CO(g) + Br_2(g) \qquad \Delta H > 0$$

Initially $COBr_2(g)$ is sealed in a 2 dm^3 container and heated to 73°C. The reaction is allowed to reach equilibrium at this temperature. The equilibrium constant for the reaction at this temperature is 0,19.

7.1 Define *chemical equilibrium*. (2)

At equilibrium it is found that 1,12 g CO(g) is present in the container.

7.2. Calculate the equilibrium concentration of the $COBr_2(g)$ (6)

7.3. Calculate the percentage of $COBr_2(g)$ that decomposed at 73 °C. (4)

7.4 Which ONE of the following CORRECTLY describes the Kc value when equilibrium is reached at a lower temperature?

$K_c < 0,19$	$K_c > 0,19$	$K_c = 0,19$

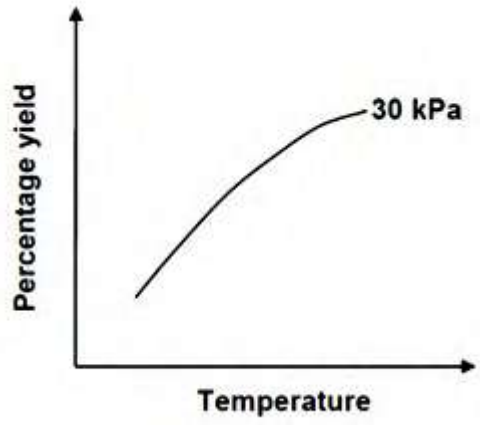
(6)

7.5 The pressure of the system is now decreased by increasing the volume of the container at 73°C and the system is allowed to reach equilibrium.
How will the number of moles of $COBr_2(g)$ be affected?
Choose from INCREASES, DECREASES or REMAINS THE SAME.
Explain the answer. (3)

[21]

QUESTION 8

8.1. A reversible gaseous reaction is allowed to reach equilibrium in a closed container at different temperatures and pressures. The graph shows the percentage yield for this reaction at 30 kPa as the temperature is increased.
Use the information in the graph above to answer the following questions

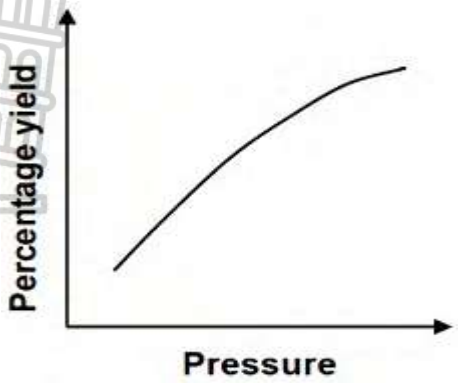


8.1.1 State Le Chatelier's principle. (2)

8.1.2 The heat of reaction (ΔH) for the forward reaction is POSITIVE. Use Le Chatelier's principle to explain this statement.

(3)

The graph below shows the percentage yield for this reaction as pressure changes at constant temperature



8.1.3. Explain the effect of an increase in pressure on the equilibrium position of a reaction. (2)

8.1.4 Which ONE of the following equations (**I**, **II** or **III**) represents the equilibrium above?

I: $2A(g) + 3B(g) \rightleftharpoons 3C(g)$

II: $A(g) + B(g) \rightleftharpoons 3C(g)$

III: $A(g) + B(g) \rightleftharpoons 2C(g)$ (2)

8.2 A mixture of 0,2 moles of hydrogen chloride ($HC\ell$) and 0,11 moles of oxygen gas (O_2) is sealed in a 200 cm^3 flask at a certain temperature. The reaction reaches equilibrium according to the balanced equation:

$$4HC\ell(g) + O_2(g) \rightleftharpoons 2C\ell_2(g) + 2H_2O(g)$$

It is found that 1,825 g of hydrogen chloride is present at equilibrium. Calculate the equilibrium constant, Kc, for this reaction at this temperature.

(9)
[18]

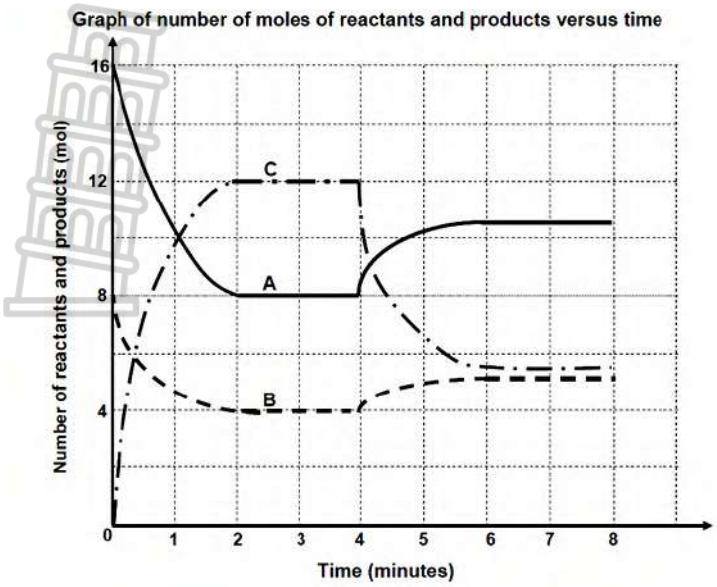
QUESTION 9

The equation below represents a hypothetical reaction that reaches equilibrium in a closed container after 2 minutes at room temperature.

The letters **x, y** and **z** represent the number of moles in the following balanced equation:

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

The graph shows the change in the number of moles of reactants and products versus time during the reaction.



9.1 Define *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, Kc, 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]

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.
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 is 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 $[H_3O+][OH^-]$ 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 acid: 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 H_3O^+ 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 (H_3O^+) 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^+)

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_4^+ and $C\ell^-$.
NH_4^+ 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:
$NH_3 + H_2O \rightleftharpoons NH_4^+ H_3O^+$
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:

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

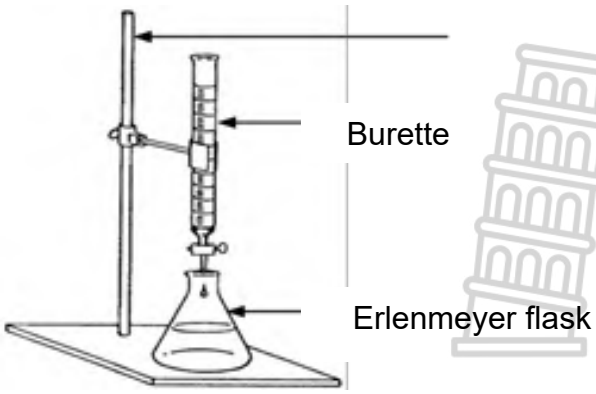
acid 1 base 2 acid 2 base 1

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



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**.

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.

1.1 Write the balanced equation for the titration reaction. (3)

1.2 Calculate the concentration of the sulphuric acid solution. (3)

1.3 Calculate the number of moles of Sulphuric acid neutralised. (3)

1.4 Calculate the concentration of the sodium hydroxide. (4)

[13]

SOLUTIONS

1.1 H_2SO_4 (aq) + 2NaOH (aq) ✓ → Na_2SO_4(aq) + 2$H_2O(\ell)$ ✓bal. ✓ (3)

1.2 $c=\frac{m}{MV}$ ✓

$=\frac{4,9}{98(0,2)}$ ✓

$c=0,25\ mol.dm^{-3}$ ✓ (3)

1.3 $c=\frac{n}{V}$ ✓

$0,25=\frac{n}{0,0207}$ ✓

$n=5,175\ x10^{-3}mol$ ✓ (3)

1.4. $\frac{na}{nb}=\frac{caVa}{cbVb}$ ✓

$\frac{1}{2}$ ✓ $=\frac{(0,25)(20,7)}{cb(10)}$ ✓

$Cb=1,035\ mol{\cdot}dm^{-3}$ ✓ (4)

[13]

EXAMPLE 2

Carbonic acid (H_2CO_3) ionises according to the following equation:

$$H_2CO_3(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + HCO_3^-(aq)$$

2.1 Is carbonic acid, H_2CO_3 (aq), a strong acid or a weak acid?
Give a reason for the answer (2)

Two beakers **A** and **B** contain the acid and a strong base respectively.

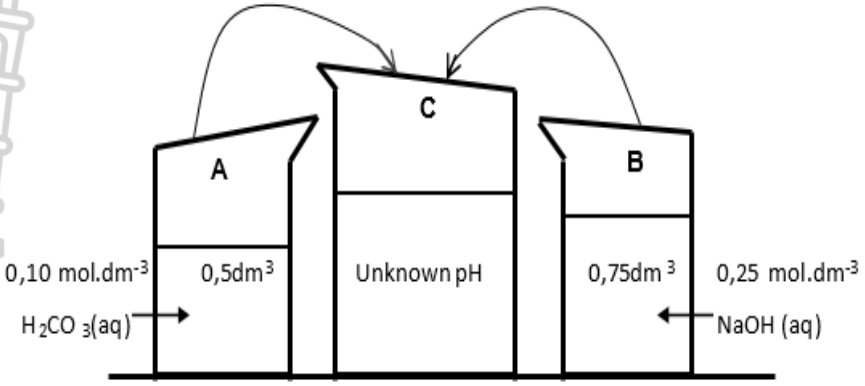
Beaker **A**: 0,5 dm^3 of carbonic acid, H_2CO_3(aq), of concentration 0,10 $mol.dm^{-3}$

Beaker **B**:0,75 dm^3 of sodium hydroxide, NaOH (aq)of concentration 0,25 $mol.dm^{-3}$

When a 0,10 $mol{\cdot}dm^{-3}$ 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

2.2 Calculate the number of moles of H_3O^+(aq) ions present in H_2CO_3 solution in beaker **A.** (3)

The contents of beakers **A** and **B** are added together in beaker **C**. The solution in beaker **C** has an unknown pH.



$H_2CO_3(aq) + NaOH(aq) \rightarrow NaHCO_3(aq) + H_2O(\ell)$

2.3 Calculate the:

2.3.1 Number of moles of hydroxide (OH^-) ions in beaker **B**. (3)

2.3.2 pH of the solution at the completion of the reaction in beaker **C**. (7)

[15]

SOLUTION:

2.1 Weak acid: It ionises incompletely/does not ionise completely in water (to form a low concentration of H_3O^+) ✓✓ (2)

2.2 $[H_3O^+] = [HCO_3^-] = 0,012 \text{ mol.dm}^{-3}$ ✓

$n = cV$

$n = 0,012 \times 0,5$ ✓

$n = 0.006$ mol ✓ (3)

2.2.1 $n(NaOH) = cV$ ✓

$n_{(NaOH)} = 0,25 \times 0,75$ ✓

$n = 0,1875$ mol

Therefore $n(OH^-) = 0,1875$ mol ✓ (3)

2.2.2 0,006 mol of acid neutralises 0,006 mol of base ✓

$n(OH^-)$ in excess 0,1875 - 0,006= 0,1815 mol

$[OH^-] = \frac{n}{V}$

$[OH^-] = \frac{0,1815}{0,5+0,75}$ ✓

$[OH^-] = 0,1452 \text{ mol·dm}^{-3}$

$Kw = [H_3O^+][OH^-] = 1 \times 10^{-14}$

therefore $[H_3O+] = \frac{10^{-14}}{0,1452}$ ✓

$= 6,89 \times 10^{-14}$

$pH = -\log [H_3O^+]$ ✓

$pH = -\log(6,89 \times 10^{-14})$ ✓

$pH = 13,16$ ✓ (7)

[15]

EXAMPLE 3

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) + 2HCℓ(aq) → $CaCl_2$ (aq) + CO_2 (g) + H_2O (ℓ)
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 $[H_3O^+]$

$$1{,}61 = \log[H_3O^+] \checkmark$$
$$[H_3O^+] = 0{,}0245 \text{ mol.dm}^{-3} \checkmark$$

Calc. excess n of H_3O^+

$$.c = \frac{n}{V} \checkmark$$
$$0{,}0245 = \frac{n}{0{,}2} \checkmark$$
$$n(\text{excess}) = 4{,}9 \times 10^{-3} \text{ mol}$$

Calc. initial n of HCℓ…

$$c = \frac{n}{V} \quad n = 0{,}15 \times 0{,}2 \checkmark \; n = 3 \times 10^{-2} \text{ mol}$$

calc. reacted n of HCℓ

$$n(\text{reacted}) = n(\text{initial}) - n(\text{excess})$$
$$n(\text{reacted}) = 3\times10^{-2} - 4{,}9\times10^{-3} \checkmark$$
$$n(\text{reacted}) = 2{,}6 \times 10^{-2} \text{ mol}$$

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 $CaCO_3$ $n = \frac{m}{M}$

$$1{,}3\,x10^{-2} = \frac{m}{100} \checkmark$$
$$\therefore m = 1,3 \text{ g} \checkmark$$

Mass of impurities = 1,5 -1,3 ✓ = 0,2 g ✓

EXAMPLE 4

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.

4.1 When oxalic acid ionizes in water, it follows the steps given below:

STEP 1 $H_2C_2O_4(aq) + H_2O(l) \rightarrow HC_2O_4^-(aq) + H_3O^+(aq)$

STEP 2 $HC_2O_4^-(aq) + H_2O(l) \rightarrow C_2O_4^{2-}(aq) + H_3O^+(aq)$

4.1.1. Define a *weak acid*. (2)

4.1.2. Identify the acid-base conjugate pair in STEP 1. (2)

4.1.3. Give a reason why oxalic acid is referred to as a diprotic acid. (1)

4.2 The oxalate ion ($HC_2O_4^-$) can act as an ampholyte. Give a reason for this statement. In a volumetric flask 2, 25 g of oxalic acid is added to water to make up a standard solution to 250 cm^3.

4.2.1. Calculate the concentration of the oxalic acid solution. (3)

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. (4)

$H_2C_2O_4(aq) + 2NaOH(aq) \rightarrow Na_2C_2O_4(aq) + 2H_2O(\ell)$

4.2.2. Calculate the concentration of the sodium hydroxide. (4)

4.2.3. Explain why phenolphthalein would be a suitable indicator for this reaction. (2)

4.3. You are given the following ionisation reaction of ethanoic acid in water: $CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$ $K_a=1,8 \times 10^{-5}$

4.3.1. 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)

4.3.2. Assume 100% dissociation of magnesium hydroxide in water. What will the concentration of the hydroxide ions in the solution be? (2)

4.3.3. 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)

[28]

Solution:

4.1.1 Ionise incompletely in solution to form a low concentration oh hydronium ions. ✓ ✓ (2)

4.1.2 H_2O /H_3O+ and $H_2C_2O_4$ / HCO_4^- ✓ ✓ (2)

4.1.3 Oxalic acid can donate two protons (H^+) during its ionisation in an aqueous solutions/It ionises to form 2 protons. ✓✓ (2)

4.2.1 $c=\frac{m}{MV}$ ✓

$c=\frac{2.25}{90(0,25)}$ ✓

c=0,1 $mol{\cdot}dm^{-3}$✓ (3)

4.2.3 Phenolphthalein✓ is a suitable indicator for the titration of oxalic acid and sodium hydroxide because the reaction involves a strong base (NaOH) and a weak acid ($H_2C_2O_4$). The endpoint of the titration occurs when the pH is greater than 7. ✓

OR Because the salt of the titration will undergo hydrolysis and form a basic salt solution✓ (2)

4.3.1 $c = \frac{m}{MV}$ ✓0,2 $= \frac{m}{58(0,5)}$ ✓m = 5,8 g ✓ (3)

4.3.2 $[OH^-]$ =2(0,20) ✓$[OH^-]$ = 0,4 $mol{\cdot}dm^{-3}$ ✓ (2)

4.3.3. $[H_3O^+][OH^-] = 1 \times 10^{-14}$ ✓

$[H_3O^+](0.4) = 1 \times 10^{-14}$ ✓

$[H_3O^+] = 2,5 \times 10^{-14}$

$pH = -\log[H_3O^+]$ ✓

$pH = -\log([2,5 \times 10^{-14})$ ✓

pH = 13,60 ✓ NO, NOT SUITABLE for consumption (5)

[28]

ACTIVITIES

MULTIPLE CHOICE QUESTIONS:

1.1 Which ONE of the following indicators is most suitable for the titration of hydrochloric acid and sodium hydroxide?

	pH
A	0,2 -1,8
B	2,9 - 4,0
C	6,0 -7,6
D	11,6-14,0

(2)

1.2 Write down the conjugate base of the following acid:

$HC\ell O_4$

A $HC\ell O_3^-$
B $HC\ell O_4^-$
C ClO_4^-
D $H_2C\ell O_4$ (2)

1.3 The EQUIVALENCE POINT, when nitric acid is titrated with an ammonium hydroxide solution, is the point where …

A Neither the acid nor the base is in excess.
B The concentration of the indicator changes.
C $[H_3O^+] = [OH^-]$
D The pH = 7 (2)

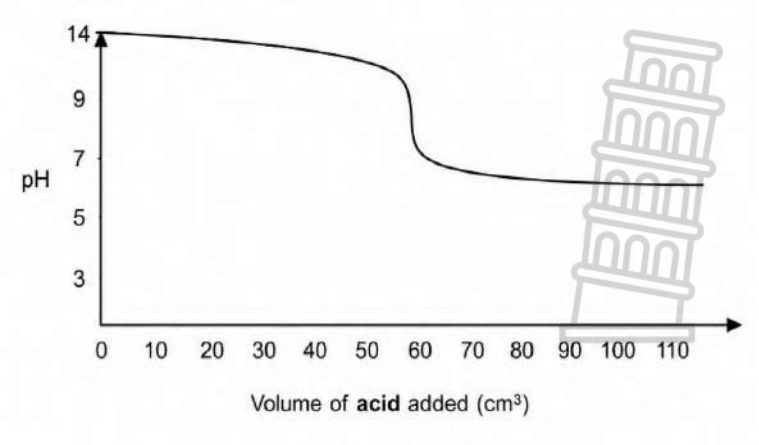
1.4 Which ONE of the following acids would ionise completely in water and form a high concentration of hydronium ions?

A Carbonic acid
B Phosphoric acid
C Nitric acid
D Ethanoic acid (2)

1.5 According to the Lowry-bronsted theory, a base…..

A Is a proton donor
B Is a proton acceptor
C Produces hydroxide ions in an aqueous solution.
D Produce hydrogen ions in an aqueous solution. (2)

1.6 The graph (not drawn to scale) for pH versus volume for the titration of an unknown acid with a base was obtained, which ONE of the following combinations and volume of acid best fits the graph.



A Strong acid-weak base
B Weak acid-strong base
C Strong acid-strong base
D Weak acid – weak base (2)

1.7 Water is added to a 0, 01 mol·dm^{-3} solution of Nitric acid. Which one of the following describes the change in concentration of hydronium ions and pH in this solution as water is added?

	[H_3O^+]	pH
A	Remain the same	Remain the same
B	Increases	Decreases
C	Increases	Increases
D	Decreases	Increases

(2)
[14]

STRUCTURED QUESTIONS:
QUESTION 2

Sulphuric acid, H_2SO_4, is an acid used in car batteries.

2.1 The equations below represent the ionisation of sulphuric acid.
Equation I : H_2SO_4 (aq) + H_2O (ℓ) ⇌ H_3O^+ (aq) + HSO_4^- (aq)
Equation II : HSO_4^- (aq) + H_2O(ℓ) ⇌ H_3O^+ (aq) + SO_4^{2-} (aq)

2.1.1 Is H_2SO_4 a strong or weak acid? (1)

2.1.2 Is sulphuric acid a MONOPROTIC or DIPROTIC acid? Provide a reason for your answer. (2)

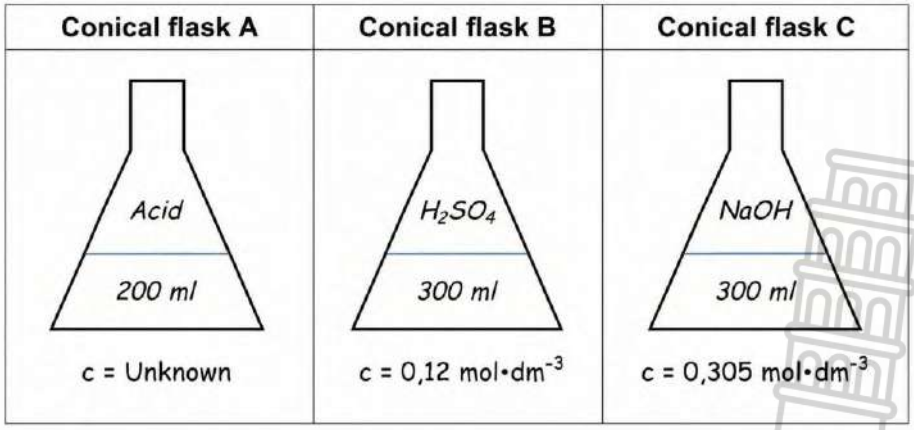
2.1.3 Write down the NAME of the conjugate base of hydrogen sulphate ion. (1)

2.2 Sodium hydrogen carbonate, $NaHCO_3$, is a salt with a pH slightly greater than 7

2.2.1 Define the term *Hydrolysis*. (2)

2.2.2 Write down a balanced chemical equation that explains why a sodium carbonate solution has a pH greater than 7 (3)

2.3. During a Chemistry practical lesson, a group of grade 12 learners notices three conical flasks A, B and C labelled as shown below. The learners mix the contents of the conical flasks A and B, assuming that both are sulphuric acid solutions. The total volume of the mixture obtained is now 150ml.



2.3.1 Calculate the pH of the H_2SO_4 solution in conical flask B, before the learners mixed it with the acid in conical flask A. (4)

Learners are now told that conical flask A contained a hydrochloric acid (HCl) solution of unknown concentration and are consequently tasked with performing a titration to neutralise the 500 ml acidic solution with the NaOH solution in conical flask C.

2.3.2 What indicator would be suitable for this titration? Choose from Methyl orange, Phenolphthalein or Bromothymol blue.
Give a reason for your choice. (2)

After performing the titration, they find that 20 ml of the acidic solution is completely neutralised by 16 ml of the Sodium hydroxide solution (NaOH) of concentration 0,305 mol·dm^{-3}

2.3.3 Calculate the concentration of the HCl solution that was initially present in conical flask A before it was mixed with the content of conical flask B. Conical flask B contained 0, 12 mol·dm^{-3} H_2SO_4 (10)

[26]

QUESTION 3

Hydrochloric acid (HCℓ) is a strong acid. It dissolves in water, as shown in the equation below:

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

3.1 Define an acid according to the *Arrhenius theory.* (2)

3.2 Explain what is meant by the term strong acid. (2)

3.3 Identify ONE conjugate acid-base pair. (2)

3.4 A 150 cm^3 hydrochloric acid, HCℓ (aq), solution with a concentration of 0, 8 mol·dm^{-3} is available for laboratory experiments.

3.4.1 Calculate the number of moles of hydrochloric acid in this solution. (3)

All of the 150 cm^3 hydrochloric acid solution, HCℓ (aq) is allowed to react with X g of calcium carbonate, $CaCO_3$(s), according to the balanced chemical equation.

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

The hydrochloric acid solution is found to be in excess.

The excess hydrochloric acid, HCℓ (aq) is neutralised by a 60 cm^3 sodium hydride NaOH (aq) solution with a concentration of 0,5 mol·dm^3.

The neutralisation reaction is as shown below:

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

3.4.2 Calculate the value of X. (7)

3.4.3 Will the salt that is formed in the neutralisation reaction undergo hydrolysis? Give a reason for the answer. (2)

3.4.4 Bromothymol blue is used as the indicator. Explain why it is the suitable indicator for this titration by referring to the pH at the equivalence point. (2)

3.5 In aqueous solutions, the concentrations of hydronium ions and hydroxide ions determine the acidity and alkalinity of a solution.

Calculate the pH of potassium hydroxide, KOH (aq), solution with concentration of 2,5 x 10^{-7} mol·dm^{-3} at a temperature of 298K (4)

A learner adds a sample of calcium carbonate to 50,0 cm^3 of sulphuric acid. The sulphuric acid is in excess and has a concentration of 1,0 mol·dm^{-3}. The balanced equation for the reaction that takes place is:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O \text{ .....}$$

The reaction is allowed to proceed until all the $CaCO_3$ is used up.

The H_2SO_4 left over from **REACTION 1** is now neutralised by 28,0 cm^3 of a 0,5 mol·dm^{-3} sodium hydroxide solution.

The balanced equation for this reaction is:

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

3.6 Calculate the mass of calcium carbonate in the sample in **REACTION 1**. (10)

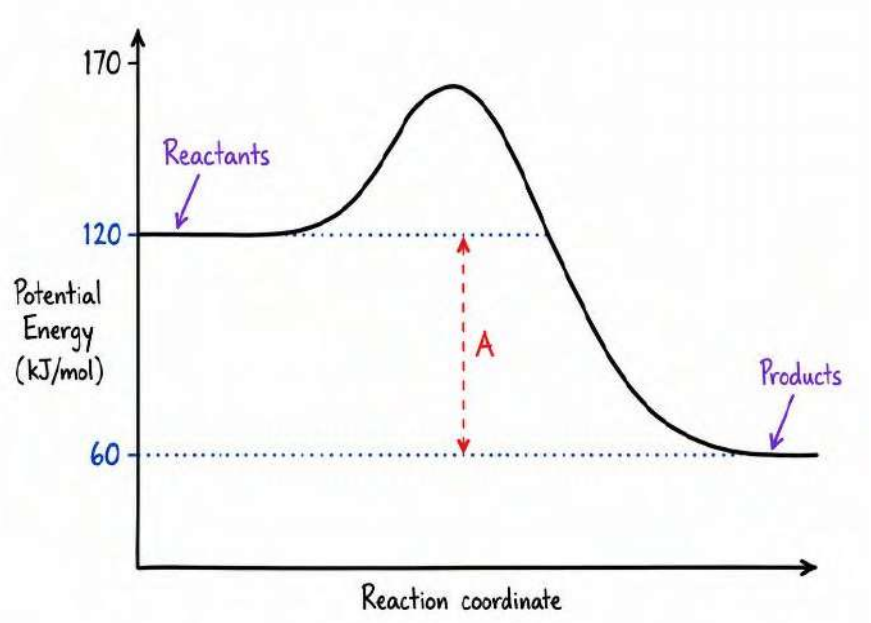
[34]

QUESTION 4

4.1 Equilibrium is established at 25 °C in an ionisation of hydrochloric acid according to the reaction.

$$HC\ell(g) + H_2O(\ell) \rightleftharpoons Cl^-(aq) + H_3O^+(aq)$$

The graph below shows the energy profile for the ionisation of hydrochloric acid above.



4.1.1 Is the ionisation of hydrochloric acid an exothermic or endothermic reaction? Provide a reason by referring to the graph. (2)

4.1.2 Write down ONE conjugate acid-base pair from the ionisation of hydrochloric acid above. (2)

4.1.3 A few drops of concentrated nitric acid, HNO_3 (conc.) are added to the equilibrium mixture. What effect does this addition have on the amount of $HC\ell$ (g)? Choose from INCREASES, DECREASES or REMAIN THE SAME. (1)

4.1.4 Explain the answer to Question 4.1.3. By using Le Chatellier's principle. (2)

4.2 A certain volume of a hydrochloric acid solution of concentration 0, 5 $mol \cdot dm^{-3}$ is added to a sample of seashells of mass 8 g in a container. The seashell contains 95% $CaCO_3$.

The hydrochloric acid solution ($HC\ell$) COMPLETELY reacts with calcium carbonate (CaCO3) in the sample according to the balanced

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

Calculate the volume, in cm^3, of the hydrochloric acid ($HC\ell$) that was added to the sample inside the container. (7)

[14]

QUESTION 5

5.1 Consider the equation for the ionisation of the HSO_3^- ion:

$$HSO_3^-(aq) + H_2O \rightleftharpoons SO_3^{2-}(aq) + H_3O^+ \quad Ka = 6,5 \times 10^{-8}$$

5.1.1 Define the term *Ionisation*. (2)

5.1.2 Give the formulae of TWO amphiprotic substances shown in the above equation. (2)

5.1.3 Explain what the size of the Ka value for this reaction indicates about HSO_3^-. (2)

5.1.4 Give the NAME of the conjugate acid of HSO_3^-. (1)

5.2 3 g of impure magnesium carbonate, $MgCO_3$, is added to 75 cm^3 of sulphuric acid of concentration of 0, 5 $mol \cdot dm^{-3}$.

The balanced equation for the reaction that takes place is:

$$MgCO_3\ (s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + CO_2(g) + H_2O(\ell) \ldots\ldots(i)$$

The reaction is allowed to proceed until all the pure magnesium carbonate reacts. The excess sulphuric acid is neutralised by adding 28 cm^3 of sodium of sodium hydroxide solution of concentration 0,5 $mol \cdot dm^{-3}$.The balanced equation for the neutralisation reaction is:

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

Calculate the percentage purity of the magnesium carbonate. (10)

[17]

QUESTION 6

6.1 A standard solution of NaOH with a pH of 13, 4 is used to neutralise 3,125 cm^3 of a 0, 4 $mol \cdot dm^{-3}$ solution of H_2SO_4. The balanced chemical equation of the reaction is:

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

6.1.1 Define the term *standard solution.* (2)

6.1.2 Is NaOH a strong acid or weak base? Provide a reason for your answer. (2)

6.1.3 Calculate the concentration of the NaOH solution acid. (5)

6.1.4 Calculate the volume of the NaOH needed to neutralise the acid. (5)

6.2 A laboratory technician neutralises an accidental spill by pouring 5 g of baking soda ($NaHCO_3$) on a 50 cm^3 hydrochloric acid solution of concentration 1, 6 $mol \cdot dm^{-3}$.

$$HC\ell\ (aq) + NaHCO_3\ (s) \rightarrow NaC\ell(aq) + CO_2\ (g) + H_2O\ (\ell)$$

Calculate the pH of the final solution. Assume the volume remains constant. (7)

[21]

QUESTION 7

7.1 NH_3 reacts with $HC\ell$ to form a salt as shown below:

$$NH_3(g) + HC\ell \rightarrow NH_4C\ell(s)$$

7.1.1 Identify the base in the above equation. (1)

7.1.2 Give a reason for your answer to Question 7.1.1. (1)

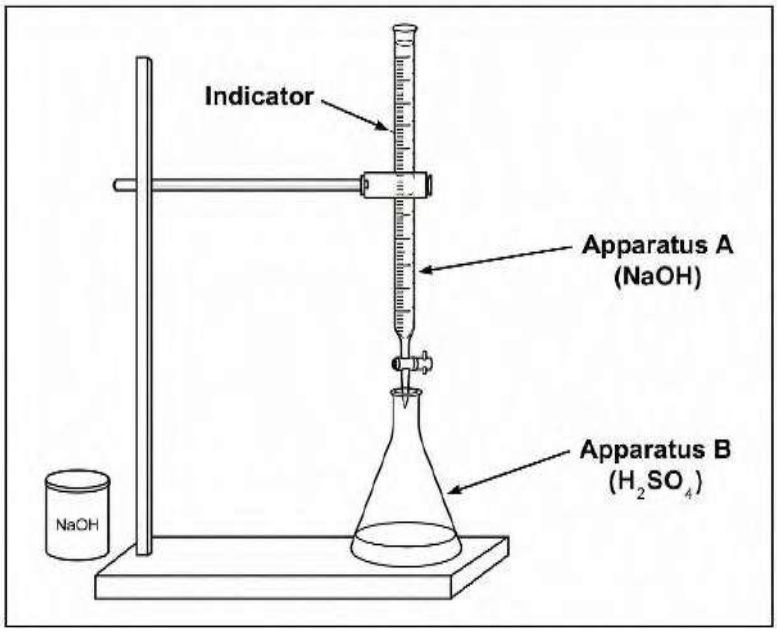
7.1.3 Write down the NAME of the salt formed. (1)

7.2 NH_4Cl can undergo hydrolysis.

7.2.1 Define the term *Hydrolysis.* (2)

7.2.2 Write down a balanced equation for the hydrolysis of $NH_4C\ell$ and indicate whether the solution will be Acidic, alkaline, or Neutral. (3)

7.3 The diagram below shows the titration of 25 ml of sulphuric acid of unknown concentration with 0, 2 $mol \cdot dm^{-3}$ sodium hydroxide.



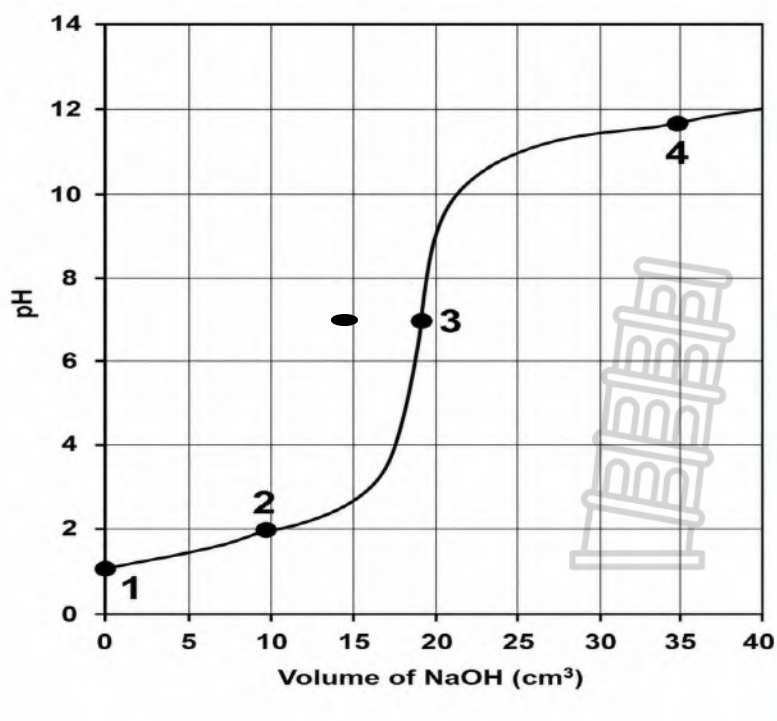
The balanced equation the reaction is:

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

7.3.1 Identify apparatus A (1)

7.3.2 Bromothymol blue was used as the indicator in the titration above. Write down the colour change observed. Choose between Blue to Yellow or Yellow to Blue (1)

During this titration, the pH of the solution was measured as the volume of the base increased. The following graph was produced.



7.3.3 Give the name of the position Labelled **3** on the Graph. Choose from Equivalence point or Endpoint. (1)

Use the graph and the information provided earlier to calculate:

7.3.4 The Original concentration of the sulphuric acid (5)
7.3.5 The pH of the solution at the point labelled **4** on the graph. (7)
[23]

QUESTION 8

8.1) 1The equations below show the reactions occurring in hydrochloric acid (HCℓ) and ethanoic acid (CH_3COOH) solutions. Both acids a have a concentration of 1,0 $mol \cdot dm^{-3}$ and are kept constant of temperature of 25^0C

I $HC\ell\ (aq) + H_2O(\ell) \rightleftharpoons C\ell^-\ (aq) + H_3O^+(aq)$ Ka = 1,3 x 10 ^{6}
II $CH_3COOH\ (aq) + H_2O\ (\ell) \rightleftharpoons CH_3COO^-\ (aq) + H_3O^+\ (aq)$ Ka=1,8 $x10^{-5}$

8.1.1 Define and acid according to the *Lowry Bronsted theory* (2)
8.1.2 Write down ONE conjugate acid-base pair in reaction **I** (2)
8.1.3 Which solution, I or II, will have a lower pH value?
Explain your answer. (3)

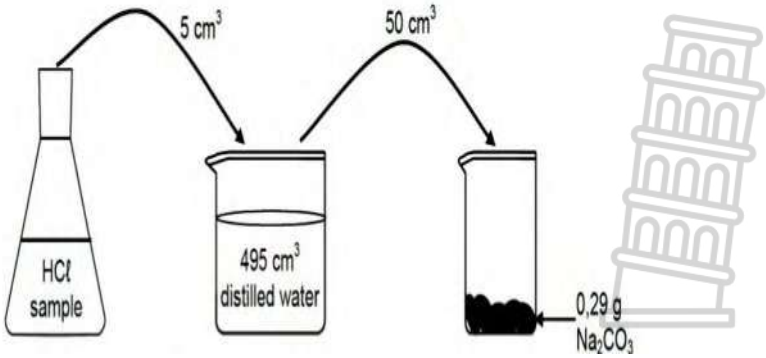
8.2) 10 cm^3 of a 1, 0 $mol \cdot dm^{-3}$ sodium hydroxide (NaOH) solution is diluted with water until its pH is 13.

8.2.1 Calculate the number of moles of NaOH in the 10cm^3 of the initial solution. (3)
8.2.2 Calculate the volume of the diluted solution in dm^3 (5)

All of the diluted sodium hydroxide solution is poured into a burette. During a titration, 15cm^3 of oxalic acid concentration 0, 09 $mol \cdot dm^{-3}$ is exactly neutralized by a certain volume of the diluted sodium hydroxide solution.
The balanced equation for the reaction is:
$2\ NaOH\ (aq) + H_2C_2O_4\ (aq) \rightarrow Na_2C_2O_4\ (aq) + 2\ H_2O\ (\ell)$

8.2.3 Calculate the volume of the diluted sodium hydroxide that is left in the burette after the titration. (5)

8.3) A laboratory technician wants to determine the concentration of a hydrochloric acid (HCℓ) sample. He adds 5 cm^3 of the HCℓ sample to 495 cm^3 of distilled water to give 500 cm^3 of dilute hydrochloric acid, HCℓ (aq). During a reaction 50 cm^3 of this dilute hydrochloric acid solution, HCℓ (aq) reacts completely with 0,29 g of sodium carbonate $Na_2CO_3(s)$



The balanced equation for the reaction is:
$Na_2CO_3\ (s) + 2HC\ell(aq) \rightarrow 2NaC\ell\ (aq) + CO_2\ (g) + H_2O(\ell)$
Calculate the concetration of the hydrochoric acid sample. (7)

[27]

QUESTION 9

9.1 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.

9.1.1 Describe the term *amphoteric substance.* (2)

9.1.2 Write down the formula of an amphoteric chemical substance (other than H_2O) (1)

9.1.3 Write down the formulae of the conjugate acid-base pairs in reaction B. (2)

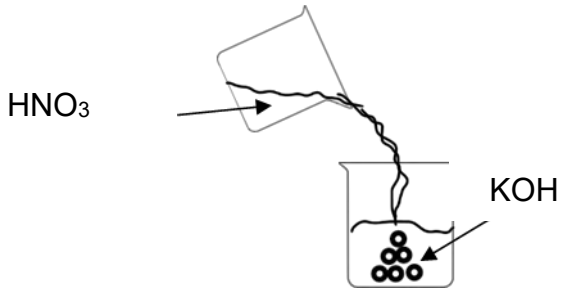
9.2 Which indicator must be used in reaction A. Choose from METHYL ORANGE, BROMOTHYMOL BLUE or PHENOLPHTHALEIN? Give a reason for the answer. (3)

9.3 Consider reactions A and C, shown below.

A $HNO_3 + KOH \rightarrow KNO_3 + H2O$

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.

9.3.1 Determine the amount (in mol) of nitric acid that was added to the KOH. (2)

9.3.2 Calculate the percentage purity of the KOH sample (9)

[19]

MATTER AND MATERIALS

ORGANIC MOLECULES

Hydrocarbon: Organic compounds that consist of hydrogen and carbon only.

Saturated compounds: Compounds in which there are no multiple (double or triple) bonds between C atoms in their hydrocarbon chains.

Unsaturated compounds: Compounds with one or more multiple (double or triple) bonds between C atoms.

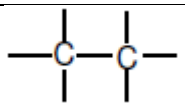
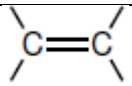
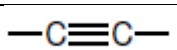
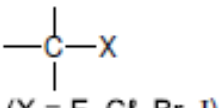
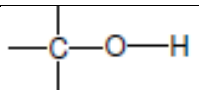
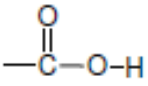
Molecular formula: A chemical formula that indicates the type of atoms and the correct number of each in a molecule.

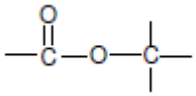
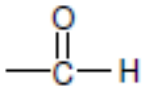
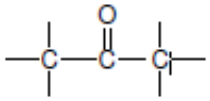
Structural formula: A structural formula of a compound shows which atoms are attached to which within the molecule.

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.

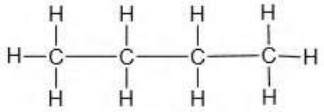
Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

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

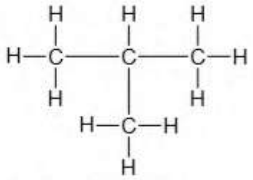
Esters		Esteryl group	RCOOR	-yl -anoate
Aldehydes		Formyl group	RCHO	-anal
Ketones		Carbonyl group bonded to C-atoms	RCOR'	-anoate

Structural isomers: 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.

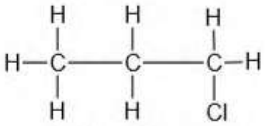


butane

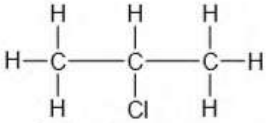


2-methylpropane

    - **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

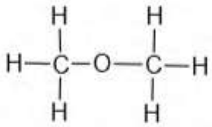


1-chromopropane

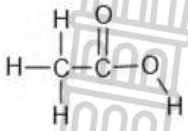


2-chromopropane

    - **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.
- 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)
Factors that influence the strength of IMF

1. Surface area

Length of the carbon chain and branched molecules. For compounds that belong to the same homologous series, the larger the surface area the higher the Melting point, the Boiling point, the Viscosity and the lower the vapour pressure.

- The more branched the organic molecules are, the more compact it becomes.
- The surface area is smaller and less Van der Waals forces are available.
- The IMF are weaker resulting in lower boiling points and melting points.
- The vapour pressure will increase.

2. The type of functional group OR homologous series

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.

London forces (Only)	**Dipole-dipole forces** In addition to London forces	**Hydrogen bonds** in addition to dipole-dipole and london forces
Alkanes Alkenes Alkynes	Ketones Aldehydes Esters Haloalkanes	Alcohols (ONE site of hydrogen Bond) Carboxylic acids (TWO sites of hydrogen bonds)

Stronger Intermolecular forces	**Weaker Intermolecular forces**
• Higher boiling point • Higher melting point • More energy needed to overcome the Intermolecular forces • Lower vapour pressure	• Lower boiling point • Lower melting point • Less energy needed to overcome the Intermolecular forces • Higher vapour pressure

Guideline for answering questions

1. State homologous series and type of intermolecular force
2. Compare the strength of intermolecular forces
3. Energy required
4. Conclusion

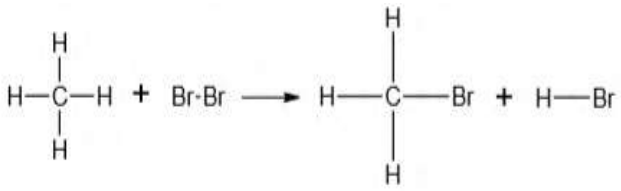
ORGANIC REACTIONS

- 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 = Cℓ, Br) with alcohols to produce haloalkanes
  - Halogenation of alkanes: The reaction of a halogen (Br_2, $C\ell_2$) with a compound
- Distinguish between saturated and unsaturated hydrocarbons using bromine water.

REACTIONS OF ALKANES

1. SUBSTITUTION

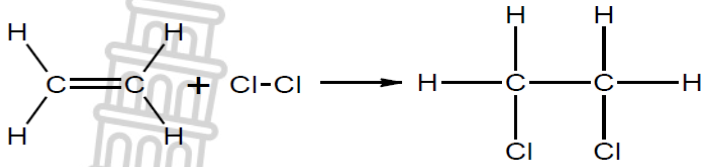
Alkane → haloalkane



Conditions: Heat/ Sunlight (UV/ hf)
Reactants: Alkane + X_2 (F_2, Cl_2, I_2, Br_2)
Type of substitution: Halogenation/ bromination. *Substitution reaction will only occur when the compound is saturated.*

REACTIONS OF ALKENES

1. ADDITION REACTION (Halogenation)

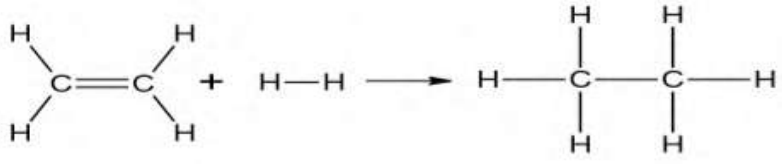


Conditions: Unreactive solvent
Type of addition: halogenation
Reactants: alkene + X_2 (X = Cl, Br)
Product: haloalkane

Bromine test: to distinguish between **alkane** and **alkene**

- Add bromine water (orange-brown) to unknown molecules.
- If bromine water discolours the molecule immediately, the molecule is an alkene.
- $CH_2CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$

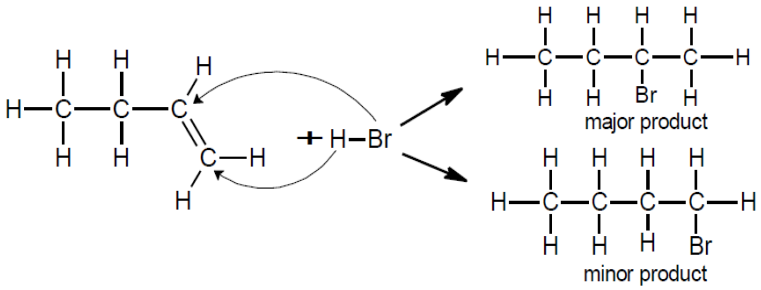
ADDITION REACTION 2 (Hydrogenation)



Conditions: Pt, Pd or Ni as catalyst
Type of addition: hydrogenation
Reactants: alkene + H_2
Product: Alkane

Application: Hydrogenation of unsaturated vegetable oils is used to manufacture margarine.

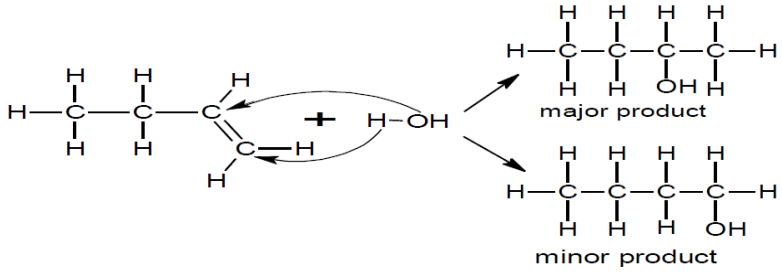
ADDITION REACTION 3 (Hydrohalogenation)



Conditions: No water; Unreactive solvent
Type of addition: hydrohalogenation
Reactants: alkene + HX (X = I, Br, Cl)
Product(s): haloalkane(s)

Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. ***(Markovnikov's rule)***

ADDITION REACTION 4 (Hydration)



Conditions: Excess H_2O; Acid (H_2SO_4/ H_3PO_4) as catalyst.
Type of addition: hydration
Reactants: alkene + H_2O Product: Alcohol(s)
Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. ***(Markovnikov's rule)***

Addition reaction will only occur when the compound is unsaturated.

ELIMINATION REACTIONS

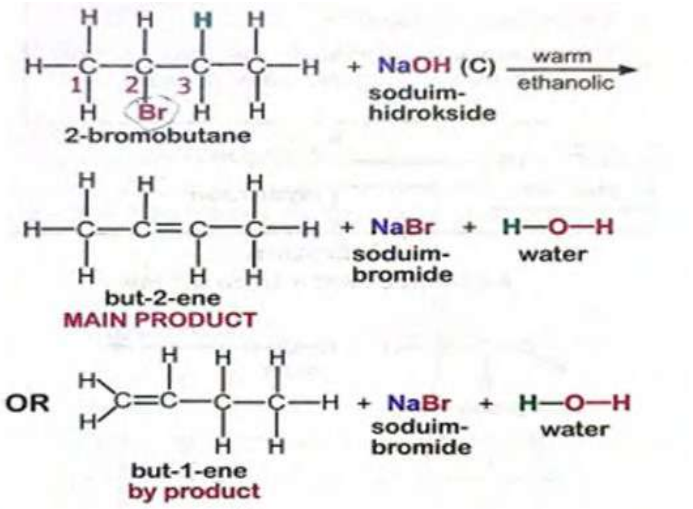
Dehydrohalogenation (Haloalkane → alkene)

Reactants: haloalkane + concentrated strong base (NaOH/KOH/LiOH)

Removal of: X-atom and H-atom

Products: alkene + salt + water

Reaction conditions: concentrated strong base (NaOH/KOH/LiOH). Dissolve in ethanol. Heat strongly under reflux.



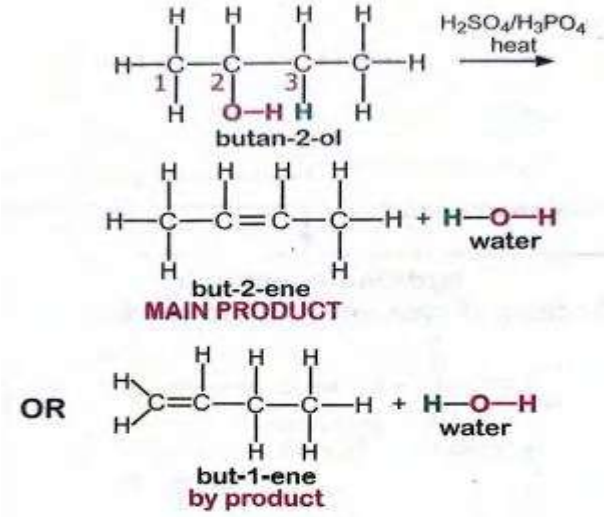
Dehydration (Alcohol → alkene)

Reactants: Alcohol + concentrated H_2SO_4

Removal of: OH-group and H-atom

Products: alkene + water

Reaction conditions: concentrated strong acid (H_2SO_4/H_3PO_4) as catalyst (dehydrating medium)



Cracking

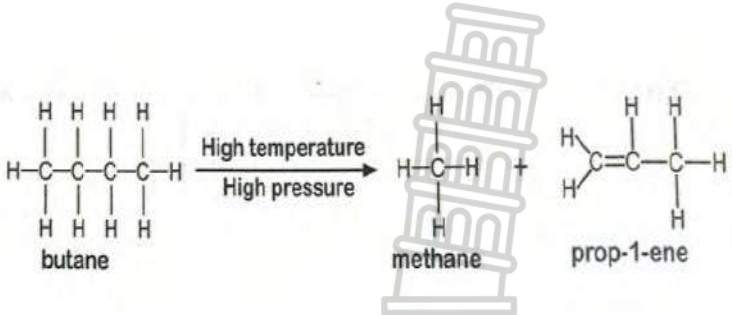
Reactants: Long alkane chains

Products: Shorter alkane + shorter alkene/s or alkene + H_2

Reaction conditions:

Thermal cracking- higher temperature and higher pressure

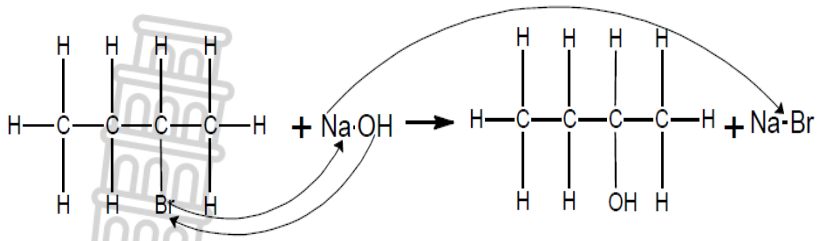
Catalytic cracking- lower temperature and lower pressure as well as catalyst(Pt, Pd, or Ni)



REACTIONS OF HALOALKANES

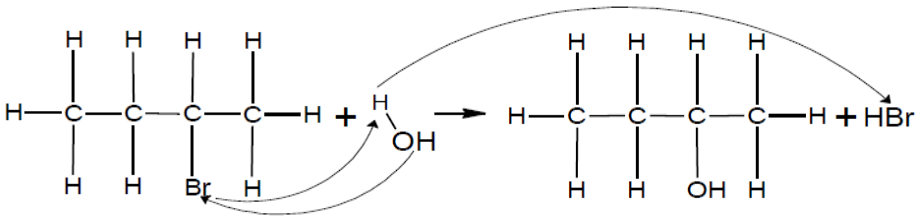
1. SUBSTITUTION:

Haloalkane → alcohol



Conditions: Diluted strong base (NaOH/KOH/LiOH) + mild heat
Type of substitution: hydrolysis/ hydration

Reactants: Haloalkane in ethanol + diluted strong base
Products: Alcohol + NaBr/KBr/LiBr



Conditions: Excess H_2O + mild heat
Type of substitution: hydrolysis
Reactants: Haloalkane + H_2O

Products: Alcohol + HBr

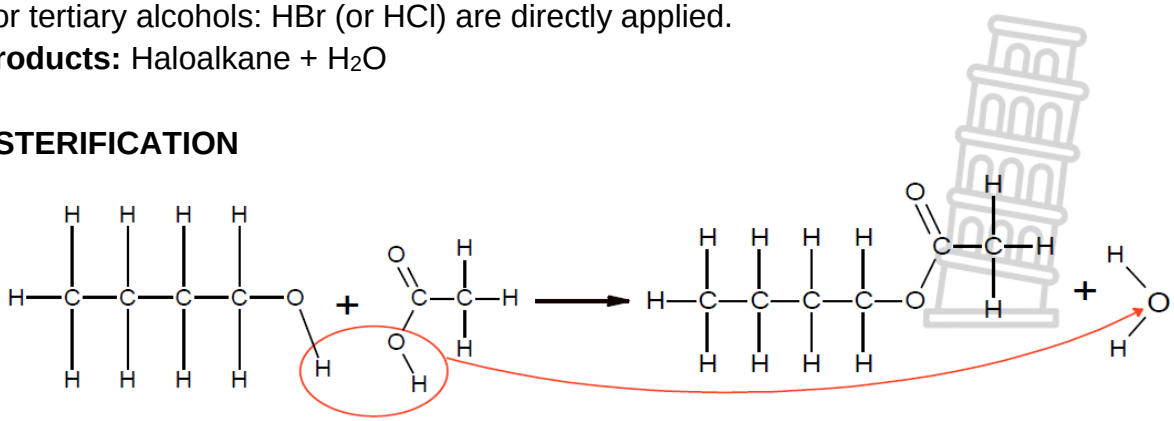
REACTIONS OF ALCOHOL
1. SUBSTITUTION

Alcohol → haloalkane

Conditions: Heat
Reactants needed: Alcohol + HX

For primary & secondary alcohols: NaBr + conc. H_2SO_4 is used to prepare HBr in reaction flask.
For tertiary alcohols: HBr (or HCl) are directly applied.
Products: Haloalkane + H_2O

ESTERIFICATION



Conditions: Concentrated H_2SO_4 as catalyst + heat
Reactants: Alcohol + carboxylic acid in the presence of H_2SO_4 catalyst
Products: Ester + water

- The process whereby esters is formed is called **esterification.**

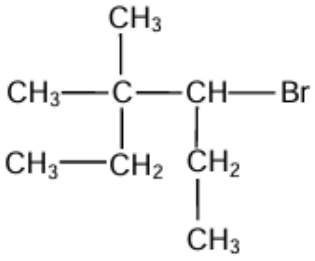
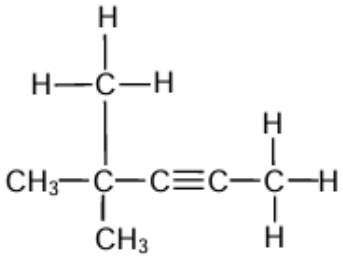
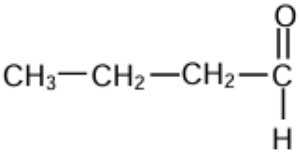
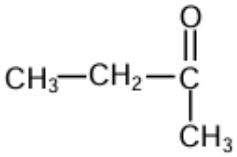
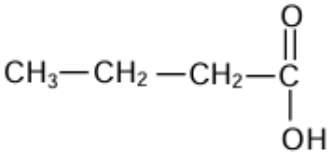
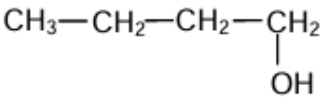
- Esters form when an **alcohol** reacts with a **carboxylic acid** when **heated** (condensation reaction).
- The catalyst is **concentrated sulphuric acid (H_2SO_4)**, a **dehydrating agent** that **extracts** the **water.**
- The **homologous series** is **esters** and the name, therefore, ends in "**-oate".**
- The **alcohol** serves as the **alkyl** and the **carboxylic acid** is the **alkanoate**

The name of the ester example above is therefore, **butyl ethanoate.**

WORKED EXAMPLES

EXAMPLE 1

A to **F** in the table below represent six organic compounds.

A		**B**	
C		**D**	
E		**F**	

1.1 Write down the:

1.1.1 Letters that represent TWO organic compounds that are isomers of each other (1)

1.1.2 Type of isomers (CHAIN, FUNCTIONAL or POSITIONAL) identified in QUESTION 1.1.1 (1)

1.1.3 GENERAL FORMULA of the homologous series to which compound **B** belongs (1)

1.1.4 NAME of the functional group of compound **F** (1)

1.2 Write down the IUPAC name of:

1.2.1 Compound A (3)

1.2.2 Compound B (2)

1.2.3 Compound C (2)

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SOLUTIONS FOR WORKED EXAMPLE 1

1.1.1 C and D ✓ (1)
1.1.2 Functional isomers✓ (1)
1.1.3 C_nH_{2n-2} ✓ (1)
1.1.4 Hydroxyl ✓ (1)
1.2.1 4-bromo-3,3-dimethylhexane ✓✓✓ (3)
1.2.2 4,4-dimethylpent-2-yne ✓✓ (2)
1.2.3 Butanal ✓✓ (2)

Example 2

2.1 The melting points of some organic compounds are given in the table below.

COMPOUND	IUPAC NAME	MELTING POINTS (°C)
A	Propanone	-95,4
B	Butanone	-86,9
C	Pentan-2-one	-77,8
D	3-methylbutanone	-92

2.1.1 To which homologous series do the above compounds belong? (1)
The melting points of compounds **A**, **B** and **C** are compared.
2.1.2 Write down the controlled variable for this comparison. (1)
The melting points of compounds **C** and **D** are compared.
2.1.3 Fully explain the difference in the melting points of these two compounds. (4)

2.2 The table below shows the results obtained from an experiment to determine the vapour pressure of different STRAIGHT CHAIN primary alcohols at 300 K.

ALCOHOL	VAPOUR PRESSURE (kPa)
CH_3OH	16,8
C_2H_5OH	7,88
C_3H_7OH	2,8
C_4H_9OH	0,91
$C_5H_{11}OH$	0,88
$C_6H_{13}OH$	0,124

2.2.1 Define the term *vapour pressure*. (2)
2.2.2 Write down a suitable conclusion for this investigation. (2)
2.2.3 Write down the IUPAC name of the alcohol with the HIGHEST boiling point. (2)
2.2.4 The experiment is now repeated at 320 K. Will the vapour pressure of each compound INCREASE, DECREASE or REMAIN THE SAME? (1)

SOLUTIONS FOR WORKED EXAMPLE 2

2.1.1 Ketone ✓
2.1.2 Functional group/ homologous series ✓
2.1.3 **Pentan -2-one/C**

- **Structure:**
  Longer chain length/less branched/less compact/less spherical/larger surface area (over which intermolecular forces act). ✓
- **Intermolecular forces:**
  Stronger intermolecular forces/Van der Waals forces/*London forces*/ dipole-dipole forces. ✓
- **Energy:** More energy needed to overcome the intermolecular forces/Van der Waals forces/dipole-dipole forces. ✓
  Higher melting point. ✓

2.2.1 The pressure exerted by a vapour at equilibrium with its liquid in a closed system.✓✓

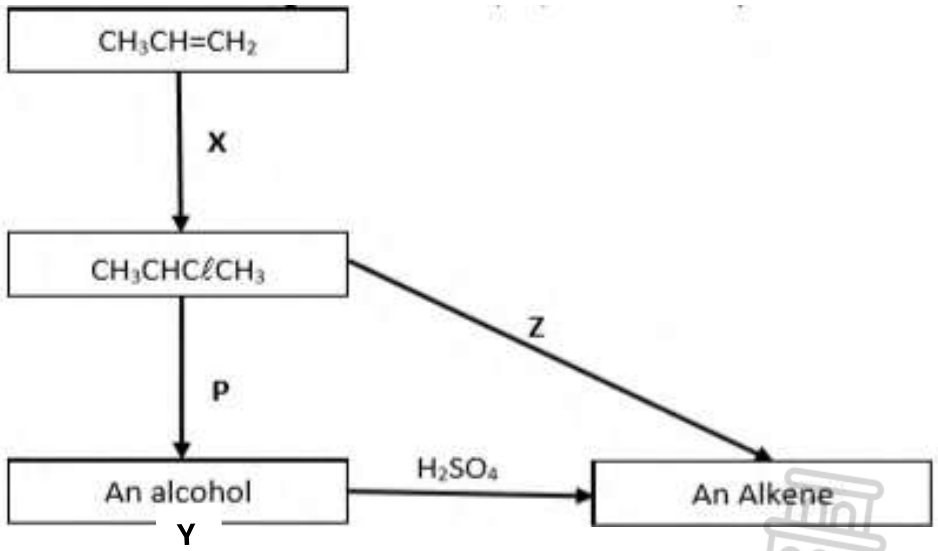
2.2.2 Vapour pressure decreases with increase in number of C atoms/chain length. ✓ ✓

2.2.3 Hexan-1-ol ✓ ✓

2.2.4 Increases ✓

EXAMPLE 3

The flow diagram below shows the preparation of the organic compounds using $CH_3CH=CH_2$ as starting material. X, Y, Z and P represent different organic reactions.



3.1. To which homologous series does $CH_3CH=CH_2$ belong? (1)

3.2. Write down the:

3.2.1 Type of reaction of which X is an example (1)

3.2.2 Structural formula and IUPAC name of the alcohol produced during reaction P. (3)

3.2.3 The type of reaction of which Y is an example. (1)

3.2.4 Function of the acid in reaction Y. (1)

3.3 For reaction Z, write down:

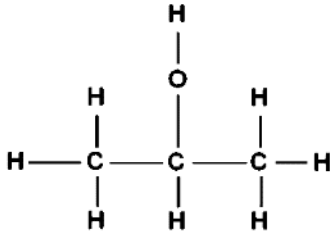
3.3.1 The NAME of the inorganic reagent needed. (1)

3.3.2 TWO reaction conditions needed. (2)

SOLUTIONS FOR WORKED EXAMPLE 3

3.1 Alkene ✓

3.2.1 Addition/ Hydrohalogenation ✓

3.2.2 

Propan-2-ol ✓ ✓ ✓

3.2.3 Elimination/ dehydration ✓

3.2.4 It serves as a dehydrating agent. ✓

3.3.1 Sodium hydroxide/ Potassium hydroxide ✓

3.3.2 Concentrated strong base (NaOH/ KOH) ✓ , Heat under reflux ✓

QUESTION 1 (MULTIPLE CHOICE QUESTIONS)

1.1 Which ONE of the compounds below is a carboxylic acid?

A CH_3CHO
B CH_3COCH_3
C CH_3COOH
D CH_3OH (2)

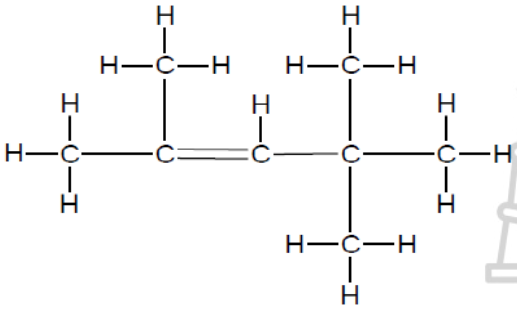
1.2 The reaction represented by the equation below takes place in the presence of a catalyst.

$$C_{13}H_{28}\ (l) \longrightarrow C_2H_4\ (g) + X\ (g) + C_8H_{18}\ (l)$$

What is the molecular formula of compound **X?**

A CH_4
B C_3H_6
C C_3H_8
D C_3H_4 (2)

1.3 Consider the structural formula of an organic compound below.



Which ONE of the following is the correct IUPAC name of this compound?

A 2,2,4-trimethylpent-2-ene
B 2,2,4-trimethylpent-3-ene
C 2,4,4-trimethylpent-2-ene
D 2,4,4-trimethylpent-3-ene (2)

1.4 Which ONE of the following compounds has two sites of hydrogen bonds between its molecules?

A Ethanal
B Ethanol
C Ethene
D Ethanoic acid (2)

1.5 Which ONE of the following is the correct formula of methylbutanoate?

A $CH_3CH(OH)CH(CH_3)CH_3$
B $HCOOCH(CH_3)CH_2CH_3$
C $CH_3CH_2CH(CH_3)CHO$
D $CH_3COCH(CH_3)CH_3$ (2)

1.6 How many types of Van der Waals forces are present between the molecules of CH_3CH_2Br?

A 1
B 2
C 3
D 4

1.7 A compound $CH_3(CH_2)_5CH_3$ undergoes the following reaction

$$CH_3(CH_2)_5CH_3 \longrightarrow \mathbf{R} + CH_3(CH_2)_2CH_3$$

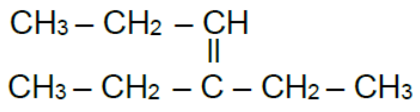
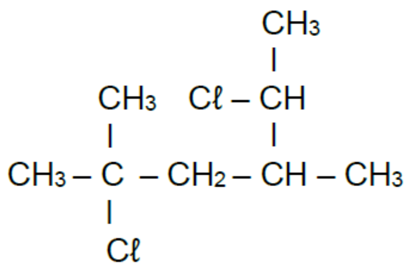
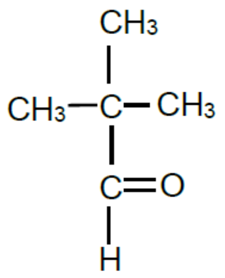
Which ONE of the following combinations CORRECTLY describes the type of reaction and the IUPAC name of compound **R**? (2)

	TYPE OF REACTION	**IUPAC NAME**
A	Elimination	Propane
B	Addition	Propene
C	Cracking	Propane
D	Cracking	Propene

STRUCTURED QUESTIONS

QUESTION 2

The letters A to H 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 letters(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)

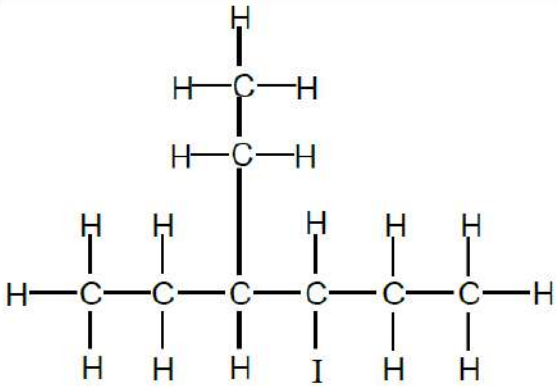
2.4.3 H (2)

2.5 Compound B undergoes complete combustion. Using MOLECULAR FORMULAE, write down the balanced equation for this reaction. (3)

[22]

QUESTION 3

The letters A to F in the table below represent organic compounds.

A	$C_5H_{10}O$	**B**	
C	Butanoic acid	**D**	$(CH_3)_3COH$
E	$CH_2C(CH_3)_2$	**F**	$HCOOCH_2CH_2CH_3$

3.1 Define the term *unsaturated compound.* (2)

3.2 Write down the LETTER that represents EACH of the following:

3.2.1 An unsaturated compound (1)

3.2.2 A functional isomer of compound C (1)

3.3 Name the TWO homologous series to which A belongs. (2)

3.4 Is compound D a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)

3.5 Write down the IUPAC name of:

3.5.1 Compound B (3)

3.5.2 The POSITIONAL isomer of compound D (2)

3.6 Ethanol reacts with compound C to form an organic compound Z.
Write down the:

3.6.1 Type of reaction (1)

3.6.2 STRUCTURAL FORMULA of compound Z (2)

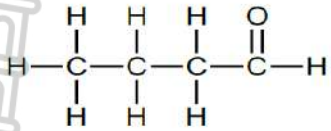
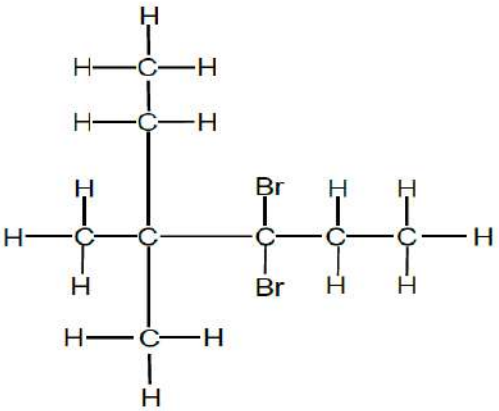
3.7 Write down the:

3.7.1 Empirical formula of compound F (1)

3.7.2 STRUCTURAL FORMULA of the CHAIN ISOMER of compound E. (2)

QUESTION 4

The letters **A** to **H** in the table below represent eight 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**	$CH_3C(CH_3)_2CH_2CH_3$

4.1 Write down the LETTER that represents EACH of the following:

4.1.1 An alcohol (1)

4.1.2 A compound with a formyl group (1)

4.1.3 An unsaturated compound (1)

4.2 Write down the IUPAC name of compound:

4.2.1 B (3)

4.2.2 E (3)

4.3 Two different compounds in the above table are functional isomers.

4.3.1 Define the term *functional isomer.* (2)

4.3.2 Write down the LETTERS that represent these functional isomers. (1)

4.4 Compound **F** is formed when a carboxylic acid reacts with another organic compound, **X,** in the presence of a catalyst.

Write down the:

4.4.1 NAME or FORMULA of the catalyst (1)

4.4.2 Type of reaction (1)

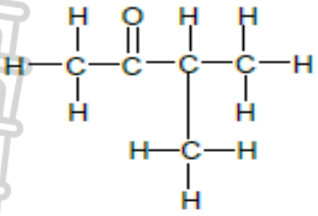
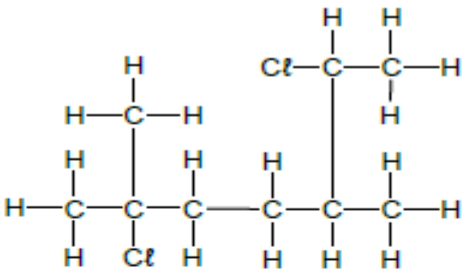
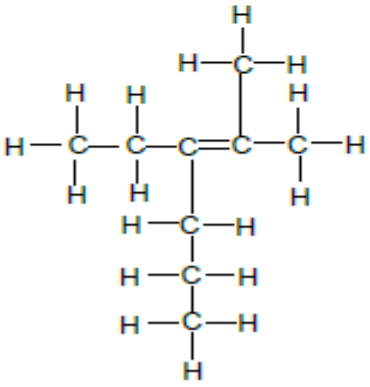
4.4.3 STRUCTURAL FORMULA of compound **F** (2)

4.4.4 IUPAC name of compound **X** (2)

[18]

QUESTION 5

The letters A to G in the table below represent organic compounds.

A		B	
C	$CH_3CH(CH_3)CH_2CHO$	D	$C_4H_{10}O$
E	C_3H_8	F	Pentane
G			

5.1 Write down the LETTER(S) that represent(s) EACH of the following:

5.1.1 An alcohol (1)

5.1.2 TWO compounds that are functional isomers of one another (1)

5.1.3 TWO compounds that belong to the same homologous series (1)

5.2 Write down the:

5.2.1 IUPAC name of compound A (3)

5.2.2 IUPAC name of compound B (3)

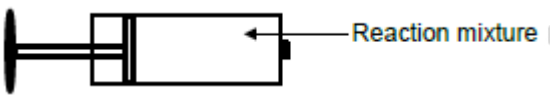
5.2.3 IUPAC name of compound G (3)

5.2.4 STRUCTURAL FORMULAE of two STRAIGHT CHAIN positional isomers of compound D (4)

5.3 Compound E, $C_3H_8(g)$, reacts with oxygen, $O_2(g)$, according to the balanced equation:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

Initially 8 cm^3 of compound E and 50 cm^3 of oxygen were injected into a container of adjustable volume and allowed to react.



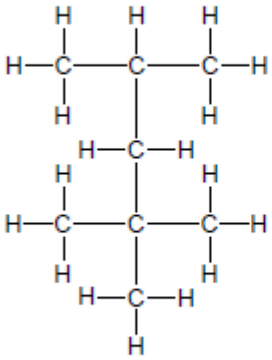
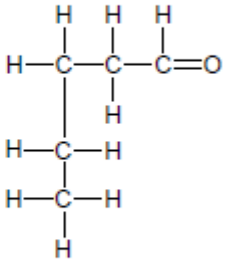
5.3.1 Write down the name for this type of reaction. (1)

5.3.2 Calculate the TOTAL volume of the GASES present in the container at the end of the reaction. (5)

[22]

QUESTION 6

The letters A to F in the table below represent organic compounds.

A	$CH_3COCH(CH_3)_2$	B	3,3-dimethylhexane
C		D	
E	$C_2H_4O_2$	F	Propan-1-ol

6.1 Write down the letter(s) representing:

6.1.1 An aldehyde (1)

6.1.2 Functional isomers (1)

6.1.3 A carboxylic acid (1)

6.2 Write down the general formula of the homologous series to which compound B belongs. (2)

6.3 For compound C, write down the:

6.3.1 Letter of the molecule that is its structural isomer (1)

6.3.2 Type of structural isomerism named in QUESTION 6.3.1 (1)

6.3.3 IUPAC name (3)

6.4 For compound A, write down the structural formula of its chain isomer. (3)

6.5 Compounds E and F react to form an organic molecule. For this reaction, write down the:

6.5.1 Type of reaction (1)

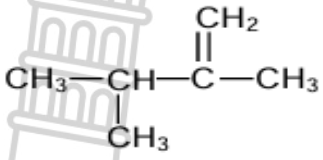
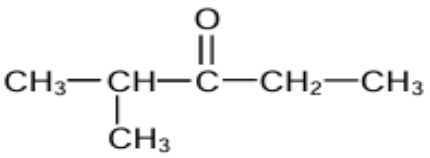
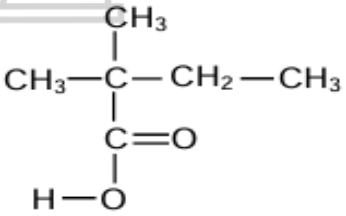
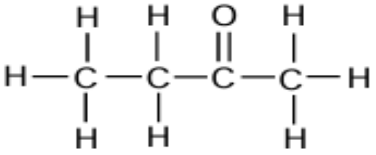
6.5.2 NAME or FORMULA of the catalyst used (1)

6.5.3 IUPAC name of the ORGANIC product formed (2)

[17]

QUESTION 7

The letters A to H in the table below represent eight organic compounds.

A	Heptanoic acid	**B**	$CH_3(CH_2)_3COOCH_3$
C	4-ethyl-3,3-difluorohexane	**D**	Hexanoic acid
E		**F**	
G		**H**	

7.1 Define the term *organic compound*. (1)

7.2 Write down the IUPAC name of compound:

7.2.1 E (2)

7.2.2 H (2)

7.3 Write down the:

7.3.1 STRUCTURAL formula of compound B (2)

7.3.2 STRUCTURAL formula of compound C (3)

7.3.3 General formula of the homologous series to which compound E belongs (1)

7.3.4 STRUCTURAL formula of the FUNCTIONAL group of compound F (1)

7.3.5 IUPAC name of the alcohol needed to produce compound B (2)

7.4 Write down the letter(s) of the compound(s) that:

7.4.1 Is a FUNCTIONAL isomer of compound G (1)

7.4.2 Are CHAIN isomers of each other (1)

[16]

QUESTION 8

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

8.1 Define the term *vapour pressure*. (2)

8.2 The vapour pressures of compounds **A**, **B** and **C** are given in random order below

79 kPa	146 kPa	58 kPa

8.2.1 Write down the vapour pressure of compound **C** (1)

8.2.2 Fully explain your answer to QUESTION 8.2.1 (3)

8.3 Compounds **D** and **E** are compared.

8.3.1 Which compound has the lower boiling point? (1)

8.3.2 Fully explain the difference in the vapour pressures between compounds **D** and **E**. (4)

[11]

QUESTION 9

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**

9.1 Define the term *boiling point*. (2)

9.2 Which ONE of compounds A, B or C is mainly in the liquid phase at 100 °C? (1)

9.3 Explain the difference in the boiling points of compounds A and B. (3)

9.4 Consider the boiling points below.

75 °C	120 °C	126 °C

9.4.1 Which ONE of these values represents X, the boiling point of compound D? (1)

9.4.2 Fully explain the answer to QUESTION 9.4.1. (2)

9.5 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 10

10.1 The boiling points of straight chain aldehydes and straight chain carboxylic acids are compared. The table below shows the results obtained.

	INVESTIGATION 1	INVESTIGATION 2
Number of carbon atoms in the compound	**Boiling point of aldehydes (°C)**	**Boiling point of carboxylic acids (°C)**
1	-19	101
2	20	118

3	49	141
4	75	164

10.1.1 Define the term *homologous series.* (2)

10.1.2 Write down the:

(a) NAME of the FUNCTIONAL GROUP of the aldehydes. (1)

(b) IUPAC NAME of the compound with the highest vapour pressure in this comparison (2)

10.1.3 For INVESTIGATION 2:

(a) Write down the controlled variable. (1)

(b) Describe the trend in the boiling points. (1)

(c) Fully explain the answer to QUESTION 10.1.3(b) (2)

10.1.4 Write down the boiling point butanal. (1)

10.2 The vapour pressures of compounds A and B are compared.

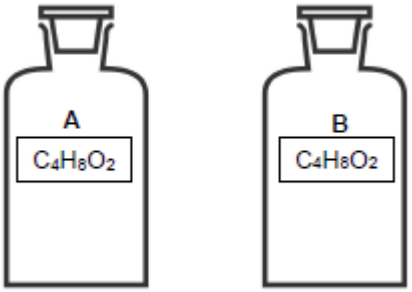
A	$CH_3CH_2CH_2CH_2CH_2OH$
B	$CH_3CH_2CH_2COOH$

How does the vapour pressure of compound A compare to that of compound B? choose from HIGHER THAN, LOWER THAN or EQUAL TO. Fully explain the answer. (4)

[14]

QUESTION 11

Two bottles contain compounds A and B with the same molecular formula, $C_4H_8O_2$. These compounds are straight chain organic molecules that belong to two different homologous series.



The boiling points are used to distinguish between the two compounds.

11.1 Define the term *homologous series*. (1)

11.2 Identify the TWO homologous series to which these compounds belong. (2)

The following are the vapour pressures of these compounds at a given temperature:

Compound A	0,071 kPa	Compound B	9,7 kPa

11.3 Write down the:

11.3.1 STRUCTURAL FORMULA of compound A (2)

11.3.2 IUPAC name for a possible compound B (2)

11.4 Write down the strongest type of Van der Waal's forces between the molecules in:
11.4.1 Compound A (1)
11.4.2 Compound B (1)
11.5 Which compound, A or B, has a higher boiling point? Give a reason for the answer by referring to the strength of the intermolecular forces. (2)
11.6 The boiling point of compound A is measured again on another day when the atmospheric pressure is much lower.
How will the boiling point of this compound now be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)
[12]

QUESTION 12
The boiling points of four organic compounds are shown in the table below.

COMPOUND		BOILING POINT (°C)	MOLAR MASS ($g.mol^{-1}$)
A	CH_3CH_2COOH	141,1	74
B	$CH_3(CH_2)_3OH$	.....	74
C	$CH_3CH(CH_3)CH_2OH$	108	74
D	$CH_3COCH_2CH_3$	79,6	72

12.1 Define the term *boiling point*. (2)
12.2 Compounds C's boiling point is lower than that of compound B. Fully explain. (3)
12.3 Consider compounds A, B and D.
12.3.1 Predict the value of the boiling point of compound B in °C. Choose from: (1)

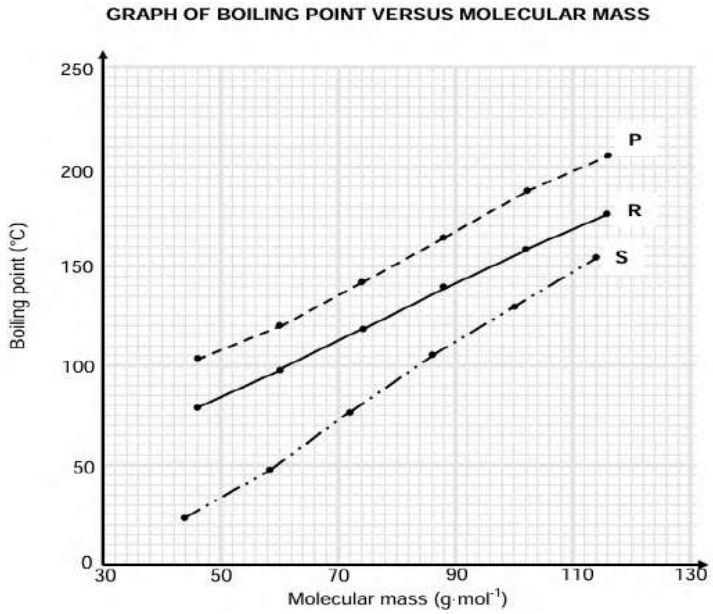
145	141	117,7

12.3.2 Fully explain the answer to QUESTION 12.3.1. (6)
12.4 The vapour pressures of three straight-chained alkanes E, F and G are shown below.

COMPOUND		VAPOUR PRESSURE at 25 °C (kPa)
E	C_2H_6	4187
F	C_3H_8	1050
G	C_4H_{10}	250

12.4.1 Write the IUPAC NAME of the compound with the highest BOILING POINT. (2)
12.4.2 Fully explain the trend in the vapour pressure from compound E to compound G. (3)
[17]

QUESTION 13
The relationship between boiling point and the molecular mass of aldehydes, carboxylic acids and primary alcohols is investigated. Curves P, R and S are obtained. All compounds used are straight chain molecules.



13.1 Define the term *boiling point*. (2)

13.2 Write down the conclusion that can be made for curve P. (2)

13.3 Explain the answer to QUESTION 13.2 in terms of the structures of the compounds. (2)

13.4 Curve R represents the alcohols.

13.4.1 Which homologous series is represented by curve S? (1)

13.4.2 Explain the answer to QUESTION 13.4.1 by referring to the strength of intermolecular forces. (2)

13.5 For curve R, write down the:

13.5.1 Molecular mass of the compound with a boiling point of 97 °C (1)

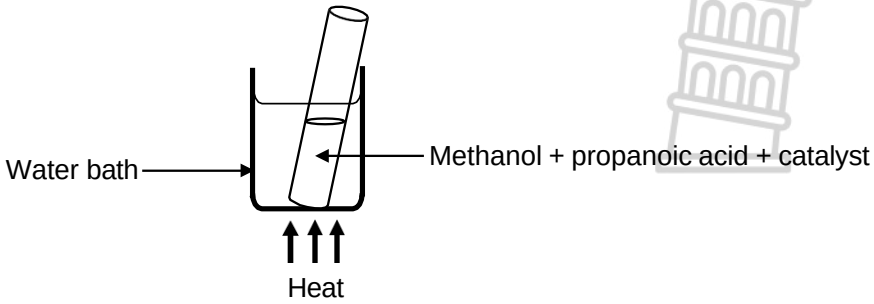
13.5.2 IUPAC name of the compound in QUESTION 13.5.1 (2)

13.6 Two compounds, A and B, used in this investigation have a molecular mass of 74 g·mol^{-1}. A has a boiling point of 118 °C and B a boiling point of 142 °C. Explain the difference in these boiling points by referring to the structures of these compounds. (3)

[15]

QUESTION 14

14.1 In an experiment, a test tube containing methanol, propanoic acid and a catalyst is heated in a water bath.



Write down:

14.1.1 The NAME or FORMULA of the catalyst (1)

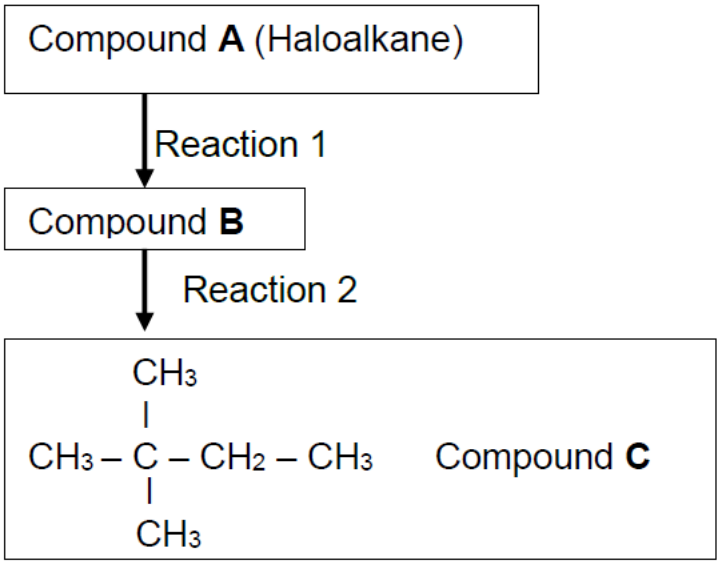
14.1.2 The type of reaction taking place (1)

14.1.3 TWO reasons why the use of a water bath is preferred in this Experiment (2)

14.1.4 The balanced equation for this reaction using STRUCTURAL FORMULAE (5)

14.1.5 The IUPAC name of the organic product for this reaction (2)

14.2 Compound A, a six-carbon branched haloalkane, is used in a two-step reaction to prepare compound C.
Reaction 2 is an ADDITION reaction.



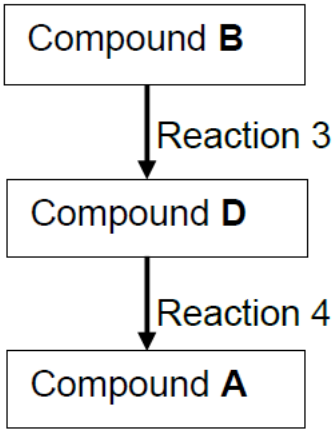
Write down:

14.2.1 The NAME or FORMULA of the inorganic reactant in reaction 2 (1)

14.2.2 The IUPAC name of compound B (2)

14.2.3 The type of reaction represented by reaction 1 (1)

Compound B is now used in a two-step reaction to prepare compound A.
Reaction 4 is a SUBSTITUTION reaction.

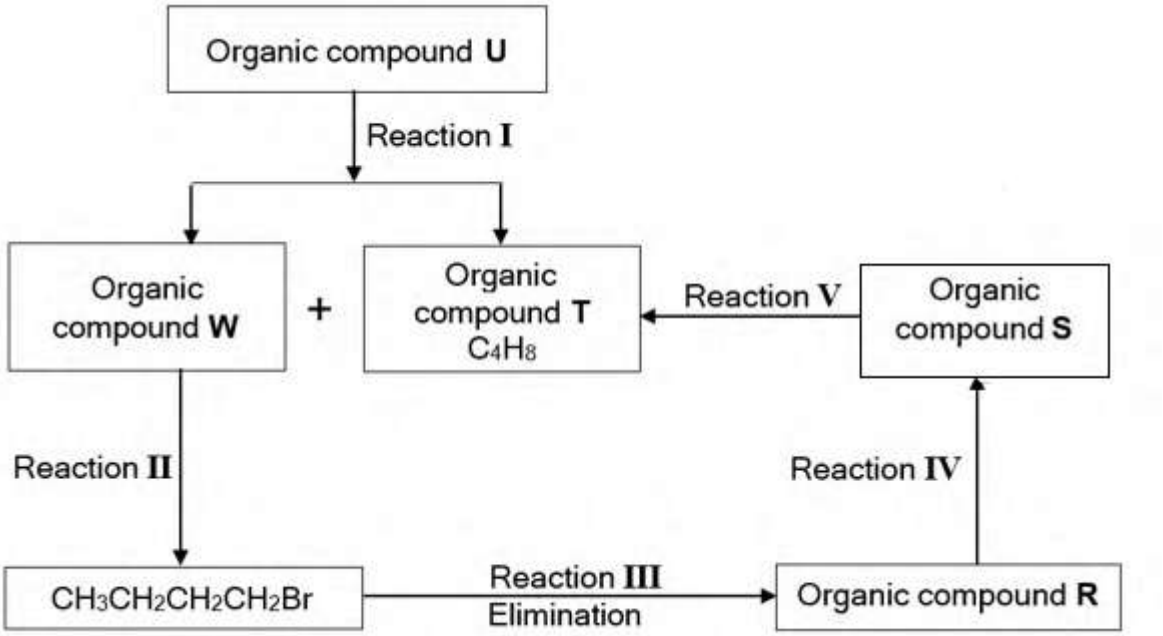


Write down

14.2.4 The NAME or FORMULA of the catalyst used in reaction 3 (1)
14.2.5 The IUPAC name of compound D (2)
14.2.6 The type of reaction represented by reaction 3 (1)
14.2.7 The type of haloalkane represented by compound A (Choose from primary, secondary or tertiary.) (1)
[20]

QUESTION 15

Study the flow diagram below.
Reaction **I** is a CRACKING REACTION forming two organic compounds, **W** and **T**, as the ONLY products



15.1 Define the term *cracking reaction*. (2)
15.2 Is the product in reaction **II** a PRIMARY, SECONDARY or TERTIARY haloalkane? Give a reason for the answer. (2)
15.3 Write down the:
15.3.1 STRUCTURAL FORMULA of compound **W** (3)
15.3.2 MOLECULAR formula of compound **U** (1)
15.4 For reaction **II,** write down:
15.4.1 The NAME or FORMULA of the inorganic reactant (1)
15.4.2 The type of reaction (Choose from SUBSTITUTION, ADDITION or ELIMINATION.) (1)
15.4.3 ONE reaction condition (1)
15.5 Write down the TYPE of elimination in reaction **III.** (1)
15.6 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:

15.6.1 The balanced equation for reaction **IV**, using STRUCTURAL FORMULAE and the correct inorganic reagent shown above (5)

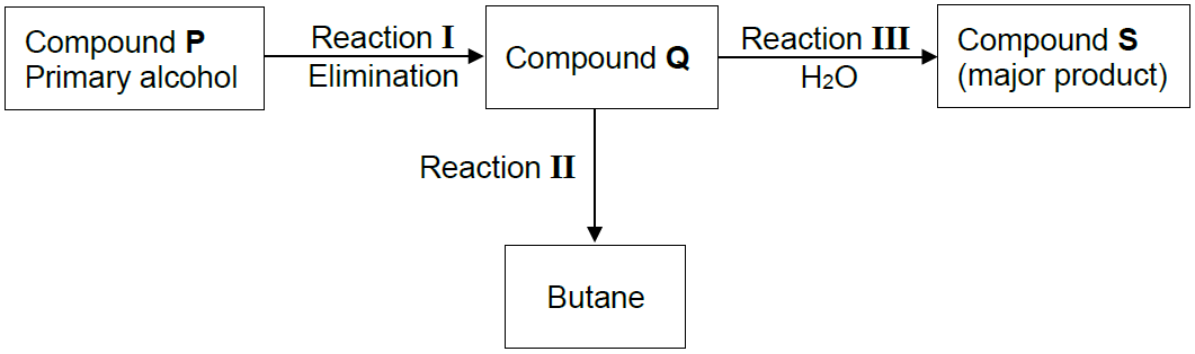
15.6.2 The balanced equation for reaction **V**, using STRUCTURAL formulae and the correct reagent shown above (3)

15.6.3 The IUPAC name of compound **T** (2)

[20]

QUESTION 16

In the flow diagram below, a primary alcohol P is used as a starting reactant to form different organic compounds under different reaction conditions.



16.1 Write down the TYPE of:

16.1.1 Addition reaction represented by reaction II. (1)

16.1.2 Elimination reaction represented by reaction I. (1)

16.2 Write down the IUPAC name of compound P. (2)

16.3 Consider reaction III.

Write down:

16.3.1 The balanced equation using CONDENSED structural formulae (4)

16.3.2 The NAME or FORMULA of a suitable catalyst (1)

16.4 Butane can be converted to compound P in a TWO-STEP reaction. Use STRUCTURAL FORMULAE and write down the balanced equations for these TWO reactions. (5)

16.5 Write down a balanced equation using MOLECULAR FORMULAE for the complete combustion of butane. (3)

[17]

QUESTION 17

Study the three organic reactions I, II and III below. Compounds T and W are organic compounds. R and S are inorganic substances. Consider only the major products.

I	$HBr(g) + T \longrightarrow W$
II	$W + NaOH(aq) \longrightarrow CH_3CH(OH)CH_2CH_3 + R$
III	$CH_3CH(OH)CH_2CH_3 \xrightarrow{S} T + H_2O(\ell)$

Write down the:

17.1.1 IUPAC name of compound W (2)

17.1.2 NAME or FORMULA of R (1)
17.1.3 TWO names for the type of reaction in reaction I (2)
17.1.4 NAME or FORMULA of S (1)
17.1.5 STRUCTURAL formula of compound T (2)

Compound W can be converted to compound T in one step.

17.1.6 State, besides heat, ONE other reaction condition for this conversion. (1)

17.2 A compound with the formula $C_{10}H_{22}$ undergoes a cracking reaction according to the equation:

$$C_{10}H_{22}(\ell) \rightarrow 2X(g) + C_4H_{10}(g)$$

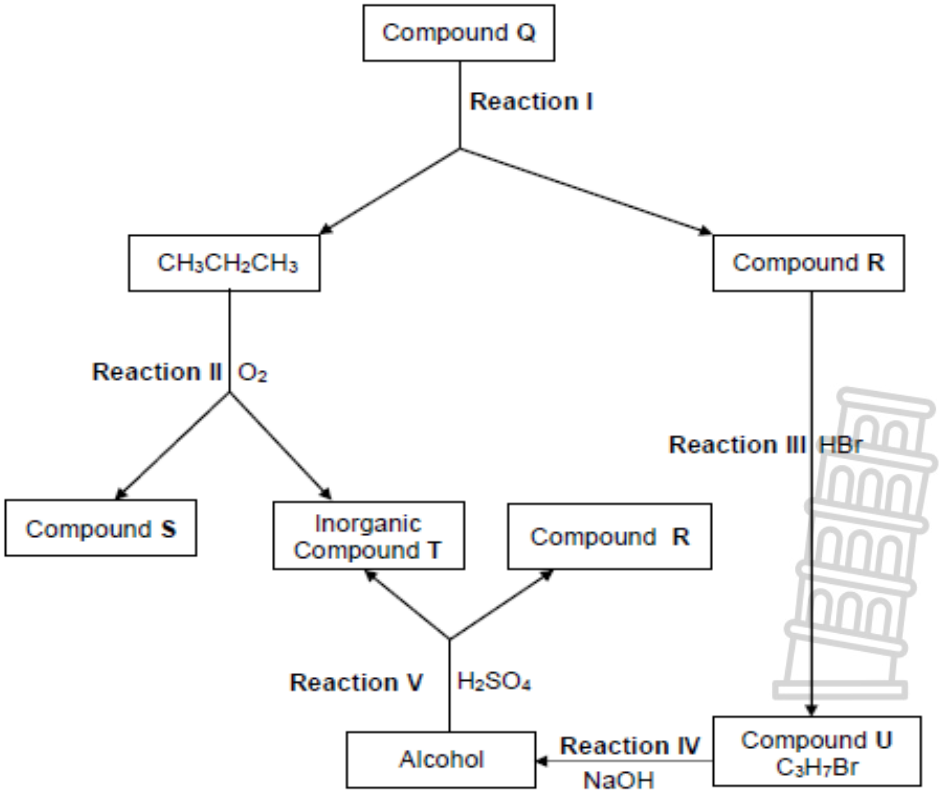
The mixture of the two products is bubbled in bromine water, $Br_2(aq)$, in a darkened room.

17.2.1 State ONE change, besides a change in temperature, that will be observed when the mixture is bubbled in $Br_2(aq)$. (1)
17.2.2 Write down the STRUCTURAL FORMULA of X. (2)
17.2.3 Which compound, X or C_4H_{10}, reacts faster with $Br_2(aq)$? Explain the answer. (3)

[15]

QUESTION 18

The flow diagram below shows a number of organic reactions. Reaction I is CATALYTIC CRACKING.



18.1 Define the term *cracking*. (2)
18.2 Consider reaction II.
18.2.1 What type of reaction is it? Choose from ENDOTHERMIC or EXOTHERMIC. (1)

18.2.2 Using MOLECULAR FORMULAE, write down the balanced chemical equation. (3)

18.2.3 Write down the NAME of compound S. (1)

18.3 In reaction III, compound R reacts with HBr to form compound U, which is a major product with molecular formula C_3H_7Br.

For reaction III, write down:

18.3.1 The type of reaction (1)

18.3.2 ONE reaction condition (1)

18.3.3 The IUPAC name of compound U (2)

18.4 For reaction IV, write down the:

18.4.1 Structural formula of the alcohol formed (2)

18.4.2 Type of reaction (1)

18.5 For reaction V, write down the:

18.5.1 Type of elimination reaction (1)

18.5.2 IUPAC name of compound R (2)

[17]

QUESTION 19

19.1 Consider the cracking reaction below.

$$C_{16}H_{34} \longrightarrow C_6H_{14} + C_6H_x + 2C_yH_z$$

19.1.1 Write down the values represented by x, y and z in the equation above. (3)

Compound C_6H_{14} undergoes complete combustion.

19.1.2 Using MOLECULAR FORMULAE, write down the balanced equation for this reaction. (3)

19.2 Consider the equations for reactions I to IV below.

A and B represent organic compounds that are POSITIONAL ISOMERS. X is an inorganic product.

I	**$CH_3CH_2CHCHCH_3 + HCl \rightarrow A$**
II	**$CH_3CH_2CHCHCH_3 + HCl \rightarrow B$**
III	**A** $\xrightarrow[\Delta]{H_2O}$ $CH_3CH_2CH_2CH(OH)CH_3$ + **X**
IV	**$CH_3CH_2CH_2CH(OH)CH_3 \rightarrow CH_3CH_2CHCHCH_3 + H_2O$**

Write down the:

19.2.1 Definition of positional isomers (2)

19.2.2 Type of reaction represented by reaction I (1)

19.2.3 STRUCTURAL formula of compound B (3)

19.2.4 Formula of X (1)

19.2.5 Inorganic reagent for reaction IV (1)

Compound A can be converted directly to the organic product of reaction IV.

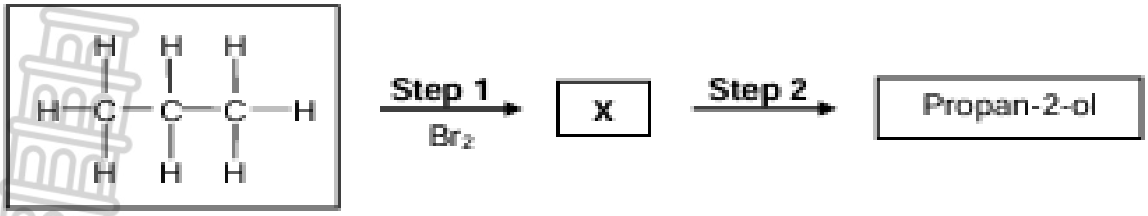
19.2.6 Besides heat, write down the reaction condition needed for this conversion. (1)

19.2.7 Write down TWO terms that describe this type of reaction. (2)

[19]

QUESTION 20

20.1 The flow diagram below shows the conversion of propane to propan-2-ol.



20.1.1 State ONE reaction condition for Step 1. (1)

20.1.2 Write down the NAME or FORMULA of the INORGANIC product formed in Step 1. (1)

20.1.3 Name the TYPE of substitution reaction represented by Step 2. (1)

20.1.4 Write down the NAME or FORMULA of the INORGANIC reagent needed in Step 2. (1)

20.1.5 Write down the IUPAC name of compound X. (1)

20.2 Ethane can be prepared from chloroethane ($CH_3CH_2C\ell$) by a TWO-STEP process. You are supplied with the following chemicals:

H_2	$HC\ell$	$C\ell_2$	H_2O	Pt	Ethanol	concentrated H_2SO_4	concentrated NaOH

Select chemicals in the table above that can be used for this preparation.
Using CONDENSED structural formulae, write down a balanced equation for EACH reaction. Indicate the reaction conditions for EACH reaction. (8)

[14]

QUESTION 21

21.1 Study the following incomplete equations for organic reactions I and II. Compounds P and Q are ORGANIC compounds and T is an INORGANIC compound.

I	$CH_3CH(CH_3)CH(Br)CH_3 + NaOH\ (conc.) \longrightarrow$ **P** (major product) + NaBr + **T**
II	CH_3COOH + compound **Q** → butyl ethanoate + H_2O

For reaction **I**, write down the:

21.1.1 Type of reaction that takes place (1)

21.1.2 IUPAC name of compound P (2)

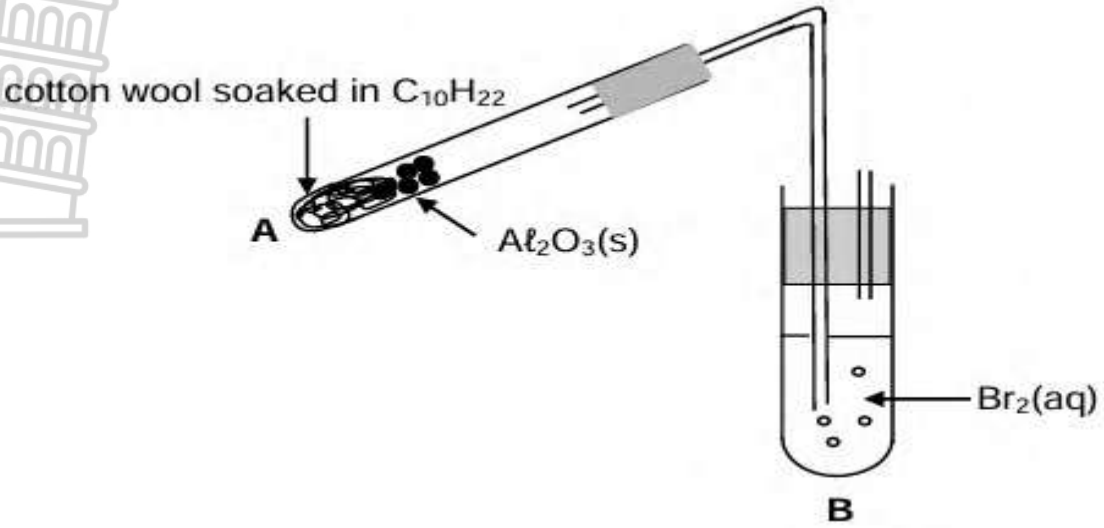
21.1.3 NAME or FORMULA of compound T (1)

For reaction II, write down:

21.1.4 TWO reaction conditions needed (2)

21.1.5 The STRUCTURAL FORMULA of compound Q (2)

21.2 The cracking of a long chain hydrocarbon, $C_{10}H_{22}$, takes place in test tube A, as shown below.



Two STRAIGHT CHAIN organic compounds, X and Z, are produced in test tube A according to the following balanced equation:

$$C_{10}H_{22}(\ell) \rightarrow 2X(g) + Z(g)$$

21.2.1 State the function of the $A\ell_2O_3(s)$ in test tube A. (1)

The organic compounds, X and Z, are now passed through bromine water, $Br_2(aq)$, at room temperature in test tube B. Only compound X reacts with the bromine water.

21.2.2 Apart from gas bubbles being formed, state another observable change in test tube B. (1)

21.2.3 Write down the TYPE of reaction that takes place in test tube B. (1)

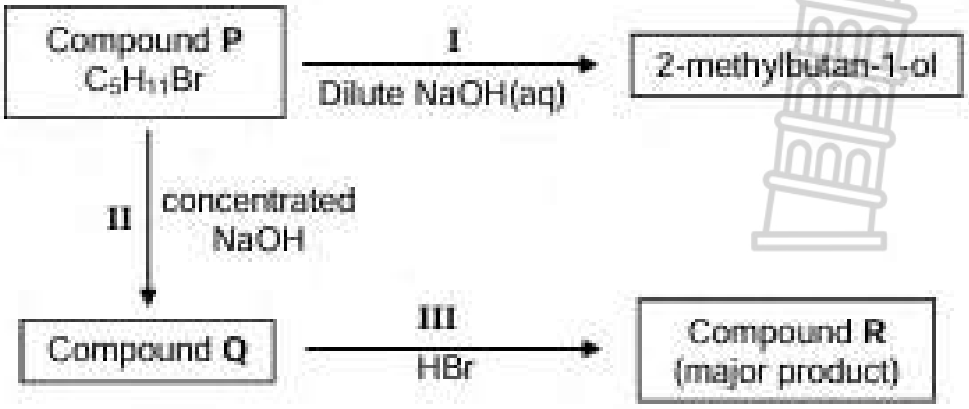
21.2.4 Write down the molecular formula of compound Z. (3)

21.2.5 Write down the STRUCTURAL FORMULA of compound X. (3)

[17]

QUESTION 22

22.1 Compound P is used as a starting reactant in each of two reactions as shown in the flow diagram below.



I, II and III represent organic reactions.

22.1.1 Name the type of reaction represented by I. (1)

22.1.2 Is 2-methylbutan-1-ol a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)

22.1.3 Write down the STRUCTURAL FORMULA of compound P. (3)

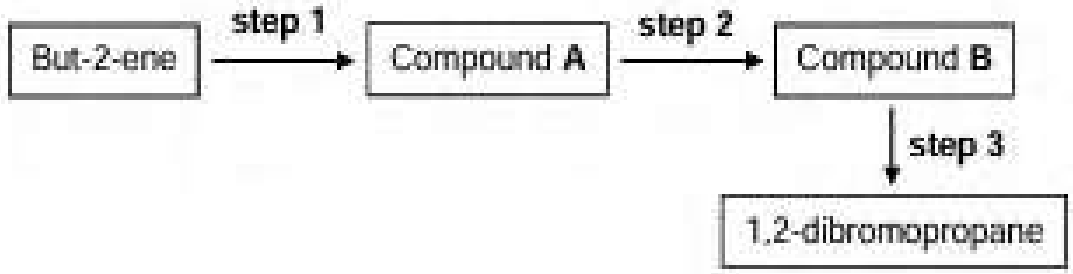
22.1.4 Name the type of reaction represented by II. (1)

22.1.5 To which homologous series does compound Q belong? (1)

22.1.6 Name the type of reaction represented by III. Choose from ADDITION, ELIMINATION or SUBSTITUTION. (1)

22.1.7 Write down the IUPAC name of compound R. (2)

22.2 1,2-dibromopropane can be prepared from but-2-ene by a three-step process as shown in the flow diagram below.



22.2.1 Using CONDENSED STRUCTURAL FORMULAE, write down a balanced equation for step 1. Indicate the reaction conditions on the arrow. (4)

22.2.2 Write down the type of reaction in step 2. (1)

22.2.3 Write down the IUPAC name of compound B. (2)

22.2.4 Using CONDENSED STRUCTURAL FORMULAE, write down a balanced equation for step 3. (3)

[21]

DOPPLER EFFECT

DOPPLER EFFECT WITH SOUND

Revision of Grade 10/11

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

$$T = \frac{1}{f} \qquad f = \frac{1}{T}$$

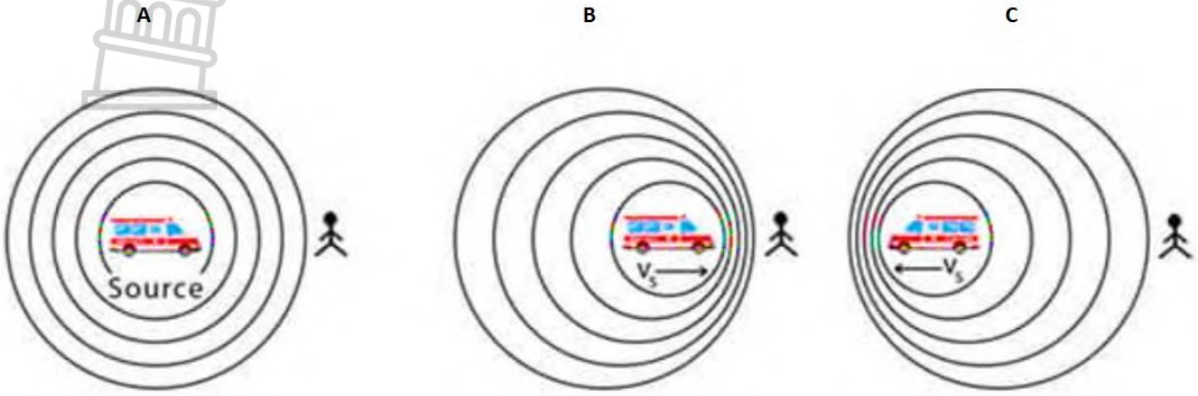
Speed of a wave (v): The speed at which a wave is transmitted through a medium/ vacuum or the rate of change of the distance covered. **Units:** $m \cdot s^{-1}$.

$$\text{Speed } (v) = \frac{\text{distance covered } (\Delta x)}{\text{time } (\Delta t)} = \frac{\lambda}{T} \qquad (\frac{1}{T} = f)$$

$\therefore v = f\lambda$

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 moves 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 meters per second $m{\cdot}s^{-1}$
v_S = speed of the sound source in meters per second $m{\cdot}s^{-1}$
v= speed of sound in the medium in meter per second $m{\cdot}s^{-1}$

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 color change.
- If the frequency/ color 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 colors. (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 it possible to determine what gases are in a star's atmosphere.***

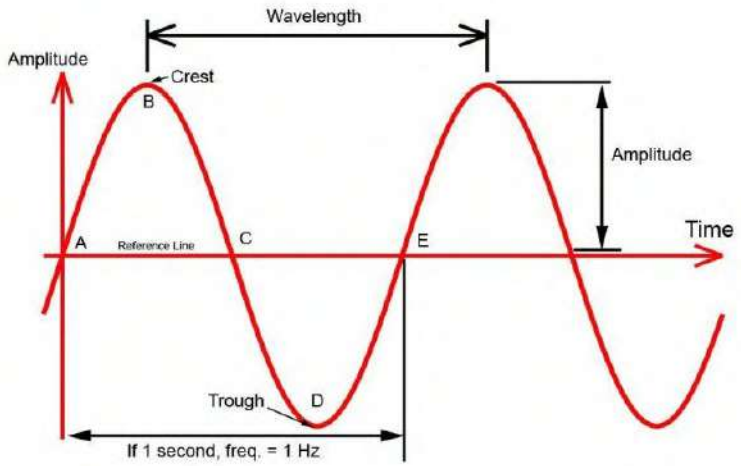
Red Shift and the Explanation of an Expanding Universe

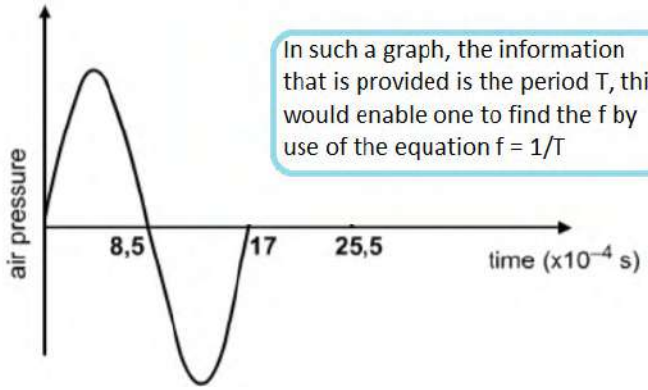
The **Big Bang Theory** is the leading explanation about how the universe began.

- 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.
- 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.

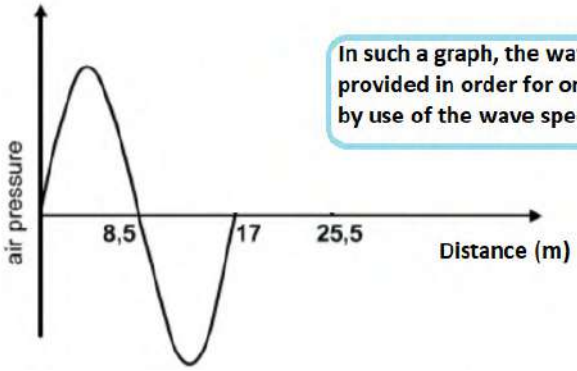
Note: The greater the shift, the greater the speed of the star.

Interpretation of Graphs

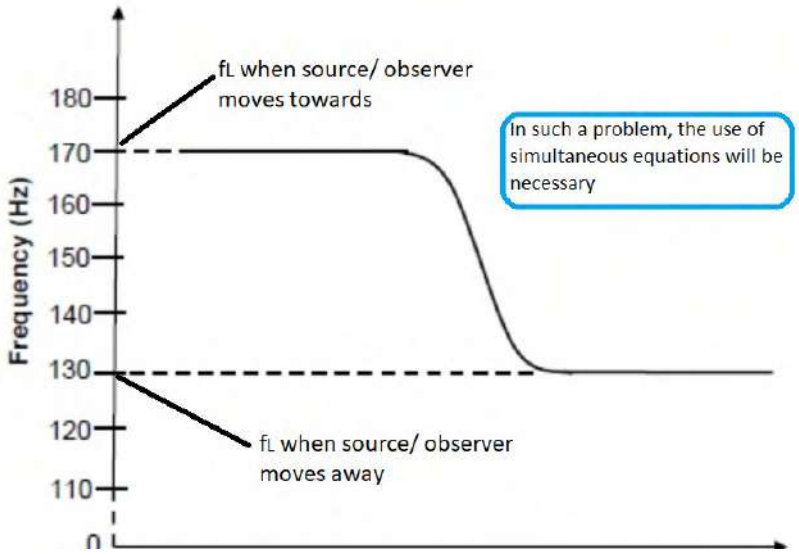




In such a graph, the information that is provided is the period T, this would enable one to find the f by use of the equation f = 1/T



In such a graph, the wavelength is provided in order for one to find f by use of the wave speed equation.



WORKED EXAMPLE 1

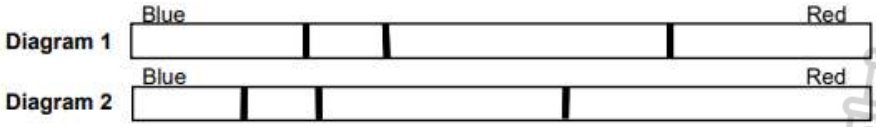
1.1 The siren of a stationary ambulance emits a note of frequency 1 130 Hz. When the ambulance moves at a constant speed, a stationary observer detects a frequency that is 70 Hz higher than that emitted by the siren.

1.1.1 State the *Doppler effect* in words. (2)

1.1.2 Is the ambulance moving towards or away from the observer? Give a reason. (2)

1.1.3 Calculate the speed at which the ambulance is travelling. Take the speed of sound in air as 343 $m \cdot s^{-1}$. (5)

1.2 A study of spectral lines obtained from various stars can provide valuable information about the movement of the stars. The two diagrams below represent different spectral lines of an element. Diagram 1 represents the spectrum of the element in a laboratory on Earth. Diagram 2 represents the spectrum of the same element from a distant star.



Is the star moving towards or away from the Earth? Explain the answer by referring to the shifts in the spectral lines in the two diagrams above. (2)

[11]

EXAMPLE 1 SOLUTIONS

1.1.1 An apparent change in observed/detected frequency/pitch/wavelength as a result of the relative motion between a source and an observer/listener.✓✓

1.1.2 Towards. Observed/detected frequency is greater than the actual frequency.✓✓

1.1.3 $$f_L = \frac{v \pm v_L}{v \pm v_s} f_s \checkmark$$

$$\therefore 1200 \checkmark = \frac{343}{342 - v_s} \checkmark (1130) \checkmark \quad \therefore v_s = 20{,}01 \text{ m} \cdot \text{s}^{-1} \checkmark$$

1.2 The star is approaching the earth. The earth and the star are approaching (moving towards) each other.✓

The spectral lines in diagram 2 are shifted towards the blue end/are blue shifted.✓

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·s^{-1} in still air.

Calculate the:

2.1.1 Wavelength of the sound detected by the person (2)

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)

2.2 Explain why the wavelength calculated in QUESTION 2.1.1 differs from that obtained in QUESTION 2.1.2. (2)

2.3 Use your knowledge of the Doppler effect to explain red shifts. (2)

[12]

SOLUTIONS

2.1.1 $v=f\lambda$✓

$\lambda=\frac{340}{520}$✓

$\lambda=0,65$ m✓

2.1.2 $f_L=\frac{v\pm v_L}{v\pm v_s}f_s$✓

$f_L=\frac{340}{340-15}$✓(520)✓

$f_L=544$ Hz

$v=f\lambda$✓

$\lambda=\frac{340}{544}$✓

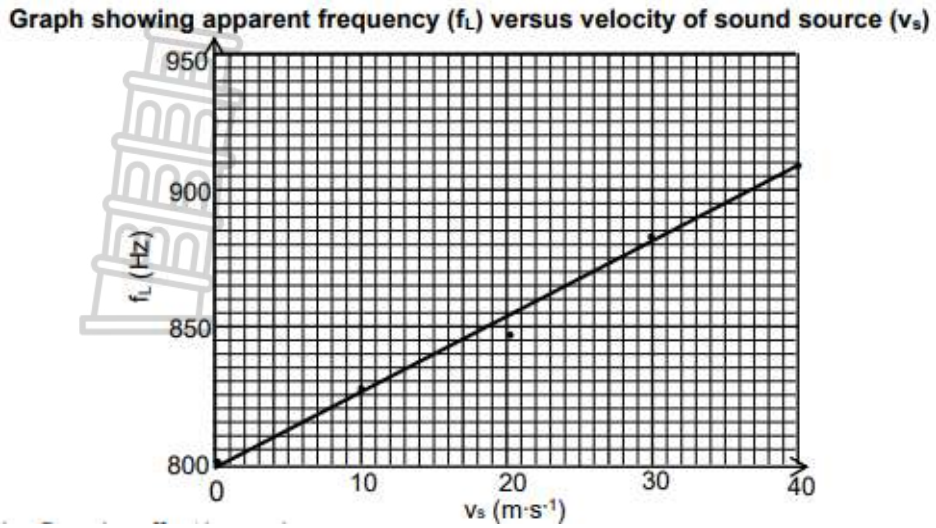
$\lambda=0,63$ m✓

2.2 The wavelength in QUESTION 2.1.2 is shorter because the waves are compressed as they approach the observer.✓✓

2.3 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



3.1 Use the information in the graph to calculate the speed of sound in air. (5)

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)

[7]

SOLUTIONS

3.1

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s \checkmark$$

$$825 \checkmark = \frac{v}{v - v_s}(800) \checkmark$$

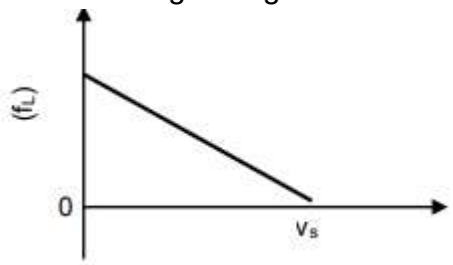
$$(1{,}03125)(v - 10) \checkmark = v$$

$$v = 330 \text{ m·s}^{-1}$$

The following values are obtained using other points

v_s (m·s^{-1})	Frequencies	v(m·s^{-1})
v_s=20	850	310
v_s=20	845	375.56
v_s=20	880	330
v_s=40	910	331

3.2 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)

4.1.2 What phenomenon is the above investigation illustrating? (1)

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

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

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)

[10]

SOLUTIONS

4.1.1 Frequency (of sound detected by the listener (observer)✓

4.1.2 Doppler Effect✓

4.1.3 Away.✓ Detected frequency of source decreases✓

4.1.4 **EXPERIMENT 2** **EXPERIMENT 3** **EXPERIMENT**

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

874 ✓$= \frac{v}{v-10}(900)$ ✓ $850 = \frac{v}{v-20}(900)$ $827 = \frac{v}{v-30}(900)$

$v = 336{,}15\ m \cdot s - 1$ ✓ $v = 340\ m \cdot s - 1$ $v = 339{,}86\ m \cdot s - 1$

4.5 Away from the earth.✓

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 An airplane flies at night and uses its radar system to navigate.
It transmits a signal with a frequency off Hz. The airplane moves between high cliffs, and the signal picked up by the radar system is (f + 20) Hz. Choose the correct statement regarding the sound that the airplane picks up,

A The sound's pitch increases as the airplane moves towards the cliffs.

B The sound's pitch remains the same as the airplane moves towards the cliffs.

C The sound's pitch decreases as the airplane moves away from the

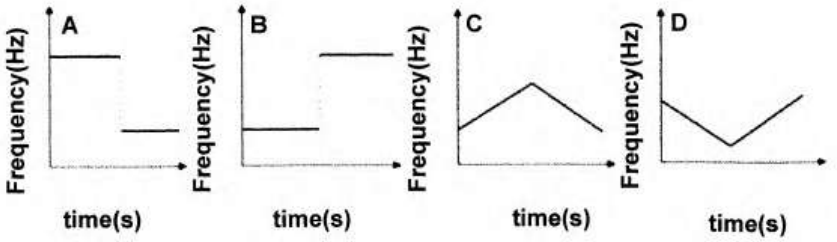
cliffs.

D The sound's pitch decreases as the airplane moves towards the cliffs. (2)

1.2 A trumpet player standing on the stage of a hall is playing some musical notes through his trumpet.
Which one of the following situations may result in a listener in an audience hearing a note at a lower pitch?(Recall when Doppler Effect takes place).

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 (2)

1.3 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?(Comprehension of frequency and interpretation of graphs)



(2)

1.4 A star's spectrum, observed from Earth, is red shifted. Which ONE of the following statements is CORRECT?

A The speed of light is increasing.
B The star is moving towards Earth.
C The frequency of each spectral line has increased.
D The wavelength of each spectral line has increased. (2)

1.5 An observer moves away from a stationary source. The pitch heard by the observer appears to change because…(Recall of relationship between pitch and frequency into Doppler Effect).

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 (2)

[10]

QUESTION 2

A stationery source emits a sound wave of frequency 5 000 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})

2.1 State the definition of *Doppler effect.* (2)

2.2 Calculate the wavelength of the waves being generated by the source. (3)

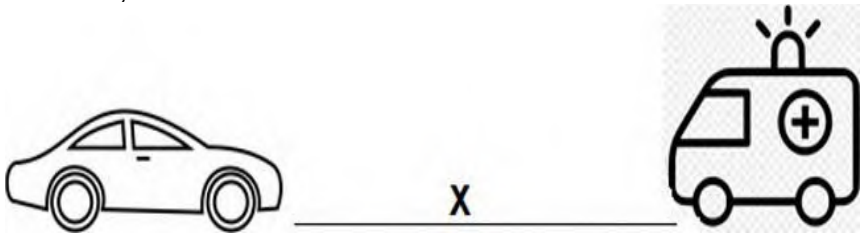
2.3 Calculate the velocity of the object if the detected wave, by the source, has frequency of 5 104 Hz. (6)

2.4 State TWO applications of the Doppler Effect in Medical Science. (2)

[13]

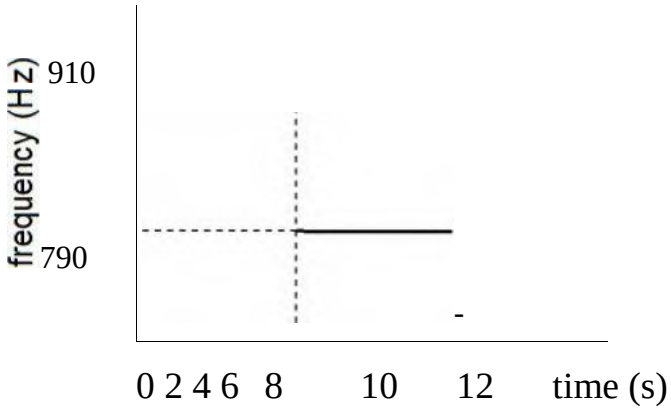
QUESTION 3

The siren of a stationary ambulance emits sound waves at a frequency of 850 Hz. An observer who is travelling in a car at a constant speed in a straight line, begins measuring the frequency of the sound waves emitted by the siren when he is at a distance X from the ambulance at time, t = 0



The observer continues measuring the frequency as he APPROACHES, PASSES, AND MOVES AWAY from the ambulance.

The measured frequencies are plotted against time as shown below



3.1 State the *Doppler effect* in words. (2)

3.2 Calculate the speed of the car. Take the speed of sound in air as 340 m·s^{-1}. (5)

3.3 Determine the distance X between the car and the ambulance when the observer BEGINS measuring the frequency. (3)

[10]

QUESTION 4

The siren of a fire truck moving at a constant speed 20 m·s^{-1}.along a straight horizontal road emits sound with a wavelength of 0,34 m. A detector on the same road records sound waves from the fire truck with a lower frequency than the sound emitted by the siren. Take the speed of sound in air as 340 m·s^{-1}.

4.1 Define *Doppler effect* in words. (2)

4.2 Is the fire truck driving TOWARDS or AWAY FROM the detector? Give a reason for your answer. (2)

4.3 Explain in terms of wave motion why the detector records sound waves with lower frequency. (3)

4.4 Calculate the:

4.4.1 Frequency of the siren (3)

4.4.2 Frequency recorded by the detector (6)

4.5 The speed of the fire truck now increased to 25 $m \cdot s^{-1}$. How will the increase in speed affect the following?
Choose from INCREASE, DECREASE or STAYS THE SAME.

4.5.1 The frequency of the sound waves emitted by the siren. (1)

4.5.2 The frequency of the sound waves recorded by the detector. (1)

[18]

QUESTION 5

An ambulance approaches a stationary observer at constant speed of 10,6 $m \cdot s^{-1}$, 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.

5.1 Name the medical instrument that makes use of the Doppler Effect. (1)

5.2 Calculate the frequency measured by the stationary observer. (2)

5.3 Calculate the speed of sound. (4)

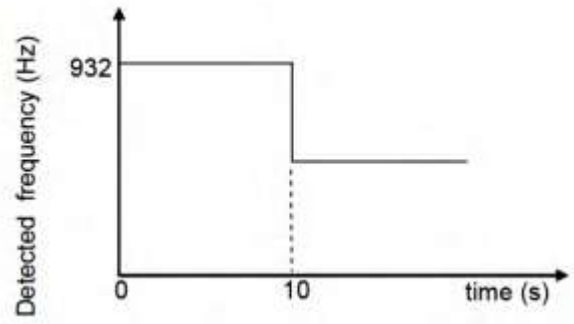
5.4 How would the wavelength of the sound wave produced by the siren of the ambulance change if the frequency of the wave were higher than 954,3Hz? Write down only INCREASE, DECREASE or STAYS THE SAME. (1)

5.5 Give a reason for the answer to QUESTION 5.4. (2)

[10]

QUESTION 6

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



6.1 Calculate the speed of the patrol car. (2)

6.2 State the *Doppler effect*. (2)

6.3 The detected frequency suddenly changes at t = 10 s. Give a reason for this change. (1)

6.4 Calculate the frequency of the sound emitted by the siren. (4)

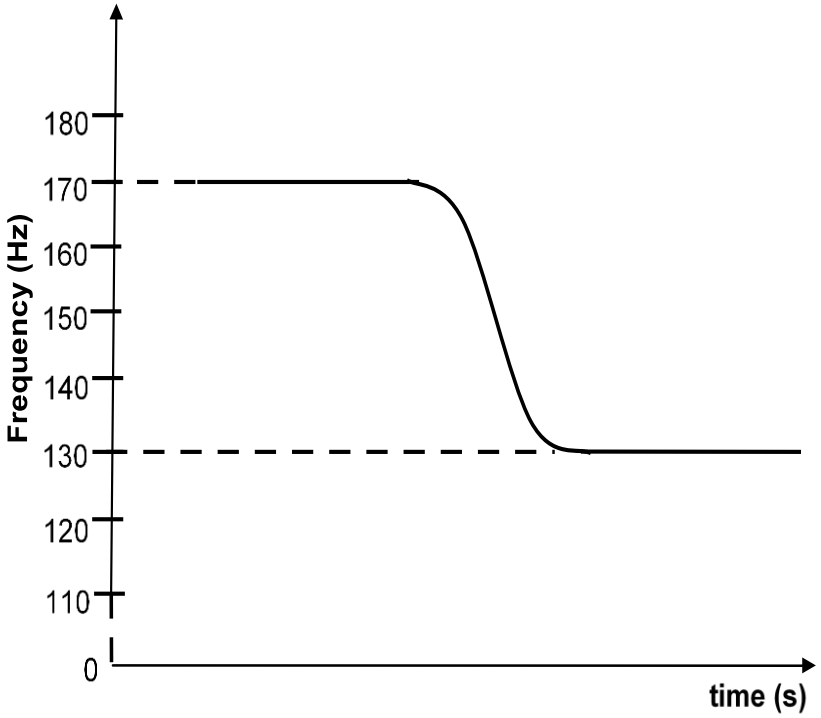
6.5 State TWO applications of the Doppler effect (2)

[11]

QUESTION 7

A police car moving at a constant velocity with its siren on, passes a stationary listener.

The graph below shows the changes in the frequency of the sound of the siren detected by the listener.



7.1 State Doppler effect in words (2)

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

7.2.1 Approaches the listener (1)

7.2.2 Moves away from the listener (1)

7.3 Calculate the speed of the police car. Take the speed of sound in air to be 340 $m \cdot s^{-1}$. (6)

[10]

QUESTION 8

An ambulance with its siren on, moves at constant velocity TOWARDS a person standing next to the road. The person measures a frequency which is 110% of the frequency of the sound emitted by the siren of the ambulance.

8.1 Name and state the phenomenon observed above. (3)

8.2 Assume that the speed of sound in air is 340 $m \cdot s^{-1}$

Calculate the speed of the ambulance (5)

8.3 How will the frequency measured by the person be affected if the speed of the ambulance increased? (1)

Write only INCREASE,DECREASE or REMAIN THE SAME.

[9]

QUESTION 9

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 450 Hz 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 $m \cdot s^{-1}$

9.1 Calculate the speed of the ambulance (6)

9.2 Calculate the frequency of sound waves emitted by the siren. (2)

9.3 What will be the frequency of the sound waves heard by the driver of the ambulance? (1)

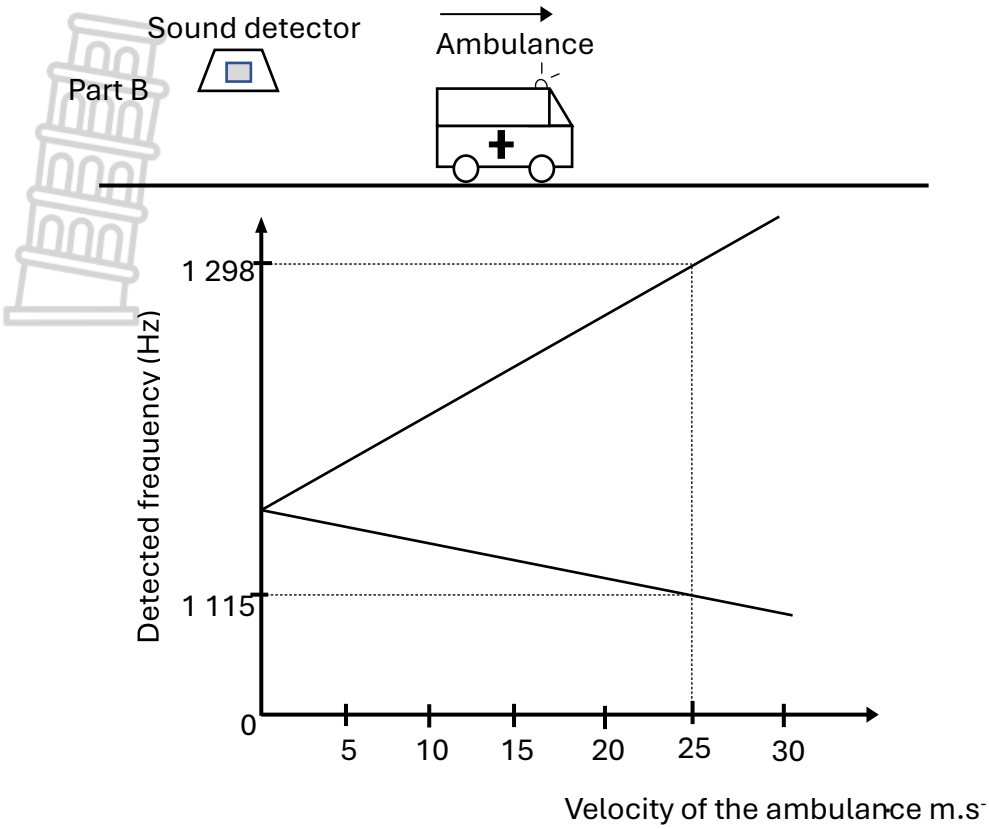
9.4 Explain what blue shift is. (2)

[11]

QUESTION 10

An investigation is performed to determine the relationship between the velocity of a moving sound source and the frequency of the sound detected.

The siren of an ambulance produces sound with a constant frequency. The ambulance, with its siren on, moves towards a stationary sound detector (Part A) and away from the stationary sound detector (Part B) at constant velocities. The experiment is repeated for different velocities of the ambulance. The detected frequency is measured for EACH velocity. The results obtained are shown in the graph below.



10.1 State the *Doppler effect*. (2)

10.2 For this experiment, write down:

10.2.1 The independent variable (1)

10.2.2 A controlled variable (1)

10.3 What conclusion can be made for Part B of this experiment? (2)

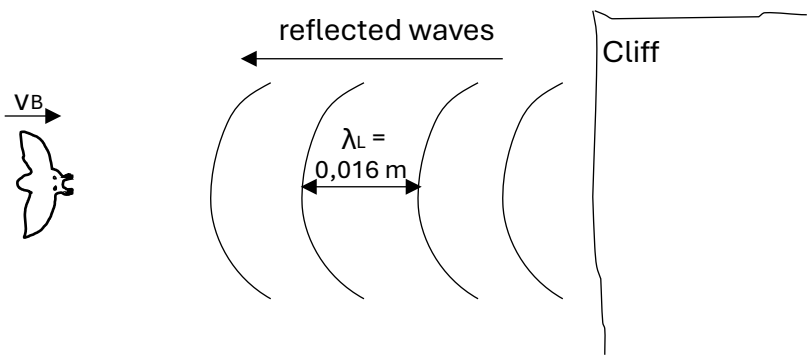
10.4 Calculate the speed of sound in air. (6)

[12]

QUESTION 11

A bat emits sound waves with a frequency f_s as it flies at a constant speed v_B towards a vertical cliff. The waves reflect off the cliff with the same frequency that they strike the cliff, and with a wavelength of λ_L = 0,016 m, as shown in the simplified diagram below.

Take the speed of sound in air to be 340 m·s^{-1}.



11.1 NAME and STATE the phenomenon that results in a change in frequency of the detected sound waves. (3)

11.2 Show that f_s, the frequency of the sound waves emitted by the bat, is $(21\ 250 - 62{,}5v_B)$. (4)

11.3 The frequency of the reflected sound waves detected by the bat is 850 Hz higher than the frequency of the sound waves emitted by the bat. Calculate the speed of the bat, v_B. (5)

[12]

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 x 10^8 m·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 x 10^8 m·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**λ** .
- 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.
- 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 x10^{-34} J·s is Planck's constant, c = 3 x 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 $E_{k(max)} = \frac{1}{2} mv^2_{max}$

  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)

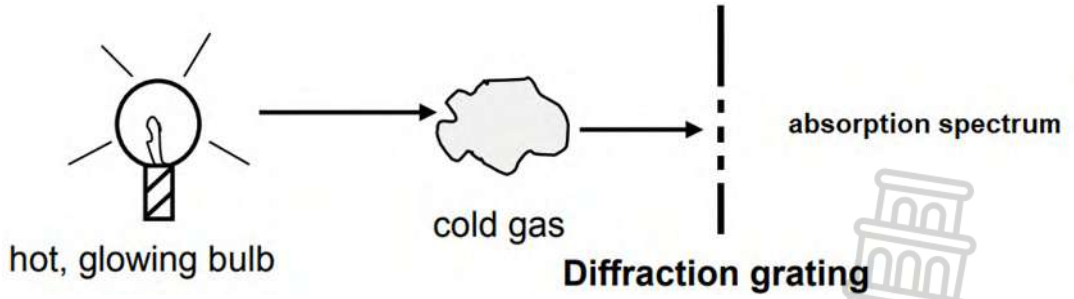
The **frequency** of the incident light is increased while its intensity (brightness) remains constant:

- Number of photoelectrons emitted remain the same
- Kinetic energy of photoelectrons increases
- the speed at which the photoelectrons move away from the metal increases

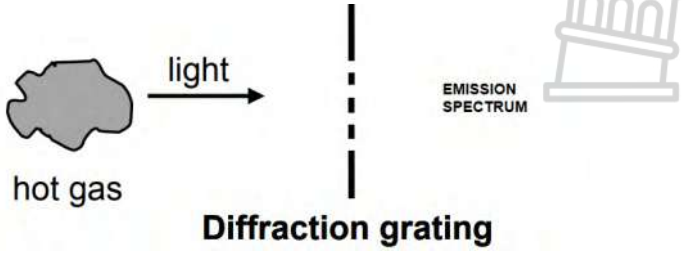
The **intensity** (brightness) of the incident light is increased while its frequency remains constant:

- 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.



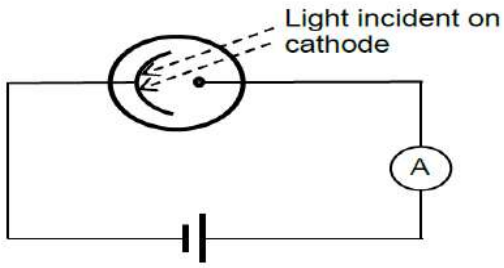
Atomic emission spectrum is formed when certain frequencies of electromagnetic radiation are emitted due to an atom making a transition from a higher energy state to a lower energy state



WORKED EXAMPLES

WORKED EXAMPLE 1

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



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

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

1.2.1 Define the term *work function*. (2)

1.2.2 Calculate the threshold frequency. (3)

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

1.3.1 Calculate the energy of photon of the light. (3)

1.3.2 Calculate the maximum speed of an electron ejected from the cathode. (4)

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

1.5 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)

[20]

SOLUTIONS

1.1 Light has a particle nature ✓ (1)

1.2.1 The minimum energy (of incident photons) that can eject electrons from a metal surface. ✓✓ (2)

1.2.2 $W_0 = hf_0$ ✓

$3,42\times10^{-19} = (6,63\times10^{-34})\ f_0$ ✓

$f_0 = 5,16\times10^{14}$ J ✓ (3)

1.3.2 $E = hf$ ✓

$E = (6,63\times10^{-34})(5,96\times10^{14})$ ✓

$E = 3,95\times10^{-19}$ J ✓ (3)

1.3.3 $E = W_0 + E_{K(max)}$ ✓

$3,95\times10^{-19}$ ✓ $= (3,42\times10^{-19}) + \frac{1}{2}(9,11\times10^{-31})v_{max}^2$ ✓

$v_{max} = 3,42\times10^{5}\ m.s^{-1}$ ✓ (3)

1.4 $q = I\Delta t$

$= (0,012)(10)$ ✓

$= 0,12$ C

$n = \frac{Q}{e}$ (4)

$n = \frac{0,12✓}{1,6 \times 10^{-19}✓}$

$n = 7,5 \times 10^{17}$ (electrons)

number of photons = $n = 7,5 \times 10^{17}$✓

1.5 Increases ✓

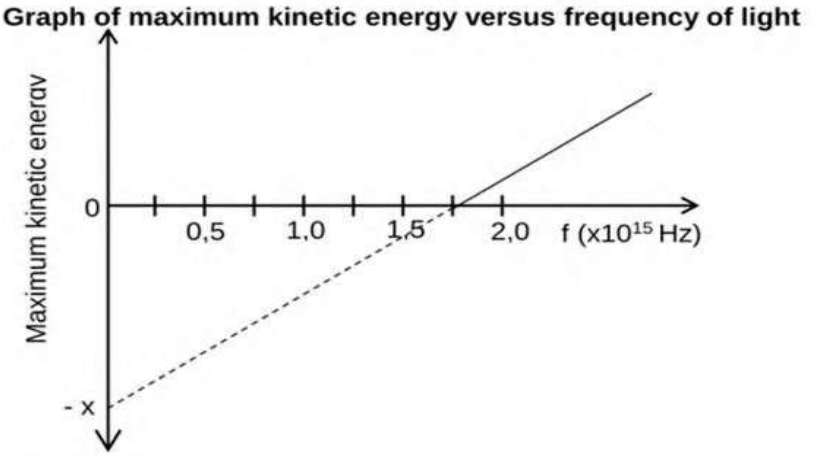
More photons strike the surface of the metal per unit time ✓ hence more (photo) electrons are ejected from the metal surface per unit time✓ (resulting in increased current). (3)

[14]

WORKED EXAMPLE 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)

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]

SOLUTIONS

2.1.1 Metal (cathode)/ work function/threshold frequency✓ (1)

2.1.2 (maximum) kinetic energy✓ (1)

2.2 Photoelectric effect✓ (1)

2.3 The minimum energy that an electron in the metal needs to be emitted from the metal surface. ✓✓ (2)

2.4.1 $W_0 = hf_0$ ✓

$=(6{,}63\times10^{-34})(1{,}75\times10^{15})$ ✓

$=1{,}16\times10^{-18}$ J ✓ (3)

2.4.2 $E = W_0 + E_{K(MAX)}$ $(6{,}63\times10^{-34})f$✓$=1{,}16\times10^{-18}+\frac{1}{2}(9{,}11\times10^{-31})(5{,}23\times10^{5})^2$✓

$f=1{,}94\times10^{-19}$ Hz✓ (4)

2.5 Increases✓

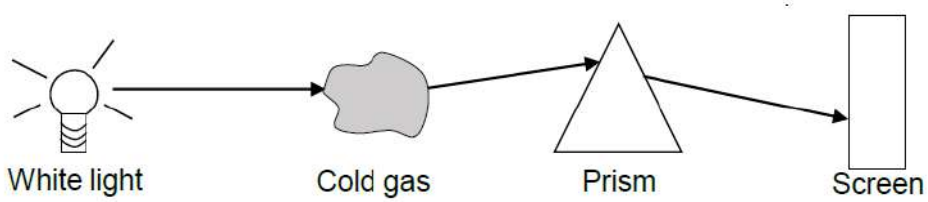
The number of photons per unit time increases✓ when the intensity of the light increase. Therefore, the number of photo-electrons per unit time increases. ✓ (3)

[15]

QUESTION 1 – MULTIPLE CHOICE QUESTIONS

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

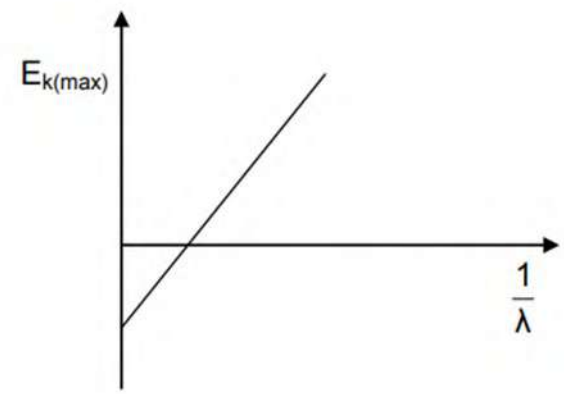


Which ONE of the following correctly describes the ENERGY TRANSITION of the atoms of the gas and the TYPE OF LINE SPECTRUM observed on the screen?

	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)

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



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)

1.3 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.
D A photon is emitted when an electron moves from a lower energy level to a higher energy level. (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 Light of a suitable frequency is shone on the surface of a metal and electrons are ejected from the metal.
Which ONE of the following is equal to the ratio of the work function to the threshold frequency of the metal?

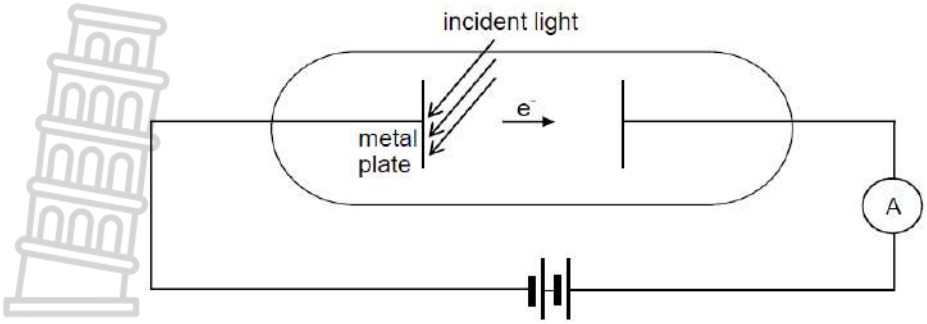
A Planck's constant
B The inverse of Planck's constant
C The energy of the incident photons
D The maximum kinetic energy of the ejected electrons (2)

[10]

STRUCTURED QUESTIONS

QUESTION 2

2.1 The apparatus illustrated in the simplified diagram below is used to demonstrate the photoelectric effect.



2.1.1 Define the term *photoelectric effect*. (2)

Incident light of frequency 1,2 x 10^{14}Hz is shone onto the metal plate and electrons are emitted.

2.1.2 Calculate the number of photoelectrons emitted in one second if the total energy transferred by the light to the metal plate per second is 1,75x10^{-9}J (4)

2.1.3 Calculate the maximum speed of a photoelectron if the threshold frequency of the metal plate is 9,09 x 10^{14}Hz. (5)

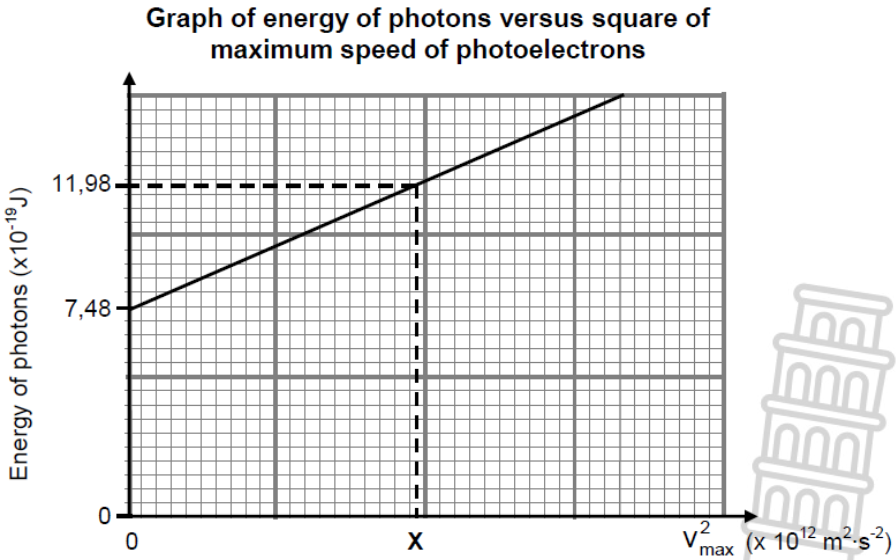
2.2 Briefly explain how an emission spectrum is formed in terms of energy transitions. (2)

[13]

QUESTION 3

During an experiment, light of different frequencies is radiated onto a silver cathode of a photocell and the corresponding maximum speed of the ejected photoelectrons are measured.

A graph of the energy of the incident photons versus the square of the maximum speed of the ejected photoelectrons is shown below.



3.1 Define the term *photoelectric effect*. (2)

Use the graph to answer the following questions.

3.2 Write down the value of the work function of silver.
Use a relevant equation to justify the answer. (3)

3.3 Which physical quantity can be determined from the gradient of the graph? (1)

3.4 Calculate the value of **X** as shown on the graph. (5)

The experiment above is now repeated using light of higher intensity.

3.5 How will EACH of the following be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

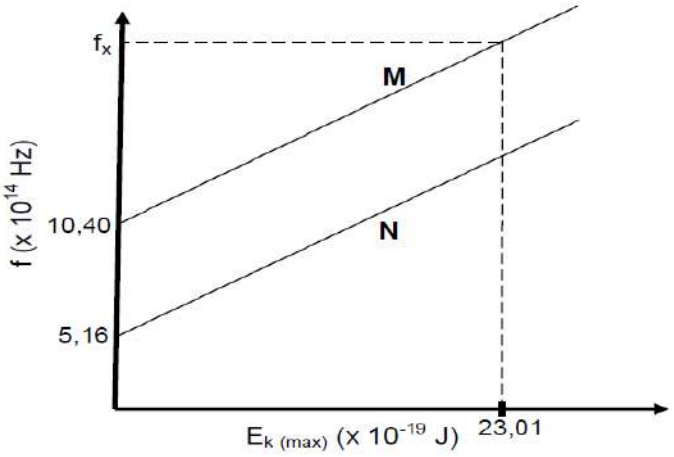
3.5.1 The gradient of the graph (1)

3.5.2 The number of photoelectrons emitted per unit time (1)

[13]

QUESTION 4

The relationship between frequency (f) and maximum kinetic energy (E_k(max) of photoelectrons emitted from two cathodes, **M** and **N**, of different photoelectric cells is investigated. The graphs below have been obtained from the results.



4.1 Define the term *threshold frequency*. (2)

4.2 How does the maximum kinetic energy of photoelectrons emitted from cathode **N** compare to the maximum kinetic energy of those emitted from cathode **M** when light of a frequency greater than 10,40 x 10^{14} Hz is shone on each of the cathodes?
Choose from GREATER THAN, SMALLER THAN or EQUAL TO. (2)

4.3 Calculate the value of frequency fx indicated on the graph. (5)

4.4 The experiment is now repeated for cathode **M** using light of frequency fx, but of higher intensity. How will EACH of the following be affected?
Choose from INCREASES, DECREASES or NO EFFECT.

4.4.1 The y-intercept of the graph (1)

4.4.2 The number of photoelectrons emitted per unit time (1)

4.4.3 The maximum kinetic energy of the emitted photoelectrons (1)

[12]

QUESTION 5

5.1 Learners conduct an experiment to determine whether electrons will be emitted from the surface of different metals when light with a single frequency is incident on the metal. The maximum kinetic energy of emitted electrons is measured when light of frequency 1,045×10^{15}Hz is used.
The results obtained are shown in the table below.

METALS	ELECTRONS EMITTED	MAXIMUM KINETIC ENERGY (J)
Zinc	YES	0

Sodium	YES	$2,53 \times 10^{-19}$
Caesium	YES	$3,50 \times 10^{-19}$
Metal M	NO	-

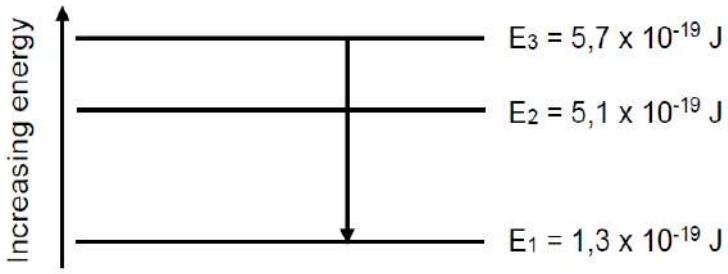
5.1.1 Define the term *work function*. (2)

5.1.2 Write down the threshold frequency of zinc. (1)

5.1.3 How does the work function of sodium compare to that of caesium? Choose from SMALLER THAN, GREATER THAN or EQUAL TO. Explain the answer. (3)

5.1.4 Light of the same frequency, but with a higher intensity, is now incident on metal M. Will electrons now be ejected? Choose from YES or NO. Give a reason for the answer. (3)

5.2 The energy diagram below (NOT drawn to scale) shows the electron energies in different energy levels, E_1, E_2 and E_3, of a certain atom.



5.2.1 An electron of this atom moves from E_3 to E_1. Photon X is emitted. Calculate the frequency of photon X. (4)

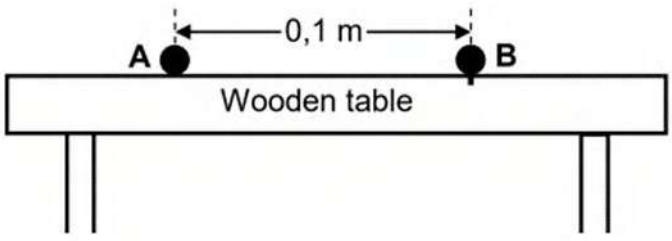
5.2.2 Is it possible for a photon with an energy of 2,5 x 10^{-19} J to be emitted from this atom? Choose from YES or NO. Give a reason for the answer. (2)

[14]

QUESTION 6

6.1 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

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

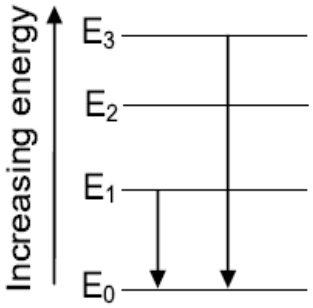
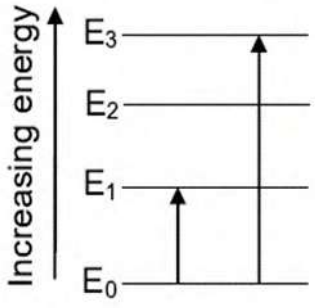


DIAGRAM B



(1)
[14]

ELECTRIC CIRCUITS

Ohm's Law

- **Ohm's law:** The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature
- Resistance $= \frac{\text{potential difference}}{\text{current}}$ (In symbols: $R = \frac{V}{I}$)
- The value $\frac{V}{I}$ is the resistance R of the conductor and is a constant.
- $R_{ext} = \frac{V_{ext}}{I_{total}}$, $(R_{ext}+r) = \frac{\varepsilon}{I_{total}}$, $r_{int} = \frac{V_{lost}}{I_{total}}$

Electrical energy

Electrical energy (W) is the energy transferred as electric charges move between points with different electric potential

$W = VI\Delta t$; $W = I^2 R\,\Delta t$; $W = \frac{V^2}{R}.\,\Delta t$

The SI unit of Electrical energy is Joule (J)

The kilowatt-hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour.

The cost of electricity usage can be calculated given the power specifications of the appliances used, duration and the cost of 1 kWh.

Cost of electricity = power rating to kilowatts × usage time in hours × local tariff

Power

Power (P) is the rate at which work is done or energy is transferred.

$P = \frac{W}{\Delta t}$, $P = VI$, $P = I^2R$, $P = \frac{V^2}{R}$

The SI unit of power is Watt (W)

INTERNAL RESISTANCE

Internal resistance (r) is defined as the opposition of flow of charge within the battery. A battery is said to produce an emf (electromotive force).

emf (Ɛ) is the maximum energy provided by a battery per unit charge passing through it.

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 = load voltage + lost voltage

$$\varepsilon = V_{terminal} + V_{internal}$$

Where

- ε – emf (electromotive force).
- V_{load} – Terminal or external voltage
- $V_{lost/internal}$ – Lost or internal voltage

The internal resistance of the battery (r) is treated as another resistor in series with the external resistance (R_{ext}). Therefore, the voltage across the external circuit (V_{load}) plus the voltage across the internal resistance ($V_{internal}$) is equal to the battery's emf (ε):

What happens to the lost volts when the external resistance is increased?

Answer and Explanation:

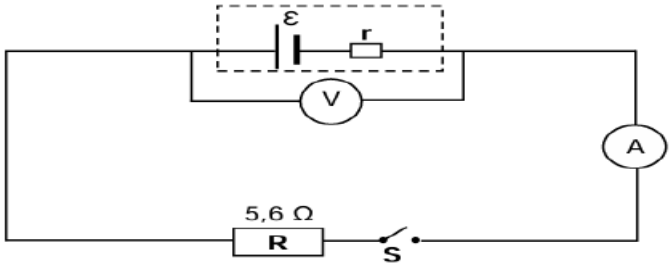
- Increasing the external resistance of the circuit will cause the total current to decrease.
- The lost volts (Ir) will decrease due to a decrease in total current

Then according to the equation $\varepsilon = V_{load} + V_{internal}$, V_{load} will increase.

WORKED EXAMPLE 1

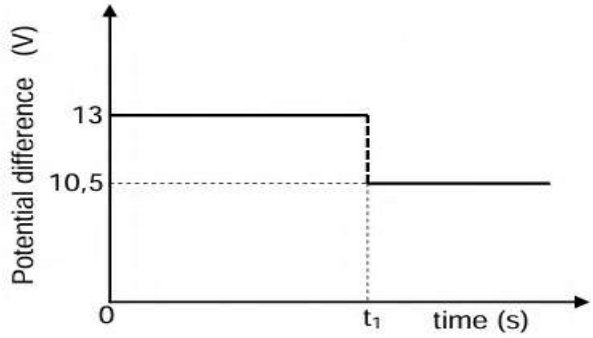
In the circuit diagram below, resistor R, with a resistance of 5,6 Ω, is connected, together with a switch, an ammeter and a high-resistance voltmeter, to a battery with an unknown internal resistance, r.

The resistance of the connecting wires and the ammeter may be ignored.



The graph below shows the potential difference across the terminals of the battery as a function of time.

At time t_1, switch S is closed.



1.1 Define the term emf of a battery. (2)

1.2 Write down the value of the emf of the battery. (1)

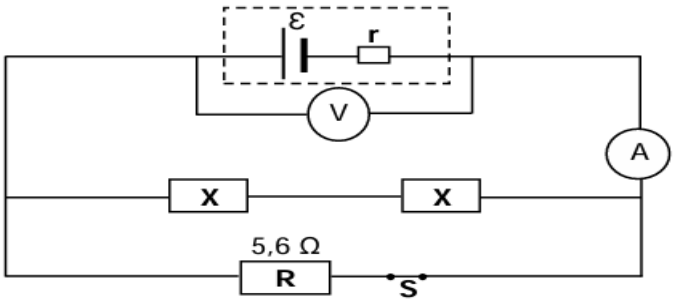
1.3 When switch S is CLOSED, calculate the:

1.3.1 Current through resistor R (3)

1.3.2 Power dissipated in resistor R (3)

1.3.3 Internal resistance, r, of the battery (3)

1.4 Two IDENTICAL resistors, each with resistance X, are now connected in the same circuit with switch S closed, as shown below.



The ammeter reading now increases to 4 A.

1.4.1 How would the voltmeter reading change? Choose from INCREASES, DECREASES or REMAINS THE SAME.
Give a reason for the answer by referring to $V_{\text{internal resistance}}$. (2)

1.4.2 Calculate resistance X. (5)

[19]

SOLUTION 1

1.1 (Maximum) energy provided (work done) by a battery per coulomb / unit charge passing through it. ✓ ✓ (2)

1.2 13 V ✓ (1)

1.3.1 $R=\frac{V}{I}$ ✓ $5.6=\frac{10.5}{I}$ ✓ I = 1.88 A ✓ (3)

1.3.2

OPTION 1

P=VI ✓= (10,5)(1,88) ✓= 19,74 W ✓

OPTION 2

$P= I^2R$ ✓= $(1.88)^2(5.6)$ ✓= 19,74 W ✓ (3)

1.3.3

OPTION 1

Ɛ = I(R + r) ✓

13 = 1,88 (5,6 + r) ✓

r = 1,31 Ω ✓

OPTION 2

$r=\frac{V_{\text{internal}}}{I}$ ✓

$=\frac{2.5}{1.88}$ ✓

r = 1,31 Ω ✓ (3)

1.4 Decreases, ✓ $v_{\text{Internal resistance}}$ /Internal volts increase ✓ (2)

Ɛ = I(R + r) ✓

13 = 4 (Rext + 1,31) ✓

Rext = 1,94 Ω

OPTION 1

$\frac{1}{R_P}=\frac{1}{R_1}+\frac{1}{R_2}$

$\frac{1}{1.94}=\frac{1}{5.6}+\frac{1}{R_2}$ ✓

R_2=2.97 Ω

$X=\frac{1}{2}(2.97)$ ✓

= 1,49 Ω ✓

OPTION 2

$\frac{1}{R_P}=\frac{1}{R_1}+\frac{1}{R_2}$

$\left[\frac{1}{1.94}=\frac{1}{5.6}+\frac{1}{2X}\ ✓\right]$ ✓

X = 1.49 Ω ✓

(5)

[19]

WORKED EXAMPLE 2

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. The internal resistance of the battery and the resistance of the conducting wires may be ignored.

Diagram 1

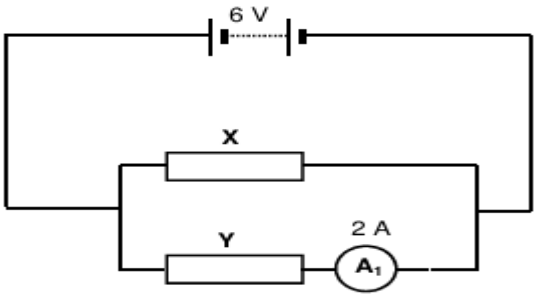
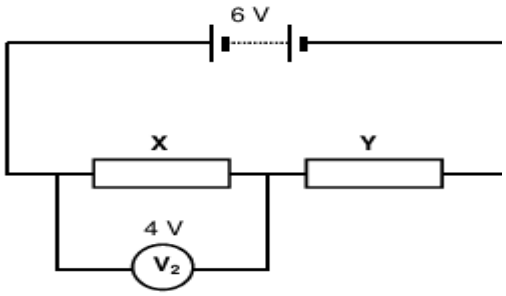


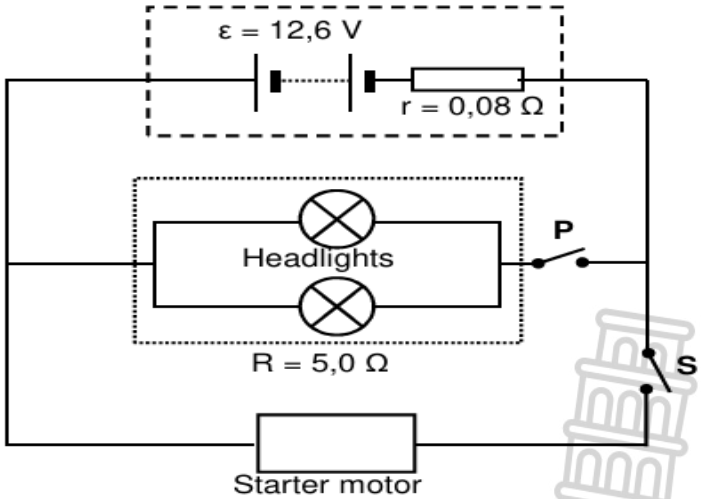
Diagram 2



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

2.1.2 Calculate the resistance of X and Y respectively. (6)

2.2 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.



2.2.1 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.

2.2.2 Calculate the potential difference across the headlights when switch P is closed. (5)

BOTH switches (P and S) are now CLOSED.

2.2.3 How will the brightness of the headlights be affected? Write down only INCREASE, DECREASE or THE SAME. Explain your answer. (4)

[18]

SOLUTIONS

2.1.1 The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature. ✓✓ (2)

2.1.2

DIAGRAM 1

$R_Y = \frac{V}{I}$ ✓

$= \frac{6}{2}$ ✓

$= 3\ \Omega$ ✓

DIAGRAM 2

$V_Y = \varepsilon - V_X = 6 - 4 = 2$ V

$R_Y = \frac{V}{I}\ 3 = \frac{2}{I}$ ✓ $I_Y = 0,67$ A

$R_X = \frac{V}{I} = \frac{4}{0,67}$ ✓ $= 5,97\ \Omega$ ✓ (6)

2.2.1 12,6 V ✓ (1)

2.2.2

$\varepsilon = I(R+r)$ ✓

12,6✓ $= I(5+0,08)$ ✓

$I = 2,48$ A

$V_{ext} = IR$

$= (2,48)(5)$ ✓

$= 12,4$ V ✓ (5)

2.2.3 Decrease ✓

Resistance decreases and I_T increases ✓

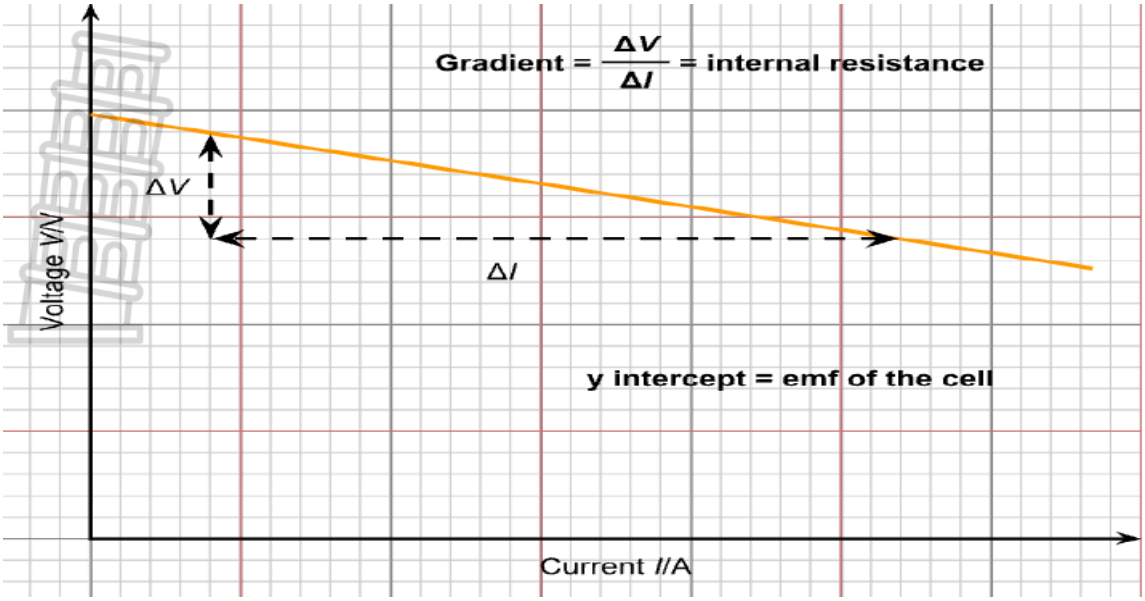
V_{int} will increase and V_{ext} will decrease (with emf constant) ✓

$\left(\text{According to } P = \frac{V^2}{R}\right)$, power will decrease ✓ (4)

[18]

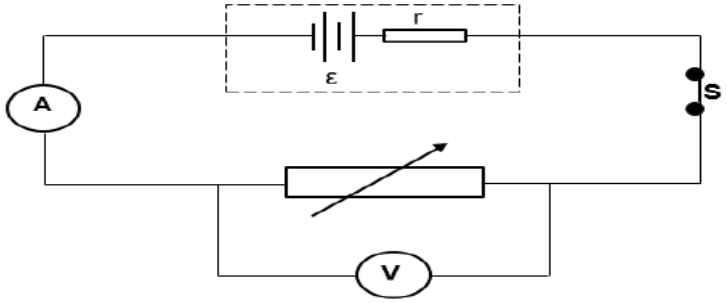
Steps to Analyze Circuit Graphs

- **Identify the axes**: Know what is plotted on the vertical (y) axis and horizontal (x) axis (commonly $V_{terminal}$ vs. I)
- **Write the core formula**: Start from the battery equation emf (Ɛ) = terminal voltage + lost voltage which expands $V_{load} = \varepsilon - I(r)$.
- **Match to** y = mx + c: Rearrange it as $V_{load} = -I(r) + \varepsilon$. Here, $y = V_{load}$, $m = -r$, $x = I$, and $c = \varepsilon$.
- **Find the intercepts**: Read the y-intercept directly as the emf (Ɛ). Find the x-intercept where V = 0, which represents the maximum short-circuit current ($I_{max} = \frac{\varepsilon}{r}$).
- **Calculate the gradient (slope)**: Use $\text{slope} = \frac{\Delta y}{\Delta x} = \frac{V_2 - V_1}{I_2 - I_1}$. . The internal resistance is $r = -(\text{slope})$.

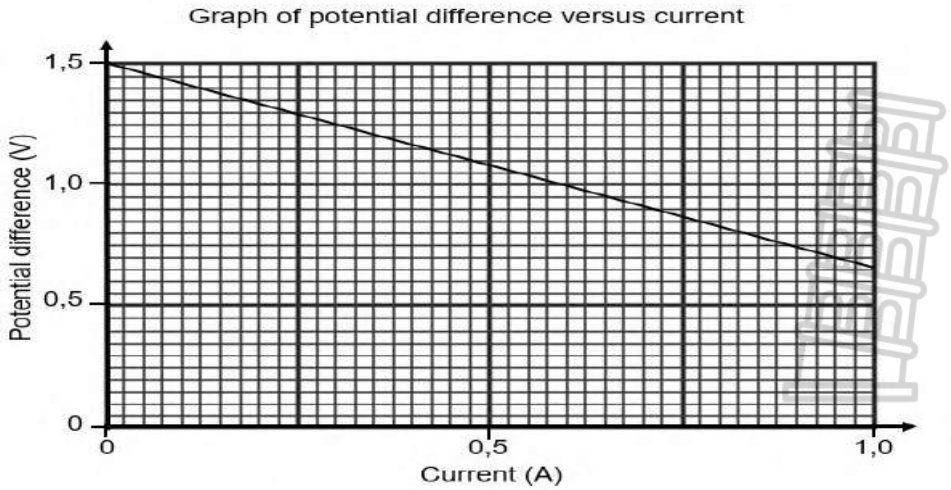


WORKED EXAMPLE 3

Grade 12 learners conduct an experiment to determine the emf (ε) and internal resistance (r) of a battery. They connect a battery to a rheostat (variable resistor), a low-resistance ammeter and a high-resistance voltmeter as shown in the diagram below.



The results obtained are shown in the graph below.



3.1 State ONE factor which must be kept constant during the experiment. (1)

3.2 Use the graph to determine the emf of the battery (1)

3.3 Calculate the gradient of the graph (3)

3.4 Which physical quantity is represented by the magnitude of the gradient of the graph? (2)

[7]

SOLUTIONS

3.1 Temperature ✓ (1)

3.2 1,5 V ✓ (1)

3.3 slope= $\frac{\Delta y}{\Delta x} = \frac{V_2 - V_1}{I_2 - I_1}$. ✓ ✓ = $\frac{0,65-1,5}{1,0-0}$ ✓ = - 0,85 = 0,85 Ω ✓ (3)

3.4 Internal resistance ✓ ✓ (2)

[7]

ACTIVITIES

MULTIPLE CHOICE QUESTIONS

QUESTION 1

1.1 A kilowatt hour refers to:

A The use of electrical appliances

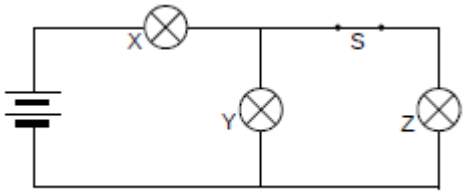
B The power of electrical appliances

C One kilowatt of electricity used for one hour

D The cost electricity specifications (2)

1.2 Three identical light bulbs, X, Y and Z, are connected in a circuit, as shown in the diagram below. Switch S is initially closed.

Ignore the internal resistance of the battery.



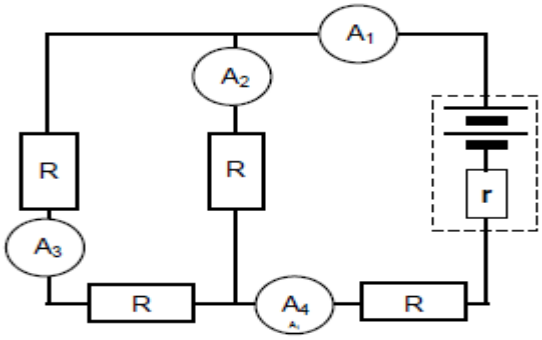
Switch S is now opened.

How will the brightness of bulbs X and Y be affected?

	BRIGHTNESS OF BULB X	BRIGHTNESS OF BULB X
A	Increase	Decrease
B	Decrease	Increase
C	Increase	Increase
D	Decrease	Decrease

(2)

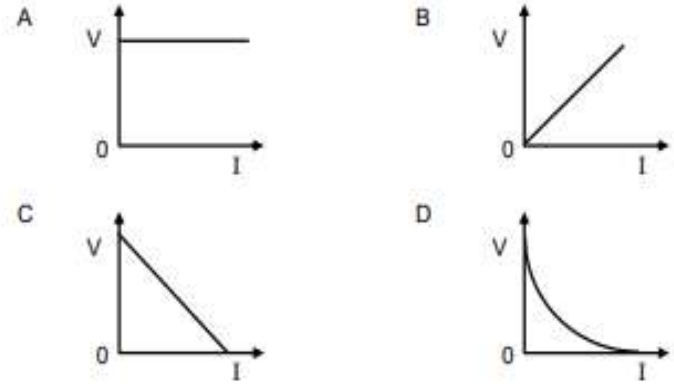
1.3 The diagram below represents a circuit in which all the external resistors have the same resistance.



Which ONE of the ammeters in the circuit will have the LOWEST reading?

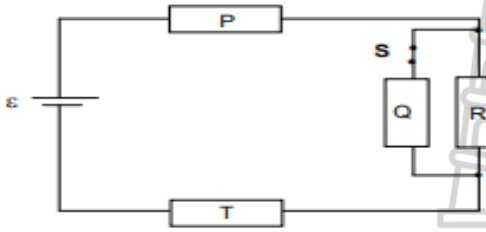
A A_1
B A_2
C A_3
D A_4 (2)

1.4 Which ONE of the graphs below best represents the relationship between potential difference (V) and current (I) for an ohmic conductor?



(2)

1.5 The four resistors P, Q, R and T in the circuit below are identical. The cell has an emf ε and negligible internal resistance. The switch is initially CLOSED.



Switch S is now OPENED. Which ONE of the following combinations of changes will occur in P, R and T?

	CURRENT IN P	CURRENT IN R	CURRENT IN T
A	Decrease	Remain the same	Decrease
B	Increase	Remain the same	Increase
C	Increase	Increase	Increase

D	Decrease	Increase	Decrease

(2)

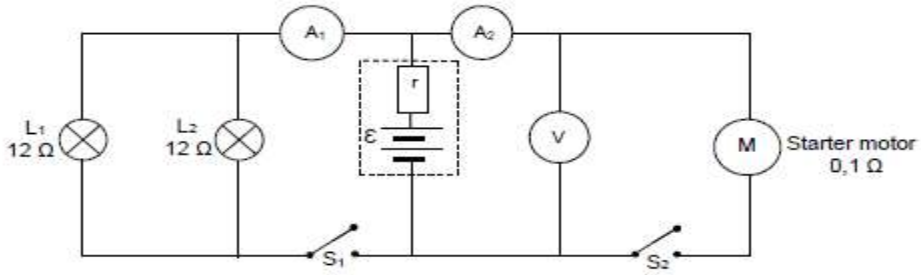
[10]

STRUCTURED QUESTIONS

QUESTION 2

Two identical headlights, L_1 and L_2, and a starter motor, M, of a car are connected to a battery, as shown in the circuit diagram below. The resistance of each headlight is 12 Ω, while the resistance of the starter motor is 0,1 Ω. The emf (Ɛ) and internal resistance (r) of the battery are unknown.

The ammeters and the connecting wires have negligible resistance, while the voltmeter has a high resistance. Switches S_1 and S_2 are initially open.



2.1 Define the term *emf*. (2)

2.2 Switch S_1 remains open while switch S_2 is closed.
The reading on ammeter A_2 is 120 A.
Calculate the reading on the voltmeter. (3)

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

2.3.1 Calculate the current passing through L_1. (3)

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

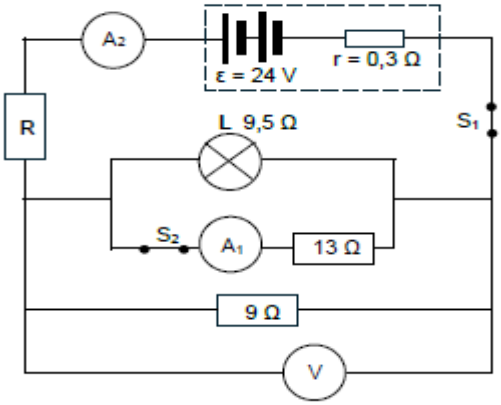
2.4 Calculate the emf of the battery. (6)

2.5 Both switches are now closed.
How will the reading on ammeter A_1 be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.
Explain the answer WITHOUT the use of a calculation. (5)

[20]

QUESTION 3

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



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

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

3.2 Calculate the:

3.2.1 Current through light bulb **L** (3)

3.2.2 Reading on ammeter A_2 (4)

3.2.3 Resistance of resistor R (5)

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

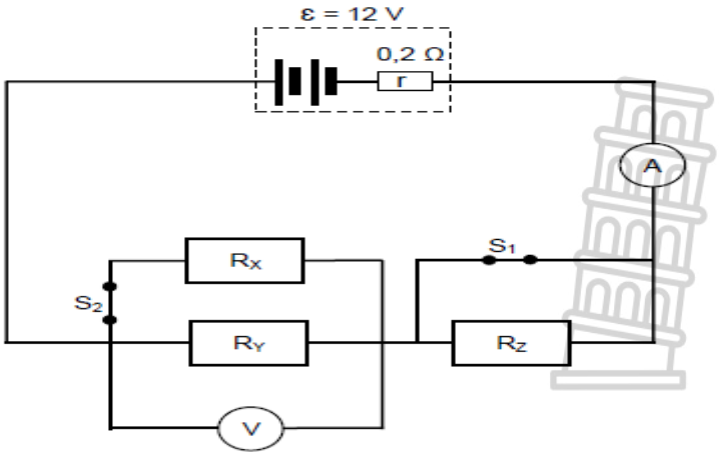
3.3 How will this affect the reading on ammeter A_1? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

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

[20]

QUESTION 4

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.



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.

4.1 Give a reason why there is no current through resistor R_Z (1)

4.2 Calculate the resistance of resistor R_Y. (5)

4.3 Calculate the power dissipated by resistor R_X. (4)

When both switches are now OPENED, the reading on the ammeter is 1,3 A.

4.4 Calculate the reading on the voltmeter. (3)

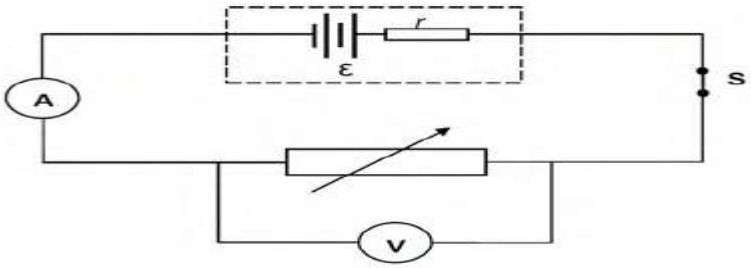
Switch S_1 remains OPEN while switch S_2 is now CLOSED.

4.5 Calculate the reading on the ammeter. (6)

[19]

QUESTION 5

5.1 A group of learners conduct an experiment to determine the emf () and internal resistance (*r*) of a battery. They connect a battery to a rheostat (variable resistor), a low-resistance ammeter and a high-resistance voltmeter as shown in the diagram below. ε



The data obtained from the experiment is displayed in the table below

READING ON VOLTMETER (V)	READING ON AMMETER (A)
2	0.58
3	0.46
4	0.36
5	0.24
6	0.14

5.1.1 State ONE factor which must be kept constant during the experiment. (1)

5.1.2 Using the information in the table above, plot the points and draw the line of best fit on the attached GRAPH SHEET. (3)

Use the graph drawn in QUESTION 5.1.2 to determine the following:

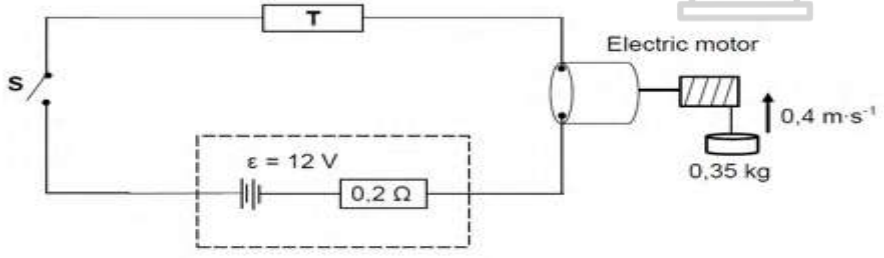
5.1.3 Emf (ε) of the battery (1)

5.1.4 Internal resistance of the battery, WITHOUT USING ANY FORM OF THE EQUATION (3)

ε = I(R + r)

5.2 A battery with an emf of 12 V and an internal resistance of 0,2 Ω are connected in series to a very small electric motor and a resistor, **T**, of unknown resistance, as shown in the circuit below.

The motor is rated **X** watts, 3 volts, and operates at optimal conditions.



When switch **S** is closed, the motor lifts a 0,35 kg mass vertically upwards at a constant speed of 0,4 $m \cdot s^{-1}$. Assume that there is no energy conversion into heat and sound.

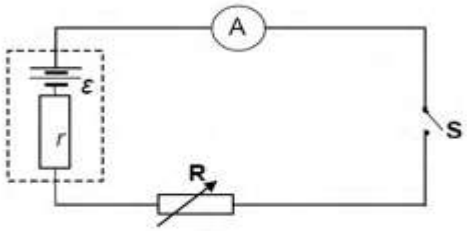
Calculate the value of:

5.2.1 **X** (3)

5.2.2 The resistance of resistor **T** (5)

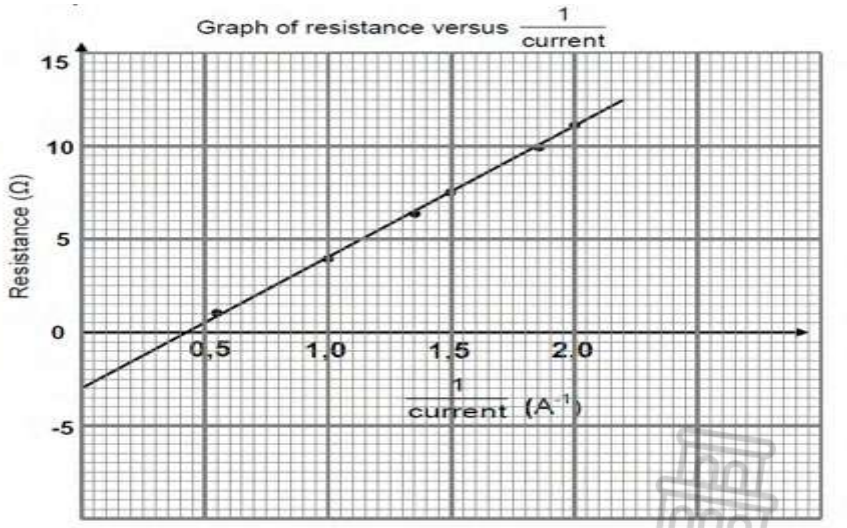
QUESTION 6

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



The learners use their recorded readings of current and resistance, together with the equation

$R = \frac{\varepsilon}{I} - r$, to obtain the graph



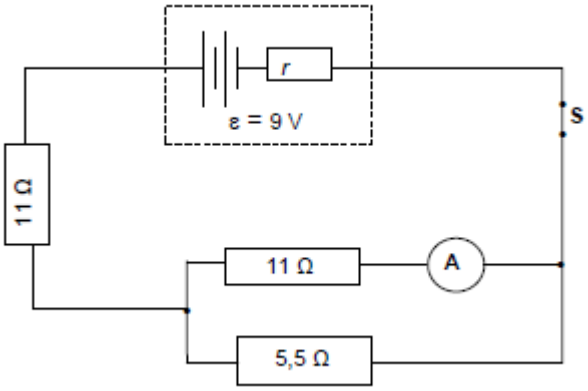
6.1 Which variable has to be kept constant in the experiment (1)

6.2 Refer to the **graph**.

6.2.1 Write down the value of the internal resistance of the cell (2)

6.2.2 Calculate the emf of the battery. (3)

6.3 In the circuit below the reading on ammeter **A** is 0,2 A. The battery has an emf of 9 V and internal resistance *r*.



6.3.1 Calculate the current through the 5,5 Ω resistor. (3)

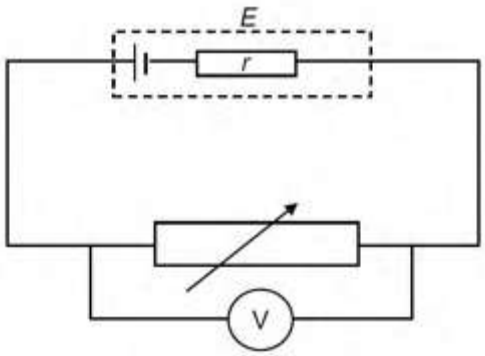
6.3.2 Calculate the internal resistance of the battery. (7)

6.3.3 Will the ammeter reading INCREASE, DECREASE or REMAIN THE SAME if the 5,5 Ω resistor is removed from the circuit? Give a reason for the answer. (2)

[18]

QUESTION 7

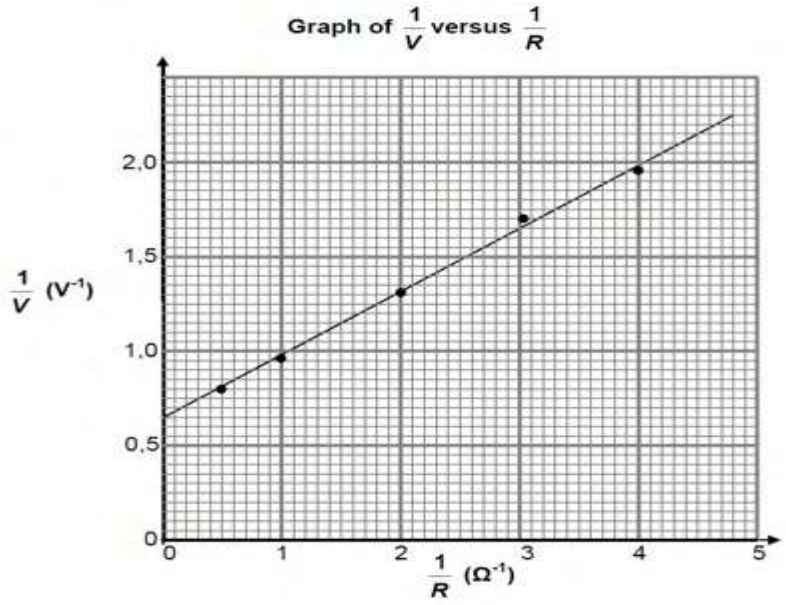
7.1 In an experiment, learners use the circuit below to determine the internal resistance of a cell.



The circuit consists of a cell of emf *E* and internal resistance *r*. A voltmeter is placed across a variable resistor which can be set to known values R.

The equation used by the learners is: $\frac{1}{V} = \frac{r}{ER} + \frac{1}{E}$

They obtain the graph below.



7.1.1 Write down a mathematical relationship for the slope of the graph. (2)

Use the information in the graph and calculate the:

7.1.2 Emf of the cell (2)

7.1.3 Internal resistance of the (3)

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

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

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

7.2.2 Calculate the resistance of resistor R_2 (5)

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

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

[18]