KWAZULU-NATAL PROVINCE

EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS)

LEARNER SUPPORT DOCUMENT

GRADE 11

PHYSICAL SCIENCES REVISION DOCUMENT

2025

PREFACE

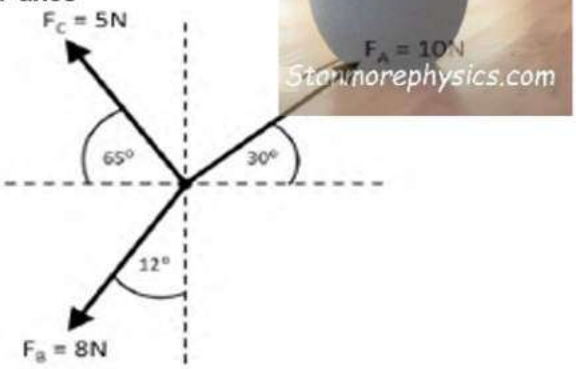
This support document serves to assist Physical Sciences learners on how to deal with curriculum gaps and learning losses. It addresses all the topics in the Grade 11 curriculum.

Activities serve as a guide on how various topics are assessed at different cognitive levels and to prepare learners for informal and formal tasks in Physical Sciences. It covers the following topics:

VECTORS IN 2 DIMENSIONS

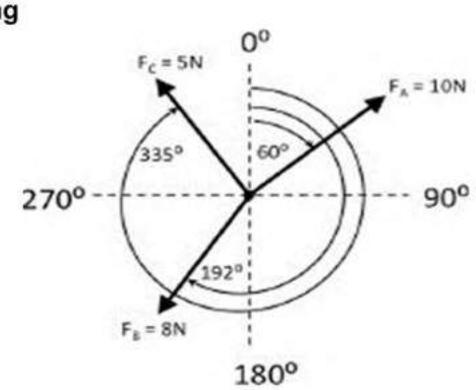
- **Vector**- A physical quantity with magnitude and direction.
  (Example: force, displacement, velocity, acceleration, electric field, etc.)
- **Scalar**- A physical quantity with magnitude only.
  (Example: time, temperature, charge, work, Energy, distance, speed, mass etc.)
- **Resultant** – is the single vector having the same effect as two or more vectors together.
- **Equilibrant** – is the force that brings equilibrium to a system of forces. It is equal in magnitude but acts in opposite direction to the resultant.
- **Triangle rule of forces** – When three forces are at equilibrium, they can be represented by the sides of a triangle taken in order.
- **Direction** of a vector acting at an angle – Different methods can be used to describe the direction of a vector:

X and Y axes



F_A: 10 N at 30° above the positive x- axis (horizontal axis)
F_B: 8 N at 12° left of the negative y- axis (vertical axis)
F_C: 5 N at 65° above the negative x- axis (horizontal axis)

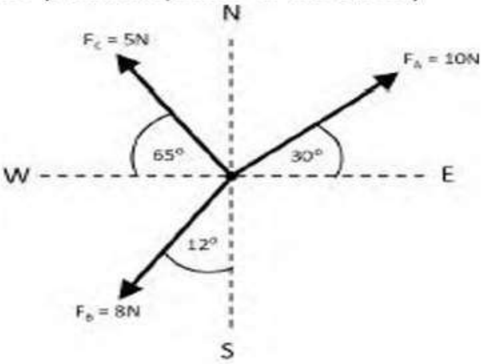
Bearing



Use North as 0° and measure **clockwise**:

F_A : 10 N on a bearing of 60°
F_B : 8 N on a bearing of 192°
F_C : 5 N on a bearing of 335°
F_A : 10 N on a bearing of 60°

Compass (Cardinal points or directions)

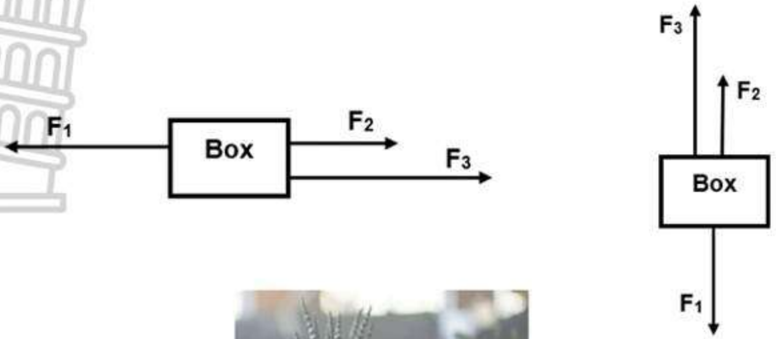


F_A : 10 N at 30° North of East
F_B : 8 N at 12° West of South
F_C : 5 N at 65° North of West

RESULTANT OF VECTORS

Resultant of co-linear vectors

- **Co-linear vectors** – Vectors that act on the same straight line.
  Example: F_1, F_2 and F_3 in the diagrams below are examples of co-linear vectors.



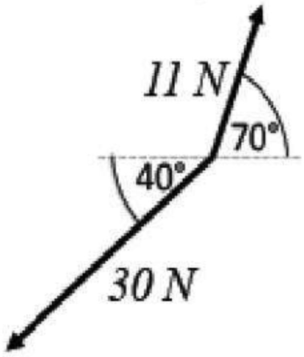
The resultant is calculated by doing the vector sum of the vectors:
(Direction: Taking Left and/or downwards as positive).
$F_R = F_1 + (-F_2) + (-F_3)$

Resultant of perpendicular vectors

WORKED EXAMPLES

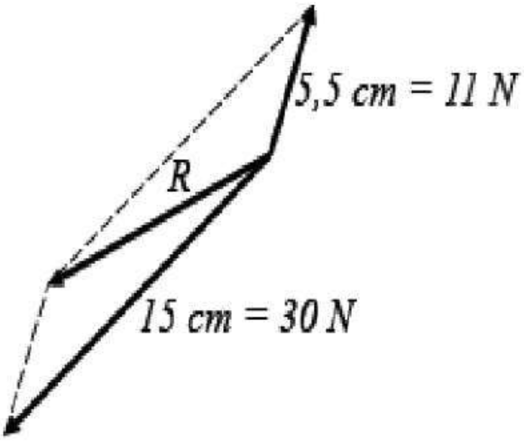
Example 1

Two forces, F_1 of magnitude 11N and F_2 of magnitude 30N, are applied on an object as shown in the diagram below. Determine the resultant force by accurate construction and by calculations.



- By construction

Draw the forces using a specified scale and accurate angle measurements.
Scale: 1cm = 2N



Measurements:

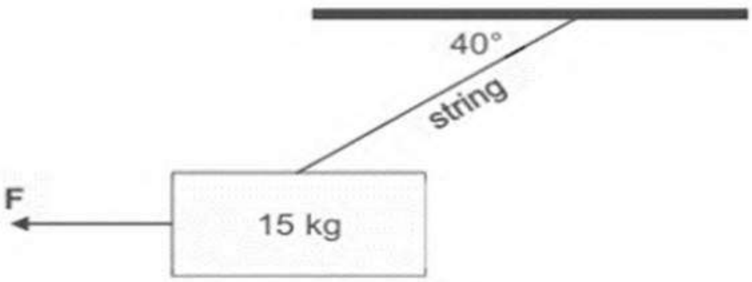
Resultant = 10,6cm = 21, 20 N at an angle of 25° below the negative x-axis.
(The equilibrant will be 21,20 N at an angle of 25° above the positive x-axis)

- By calculations
  Determine the x- and y-components of each force.
  Take East as Positive for horizontal components and North as positive for vertical components

	Vertical components	**Horizontal components**
F_1 (11 N)	F_{1x} = F cos θ = 11cos70° = = **3,76 N East**	F_{1y} = F sin θ = 11 sin 70° = **10,34 N North**
F_2 (30 N)	F_{2x} = F cos θ = 30 cos 40° = **22,98 N West**	F_{2y} = F sin θ = 30 sin 40° = **19,28 N South**
Vector sum of components	$F_x = F_{1x} + (-F_{2x})$ = 3,76 + (-22,98) = - 19, 22 = **19. 22 N West**	$F_y = F_{1y} + (-F_{2y})$ = 10,34 + (-19,28) = - 8, 94 = **8, 94N South**

Calculate the resultant using Pythagoras theorem:
$F_R^2 = F_x^2 + F_y^2$
$F_R^2 = 19,22^2 + 8,94^2$
F_R = 21, 20 N
Find angle:
$\tan\theta = \frac{8,94}{19,22}$
Θ = 24, 95°

Example 2
A billboard of mass 15 kg is suspended from a roof by means of a light inextensible string. A Force F pulls the billboard sideways, as shown in the diagram below:



When the angle between the roof and the string is 400, a closed vector diagram is obtained for all the forces acting on the billboard.

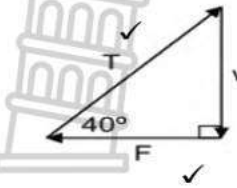
2.1 What deduction can be made when the forces acting on an object forms a closed vector diagram? (2)
2.2 Calculate the weight of the billboard. (2)
2.3 Draw a labelled closed vector diagram of all the forces acting on the billboard. Indicate the value of one of the angles. (4)
2.4 Calculate the tension in the string. (2)
2.5 The magnitude of force **F** is equal to the magnitude of the horizontal.
Give a reason why these two forces are not considered to be an action-reaction pair according to Newton's Third Law. (1)
[11]

Solution

2.1 Resultant force is zero / $F_{net} = 0$/ Object in equilibrium. ✓✓ (2)

2.2 W = mg
= (15)x(9.8) ✓
= 147 N✓ (2)

2.3



(✓1 mark for a closed vector diagram) (4)

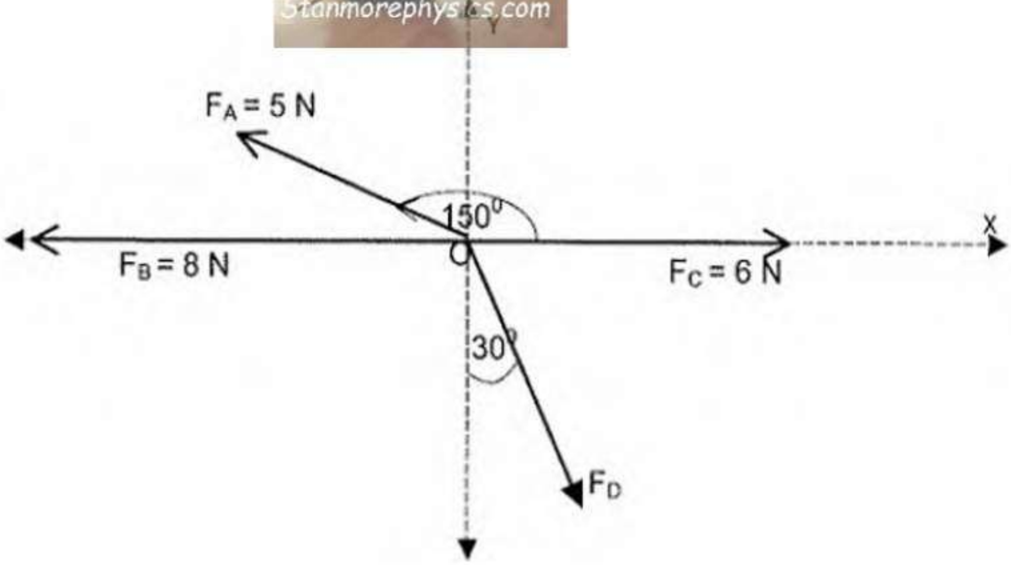
2.4 $T = \frac{w}{\sin 40}$✓
$= \frac{147}{\sin 40}$ ✓
T =228.69 N (2)

2.5 The two forces act on the same object (Newton's Third Law). ✓ (1)

[11]

Example 3

Four forces A, B, C and D act at a common point O as shown in the diagram below. The magnitudes of forces are as follows: A is 5N, force B is 8N, force C is 6N and F_D has unknown magnitude.



3.1 Define the term resultant vector. (2)

3.2 Calculate the magnitude of the resultant force B and force C . (2)

The **net horizontal** component for the forces F_A , F_B, F_C and F_D is equal to 1,25 N West.

3.3 Calculate the magnitude of force F_D (3)

3.4 Hence, calculate the magnitude of the resultant force acting at point O. (5)

3.3 Calculate the magnitude of force F_D (3)

[15]

Solution

3.1 The single vector which has the same effect as all the other vectors acting together. ✓✓ (2)

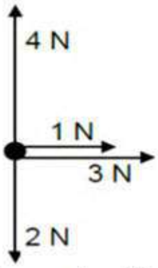
3.2 $F_R = (-F_B) + F_C = -8 + 6$✓ $= -2$ N, Therefore $F_R = 2$N West✓ (2)

3.3 $-F_B + (-F_A \cos 30^0) + F_C + F_D \cos 60^0 = 1,25$ ✓
$-8 - 4,33 + 6 + F_D \sin 60^0 = 1,25$ ✓
$F_D = 15,16$ N ✓ (3)

3.4 $F_{RY} = (5 \sin 30^0) + (-15.16 \cos 60^0)$ ✓
$= -10.63$ N. ✓
$F_R = \sqrt{1.25^2 ✓ + (-10.63)^2}$✓
$F_R = 10.70$ N✓ (5)

VECTORS IN TWO DIMENSIONS ACTIVITIES
QUESTION 1
MULTIPLE CHOICE

1.1 Four forces act on a point, as indicated in the diagram.



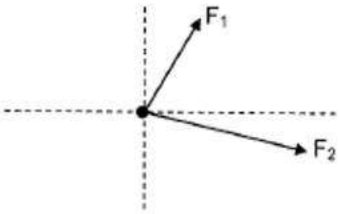
The magnitudes of the components of the resultant (net) force in the horizontal (FX) and vertical (FY) directions are …

A $F_X = 3$ N and $F_Y = 6$ N.
B $F_X = 1$ N and $F_Y = 4$ N.
C $F_X = 2$ N and $F_Y = 2$ N.
D $F_X = 4$ N and $F_Y = 2$ N. (2)

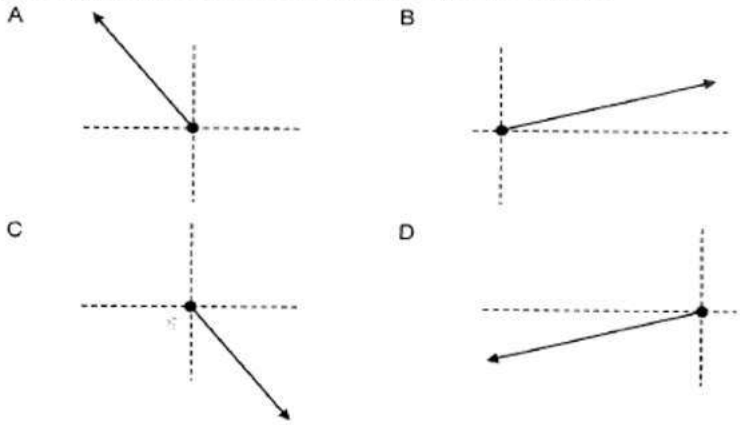
1.2 Two forces, F_1 and F_2, act on a point. If F_1 and F_2 act in the same direction the maximum resultant has a magnitude of 13 N. If forces F_1 and F_2 act in opposite directions the magnitude of the minimum resultant is 3 N. The magnitude of the two forces, in newton, is …

A 8 and 5.
B 16 and 10.
C 3 and 10.
D 10 and 7. (2)

1.3 Two forces, F_1 and F_2, act simultaneously at a point in the directions as shown in the sketch below.



Which ONE of the following represents the resultant of the two forces?



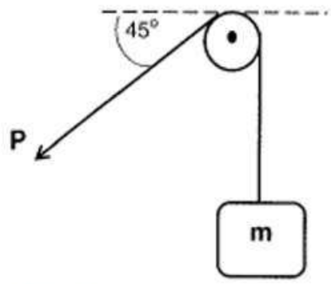
(2)

1.4 Two forces 5 N and 7 N respectively act simultaneously on an object. Which of the following CANNOT be the magnitude of the resultant for these forces?

A 12 N
B 2 N
C 13 N
D 9 N

(2)

1.5 In the diagram below, an object of mass **m** is held at rest by a string passing over a frictionless pulley. The mass of the string is negligible



The magnitude of force **P** in the strings is ...

A mg

B mg sin45°

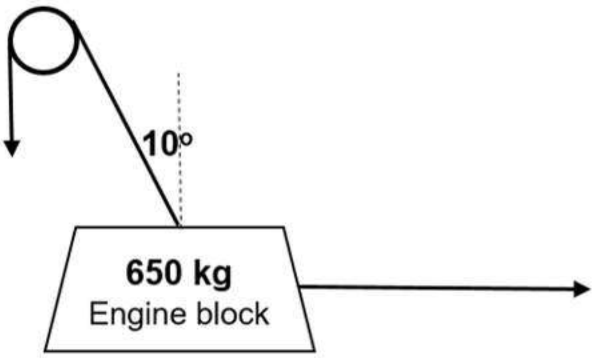
C $\frac{1}{2}mg$

D mg tan45° (2)

[10]

QUESTION 2

An engine block with a total mass of 650 kg, is suspended by a cable over a frictionless pulley. A learner pulls a rope, attached to the engine block, horizontally to the right so that the cable forms an angle an angle of 10° with vertical. It is then kept in this position.



2.1 Explain the concept of Forces in Equilibrium (2)

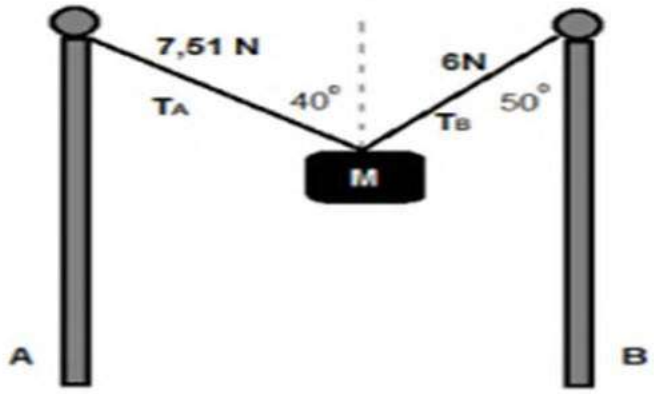
2.2 Draw a labelled, free-body vector diagram showing ALL the forces acting on the engine block. (3)

2.3 Calculate the magnitude of the tension in the cable. (3)

[8]

QUESTION 3

Heavy rain caught a learner on his way back home from school. On reaching home, he emptied his backpack and hung his backpack on the washing line between two vertical parallel poles. The bag remains in equilibrium. He realized that the angle between the washing line and pole B is 500. On further investigation he noted that force on the washing line between his bag and pole A is 7,51 N as shown in the diagram below:



3.1 Draw a vector diagram showing at least one angle and all forces acting on the bag. (4)

3.2 Write down the magnitude of the resultant of all forces acting on the bag. (2)

3.3 Name and explain the principle you used to answer question 1.2 (2)

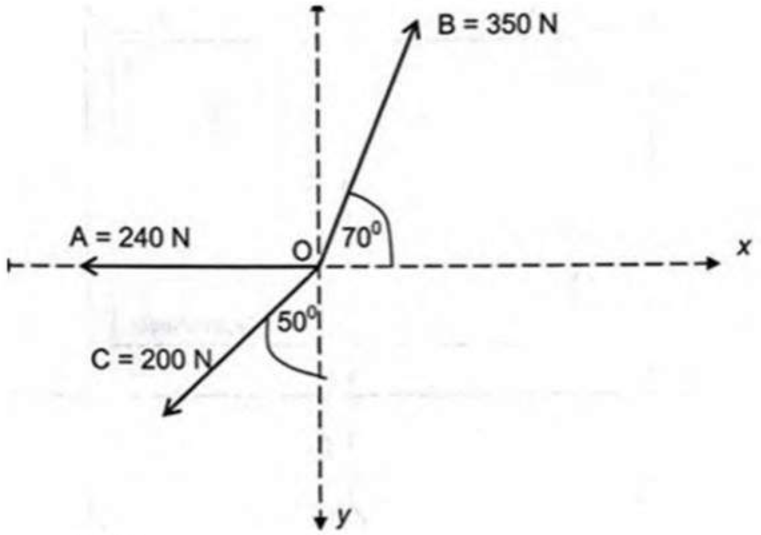
3.4 Calculate the mass of this wet bag if the force on the washing line between the bag and pole A is 7,51 N. (5)

3.5 When the bag is completely dry, the washing line become more contracted (more horizontal). How would the magnitude of FB change?
Only write down INCREASE, DECREASE or REMAINS THE SAME (2)

[15]

QUESTION 4

Three forces A, B and C of magnitudes 240N, 350 N and 200N respectively act on a point O in the directions as shown below.
The forces are not drawn to scale.



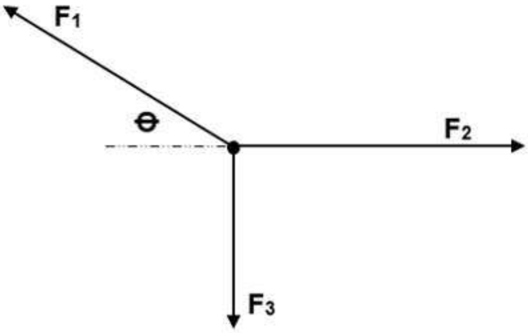
4.1 Define the term resultant force. (2)

4.2 Calculate the magnitude and direction of the resultant force. (10)

[12]

QUESTION 5

The resultant of the three forces $\mathbf{F_1}$, $\mathbf{F_2}$ and $\mathbf{F_3}$ acting at one point is ZERO.
The arrangement of the three forces is shown in the diagram below.



The magnitude of forces F_2 and F_3 are 250 N and 100N respectively.

5.1 Define the term Equilibrant of forces. (2)

5.2 Calculate the magnitude of force F_1. (3)

5.3 Determine the value of angle θ. (2)

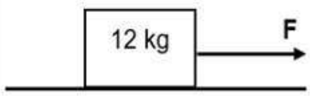
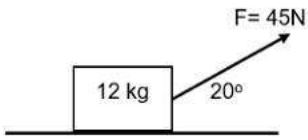
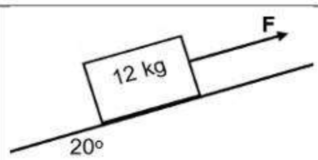
[7]

NEWTON'S LAWS

1. FORCES

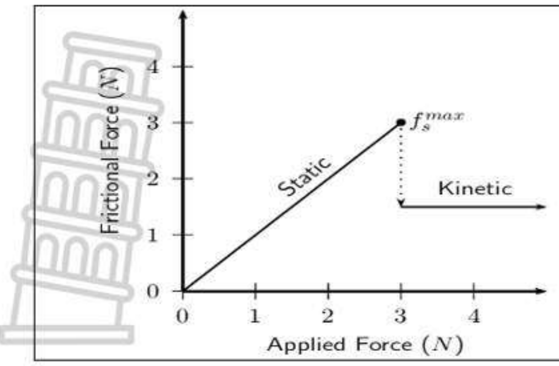
A force is a push or a pull.
A force can be either a contact force or a non-contact force.

- **Contact force** – a force exerted between objects that are in contact with each other. (e.g., Applied force, Tension, Friction, Normal.)
- **Non-contact force** – a force exerted between objects over a distance without touching each other. (e.g., Electrostatic force, Gravitational force, Magnetic force).
- **Normal force** – a force or the component of a force which a surface exerts on an object in contact with it, and which is perpendicular to the surface.
  The magnitude of the normal force depends on the gravitational force, the applied force and the surface orientation (horizontal or inclined).
  Examples:

		
N = Fg = mg = 12 x 9, 8 = 117, 6 N	N = Fg – Fy = mg – Fsinα = 12x9, 8 – 45xsin20° = 102, 21 N	N = Fg⊥ = mgcosθ = 12x9, 8 x cos 20° = 110, 51N

- **Frictional force** –
  Friction is the parallel component of the contact force on an object by the surface on which it rests or moves.
  Coefficient of friction (μ) – a value that indicates the roughness/smoothness of surfaces in contact.
  There are two types of friction: Static friction and kinetic friction.

Static friction f_s	**Kinetic friction**
Static friction is the force that opposes the tendency of motion of a stationary object relative to a surface. The maximum static friction is calculated as: $\mathbf{f_{smax} = \mu_s . N}$	Kinetic friction is the force that opposes the motion of a moving object relative to a surface. Kinetic friction is calculated as: $\mathbf{f_k = \mu_k . N}$



This graph shows how the relationship between static friction and the applied force.
f_s increases as $F_{applied}$ increases until f_{smax} is reached.
F_k is constant and less than f_{smax}. F_k is also independent of $F_{applied}$.

- **Tension** – a force developed within a rope or a string.
- **Applied force** – a push or a pull exerted on an object.

2. NEWTON'S LAWS

- **Newton's First Law of Motion**:
  A body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it.

Fnet = 0 N →
- Velocity = 0 m.s^{-1} ($v_i = v_f = 0$ m.s^{-1}) a = 0 m.s^{-2} → Object at rest (Stationary)
- Velocity ≠ 0 m.s^{-1} ($v_i = v_f \neq 0$ m.s^{-1}) a = 0 m.s^{-2} → Object moving at Constant velocity

- **Newton's Second Law of Motion**:
  When a resultant/net force acts on an object, the object will accelerate in the direction of the net force at an acceleration directly proportional to the net force and inversely proportional to the mass of the object.

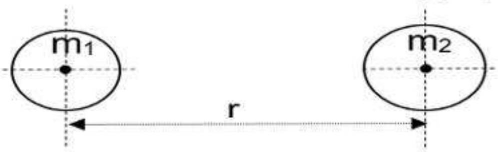
Fnet ≠ 0 N → Velocity ≠ 0 m.s^{-1} ($v_i \neq v_f$) a ≠ 0 m.s^{-2} → Object accelerates ($a = \frac{F_{net}}{m}$)

- **Newton's Third Law of Motion**:
  When object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A.

$$\boxed{F_{A\ on\ B} = F_{B\ on\ A}}$$

Forces $F_{A\ on\ B}$ and $F_{B\ on\ A}$ do not cancel each other because they act on different objects.

- **Newton's Law of Universal Gravitation**:
  Each body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.



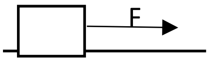
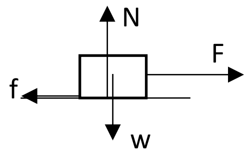
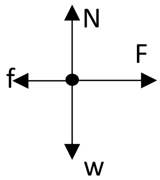
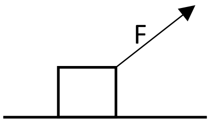
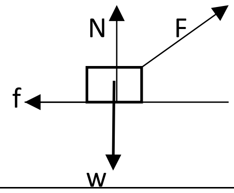
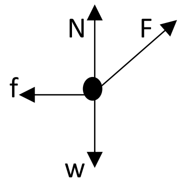
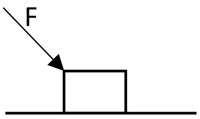
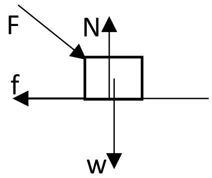
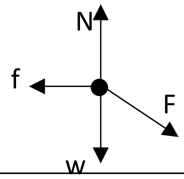
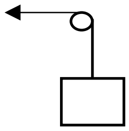
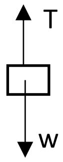
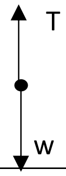
$$F = \frac{G.m_1.m_2}{r^2}$$

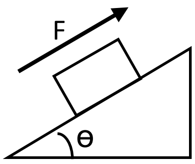
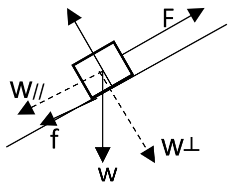
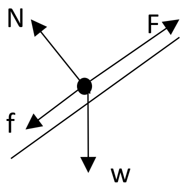
F: Gravitational force (N)
m_1, m_2: Masses (kg)
r: Distance from centres (m)
G: Gravitational constant

- **Weight -** the gravitational force exerted by the Earth on an object on or near its surface.

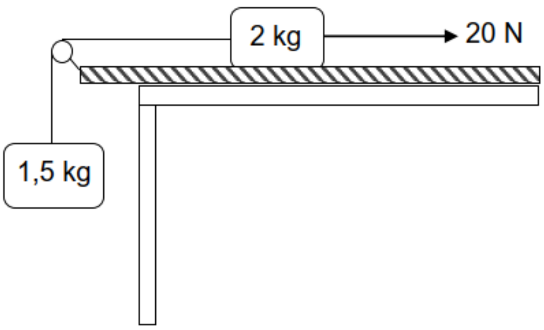
- **Mass -** the amount of matter in a body (kg).
- **Weightlessness -** the sensation experienced when all contact forces are removed.

FORCE/FREE-BODY DIAGRAMS, NORMAL AND NET FORCE EXPRESSIONS

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

Inclined (frictional)				F_{net} = ma
				F- f - $w_{//}$ =ma
				$w_{//}$ = mg sin θ
				$w_{\perp}$ = mg cos θ
				(N=$w_{\perp}$= mg cos θ)

WORKED EXAMPLES
QUESTION 1
A block of mass 2 kg is at rest on a rough horizontal surface. The block is connected to another block of mass 1,5 kg by means of a light inextensible string which hangs over a frictionless pulley. The 2 kg block experiences a constant frictional force of 3,1 N when a force of 20 N is applied to the block as shown in the diagram below. Ignore the effect of air friction.

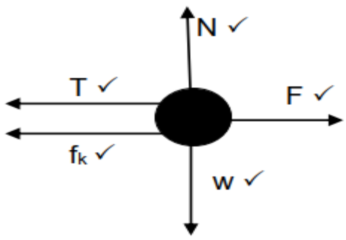


1.1 Define the term kinetic friction. (2)
1.2 Draw a labelled free-body diagram indicating all the forces on the 2 kg block. (5)
1.3 Apply a Newton's Second Law of motion to each of the blocks and calculate the magnitude of the acceleration of the blocks. (6)
1.4 Calculate the magnitude of tension in the string. (2)
[15]

SOLUTIONS

1.1 is the force that opposes the motion of a moving object relative to a surface. ✓✓ (2)

1.2



(5)

1.3 For a 2 kg block

$F_{net} = ma$
$F - T - f_k = 2a$
$20 - T - 3,1 = 2a$ ✓
$16,9 – T = 2a$
$T = 16,9 – 2a$ ……equation 1

For 1,5 kg block:

$F_{net} = ma$ ✓
$T - 1,5 (9,8)$ ✓ $= 1,5a$ ✓
$T - 14,7 = 1,5a$
$T = 1,5a + 14,7$ …. equation 2

Equation 1= equation 2

$16,9-2a = 1,5a + 14,7$ ✓
$2,2 = 3,5a$
$a= 0.63 m.s^{-2}$ ✓ (6)

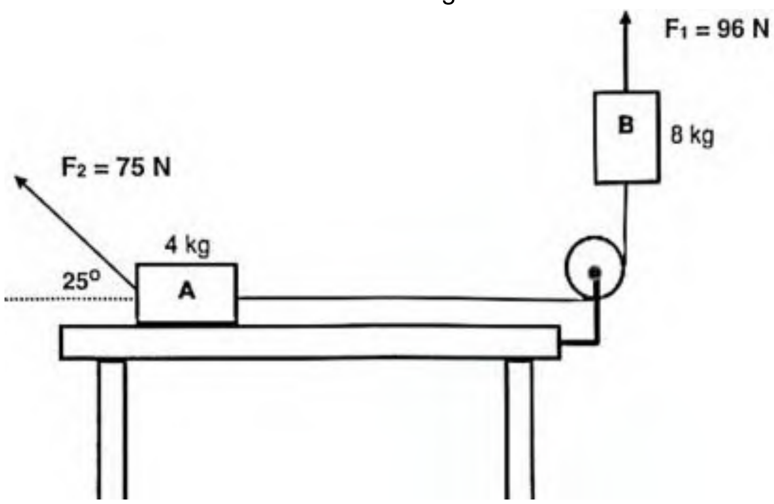
1.4 $T = 16,9 -2a$
$T = 16,9 – 2 (0,63)$ ✓
$T = 15.64$ N ✓

OR

$T = 1,5a + 14,7$
$T = 1,5 (0,63) + 14,7$
$T = 15,64$ N (2)
[15]

QUESTION 2

Block A with a mass 4 kg, that is at rest on a rough horizontal table, is connected to another block B with mass 8 kg by a light inextensible string passing over a frictionless pulley. A force F_1 of magnitude 96 N is applied vertically upwards on block B as shown in the diagram below.



A force F_2 of magnitude 75N is now applied at an angle of 25^0 with the horizontal on block A and the block accelerates to the left. The kinetic frictional force on block A is 11,76 N. Ignore the effects of air friction.

2.1 Define the term frictional force. (2)
2.2 Draw a labelled free-body diagram for block A. (5)
2.3 Calculate the magnitude of the:

2.1 Define the term frictional force. (2)

2.3.1 Acceleration of block A. (5)

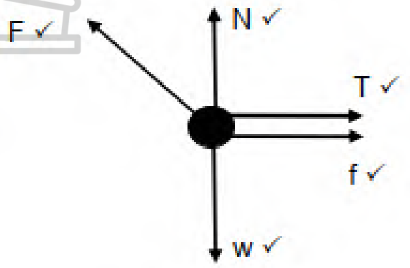
2.3.2 Tension in the rope connected to block A. (2)

[14]

SOLUTIONS

2.1 Frictional force is the force that opposes the motion of an object and which acts parallel to the surface. ✓✓ (2)

2.2



(5)

2.3.1 For block A:

$F_{net} = ma$ ✓

$Fx + (-T) + (-f) = ma$

$(75)\cos 25^0 - T - 11,76$✓ $= 4a$ ✓

$56,21 - T = 4a$

$T = -4a + 56,21$ ….(1)

For block B:

$F_{net} = ma$

$Fg + T + (-F) = ma$

$78,4 + T - 96$✓ $= 8a$

$T = 8a + 17,6$………(2)

$-4a + 56,21 = 8a + 17,6$

$12a = 38,61$

$a = 3,22\ m.s^{-2}$✓ (5)

2.3.2 For block A: $T = -4a + 56,21$

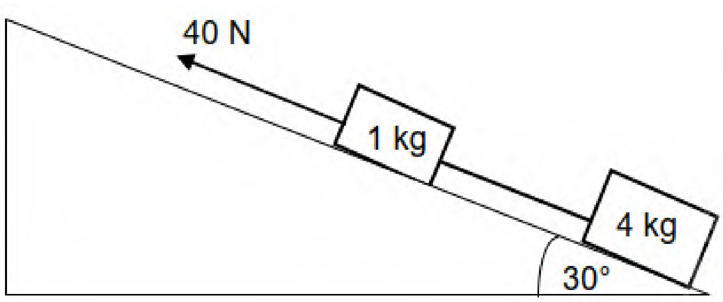
$= (-4a)(3,22) + 56,21$✓

$= 43,33\ N$✓ (2)

[14]

QUESTION 3

A block of mass 1 kg is connected to another block of mass 4 kg by a light inextensible string. The system is pulled up a rough plane inclined at 30^0 to the horizontal, by means of a constant force of 40N, parallel to the plane as shown in the diagram below.



The magnitude of the kinetic frictional force between the surface and the 4 kg block is 10 N. The coefficient of kinetic friction between the 1 kg block and the surface is 0,29.

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

3.2 Draw a labelled free-body diagram showing all the forces acting on the 1 kg block as it moves up the incline. (5)

3.3.1 Kinetic frictional force between the 1 kg block and the surface. (3)

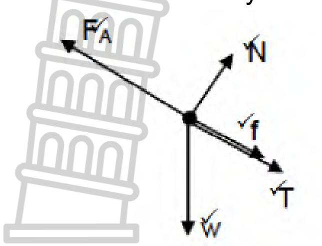
3.3.2 Tension in the string connecting the two blocks. (6)

[16]

Solutions

3.1 When Body A exerts a force on body B, body B exerts a force of equal magnitude in the opposite direction on body A. ✓✓ (2)

3.2



(5)

3.3.1 For the 1 kg block

$f_k = \mu_k N$✓

$= \mu_k mg \cos \theta$

$= 0.29\ (1 \times 9{,}8 \cos 30^0)$ ✓

$= 2{,}46$ N✓ (3)

3.3.2 $F_{net} = ma$✓

$F_A - [(T + f_{k)} + mg \sin \theta] = ma$

$40 - [T + 2{,}46 + 1\ (9{,}8)\ (\sin 30^0)] = 1(a)$

$40 - T - 7{,}36 = a$…………….. (1)

For 4 kg block

$T - (mg \sin \theta + f_{k)}$ ✓ $= 4a$✓

$T - (4 \times 9{,}8 \sin 30^0 + 10) = 4a$

$T - 29{,}6 = 4\ a$ …………. (2)

From (1) and (2)

. $a = 0{,}61\ m.s^{-2}$ ✓

$T = 29{,}6 + 4(0{,}61)$ ✓

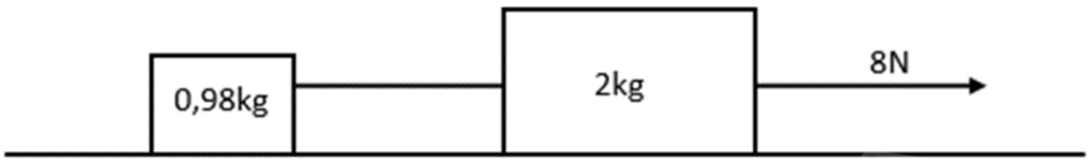
$T = 32{,}04$ N✓ (6)

[16]

ACTIVITIES- NEWTONS LAWS

QUESTION 1

An 8 N force pulls horizontally on a block of mass 2 kg. The block slides on a smooth horizontal surface. The first block is connected by a horizontal weightless inelastic string to a second block of mass 0.98 kg on the same surface.



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

1.2 Determine the acceleration of the blocks. (7)

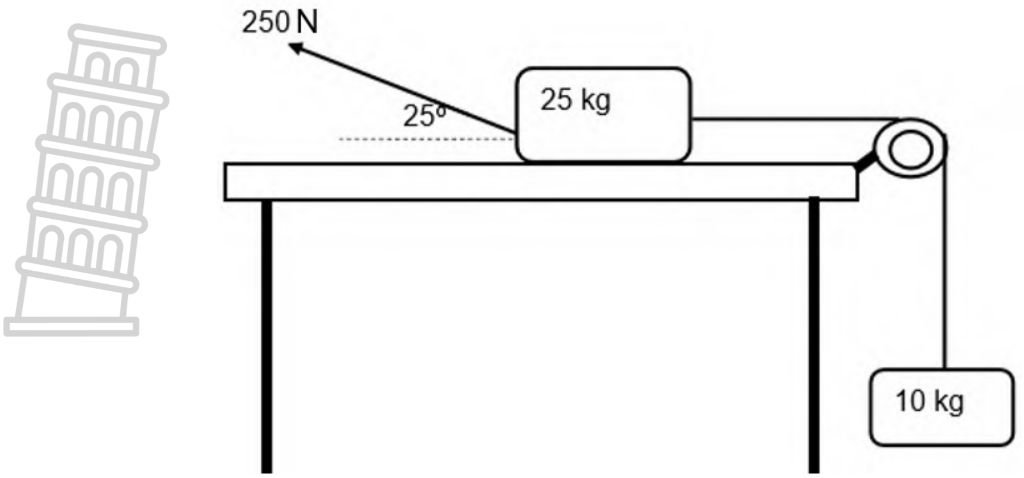
1.3 Determine the tension in the string. (3)

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

[18]

QUESTION 2

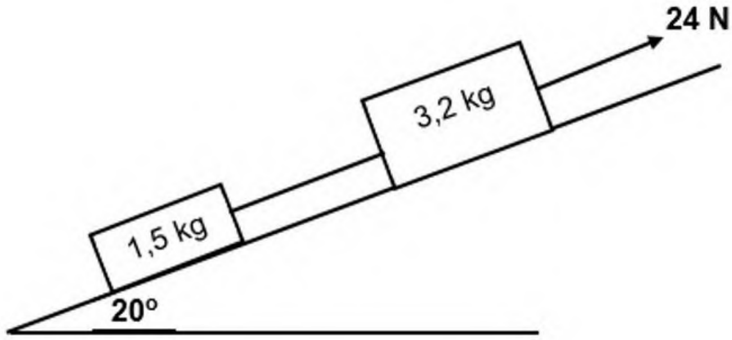
A 250 N force is applied on a block of mass 25 kg. The 25 kg block is connected to a 10 kg block by a light inextensible string through a frictionless pulley as shown on the diagram below. The 250 N force acts at an angle of 25° to the horizontal so that the system of blocks accelerates to the left. The coefficient of kinetic frictional force between the 25 kg block and the surface is 0,15.



2.1 Define the term kinetic frictional force (2)
2.2 Draw a labelled free-body diagram of all forces acting on the 25 kg block (5)
2.3 Calculate the:
2.3.1 Normal force exerted by the surface on the 25 kg block (3)
2.3.2 Acceleration of the system of blocks (7)
[17]

QUESTION 3

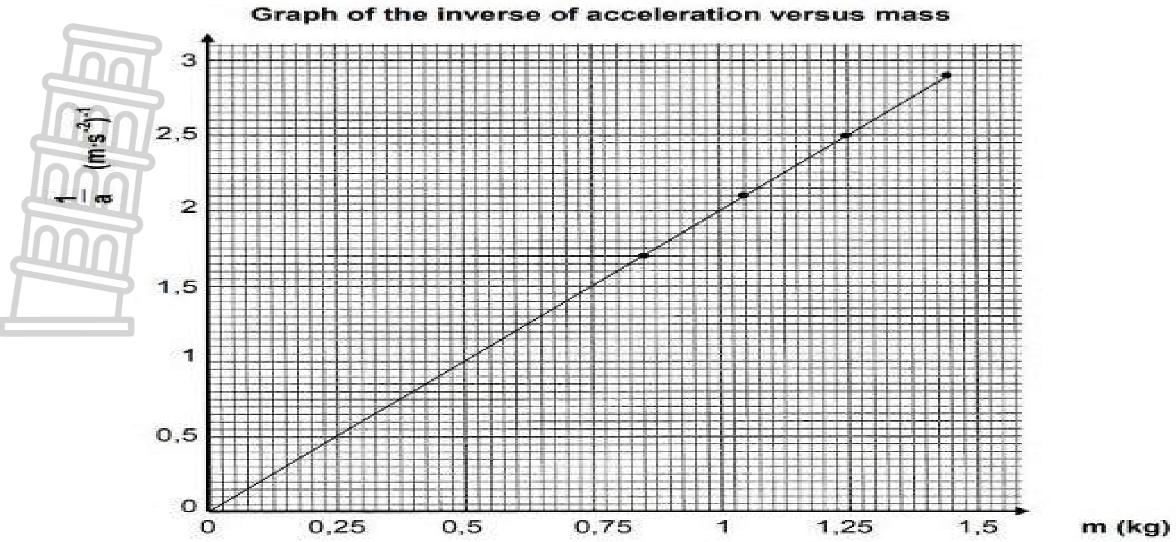
Two blocks of masses 1, 5 kg and 3, 2 kg are connected by a light inextensible string.
A 24 N force is applied on a system of blocks to move them up an inclined surface which is 25° to the horizontal at a CONSTANT VELOCITY as shown on the diagram below.
The 1, 5 kg box experiences a constant frictional force of 2 N as it moves up the incline.



3.1 State Newton's Second Law of Motion in words. (2)
3.2 Draw a labelled free-body diagram of all forces acting on the 1,5kg block. (4)
3.3 Calculate the:
3.3.1 Tension in the string connecting the blocks (5)
3.3.2 Coefficient of kinetic frictional force between the 3,2kg block and the surface (6)
[17]

QUESTION 4

4.1 Learners investigate the relationship between the mass of an object and the acceleration it experiences when a constant net force is applied on the object. They use their results to draw the graph below.



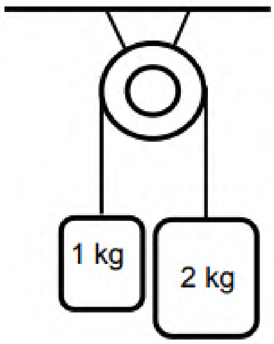
4.1.1 State Newton's Second Law of Motion in words. (2)

4.1.2 Calculate the gradient of the graph. (3)

4.1.3 Hence, determine the net force applied on the object during the experiment. (2)

4.1.4 Write down a conclusion for this experiment. (2)

4.2 In the diagram below, a 1 kg mass and a 2 kg mass are connected by an inextensible string of negligible mass. The string is passed over a light frictionless pulley so that the masses hang down as shown. Initially the system is held stationary.



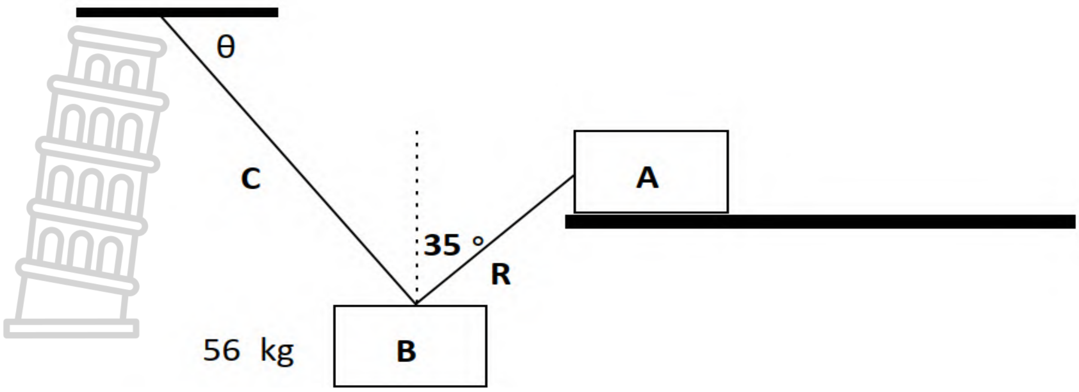
4.2.1 Draw a labelled free-body diagram showing ALL the forces acting on each block. (4)

4.2.2 Calculate the acceleration of the blocks. (5)

[18]

QUESTION 5

Block A, which is at rest on a horizontal rough surface, is used as an anchor to hold block B, with a mass of 56 kg, in the air at a certain height above the ground. The two blocks are connected with a rope R, which makes an angle of 35^0 with the vertical. Blocks B is suspended from the ceiling with cable C. Refer to the diagram below.



Block A experiences a frictional force of magnitude 200N. The system is stationary.

5.1 Define the term static frictional force (2)
5.2 What is the magnitude of the resultant force acting on block B? (1)
5.3 Draw a labelled free-body diagram indicating all the forces acting on the block B. (3)
5.4 Determine the horizontal components of the force in rope R. (1)
5.5 Calculate the vertical component of the force in cable C. (4)
5.6 Calculate the angle θ between the cable and the ceiling. (2)
[13]

QUESTION 6

Two satellites orbiting the Earth are situated on opposite sides of the Earth.
Satellite A has a mass of 3 800 kg and Satellite B has a mass of 4 500 kg. Satellite A is at a height of 25 000 km above the surface of the Earth.

6.1 State Newton's Universal Gravitational Law in words. (2)
6.2 Explain the term weightlessness (2)
6.3 Calculate the force between the Earth and the satellite A. (4)
6.4 What distance above the surface of the Earth should Satellite B be to experience the same force towards the Earth as Satellite A?
Choose from GREATER THAN, LESS THAN or EQUAL TO the distance above the Earth. Explain how you arrived to the answer. (4)
[12]

QUESTION 7

Gravitational force exist between the sun and the Earth.

7.1 Define the term weight. **(2)**
7.2 The mass of the sun is 330 000 times greater than that of the Earth. The distance between the centres of the sun and the Earth is 1,38 x 10^9 m. Calculate the gravitational force that the sun exerts on the Earth. **(4)**
7.3 How will the gravitational force that the Earth exerts on the Sun compare to the answer to QUESTION 7.2? Write only GREATER THAN, LESS THAN or EQUAL TO. Give a reason for the answer. **(2)**
[8]

ELECTROSTATICS

Principle of charge conservation

- The SI unit for electric charge is the coulomb (C).
- **Principle of conservation of charge**: The net charge of an isolated system remains constant during any physical process e.g., two charges making contact and then separating.
- Final charge after separation: $Q_{new} = \frac{Q_1 + Q_2}{2}$
- Amount of charge transferred: $\Delta Q = Q_f - Q_i$
- **Note:** This also applies to three physical identically sized spheres

$$Q_{new} = \frac{Q_1 + Q_2 + Q_3}{3}$$

Principle of charge quantization

- **The principle of charge quantization:** All charges in the universe consist of an integer multiple of the charge on one electron, i.e. $1{,}6 \times 10^{-19}$ C.
- Apply the principle of charge quantization $n = \frac{Q}{q_e}$

  where $q_e = 1{,}6 \times 10^{-19}$ C and n is an integer (whole number)

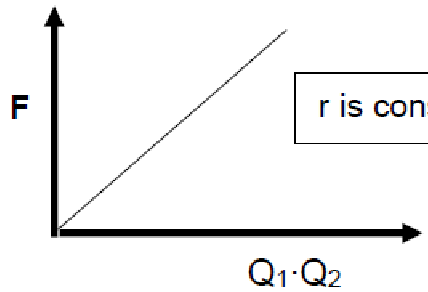
COULOMB'S LAW

The magnitude of the electrostatic force exerted by two-point charges (Q_1 and Q_2) on each other is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them.

$$\mathbf{F = k\frac{Q_1Q_2}{r^2}}$$

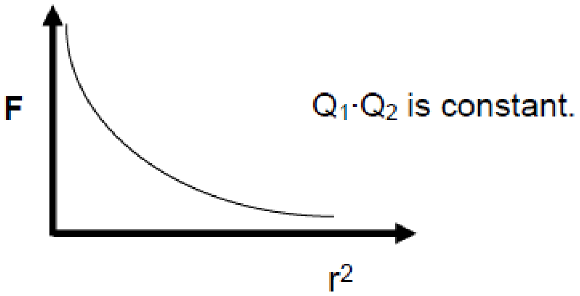
Graphical representation of Coulombs law:

- The electrostatic force is directly proportional to the product of the charges ($F \alpha\ Q_1 \cdot Q_2$)

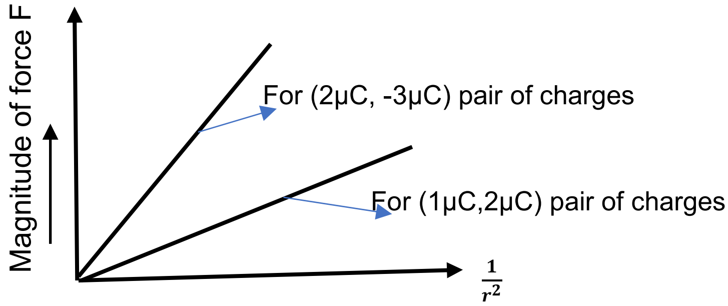


- The electrostatic force is inversely proportional to the square of the distance between the two charges.

  $F \alpha \frac{1}{r^2}$

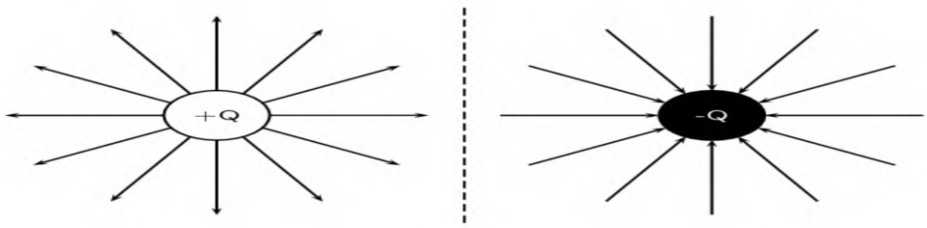


- Electrostatic force is directly proportional to the inverse of a square of a distance.

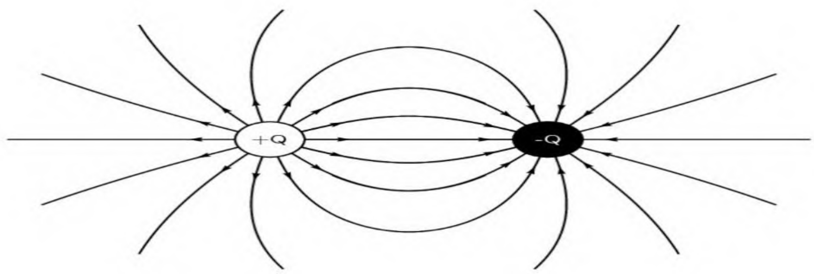


ELECTRIC FIELDS

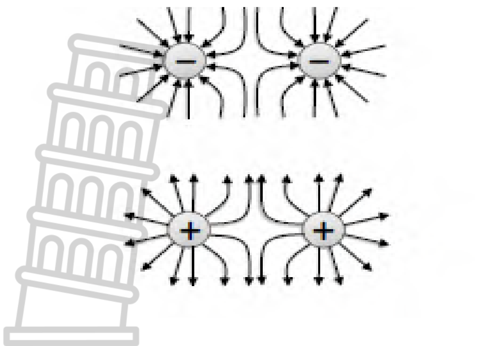
- **An electric field** is described as a region in space in which an electric charge experiences a force.
- Field lines around the single point charge



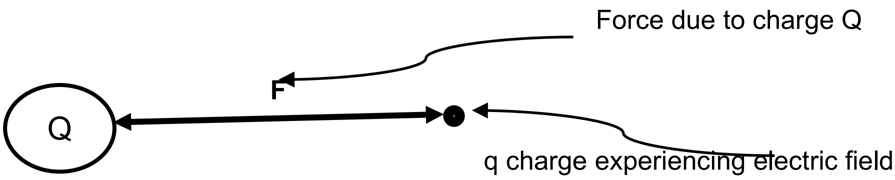
- Field lines between two unlike charges



- Electric Field Lines between the two like charges



- The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.
- **The electric field at a point** is the electrostatic force experienced per unit positive charge placed at that point.
  $E = \frac{F}{q}$
  q is the charge that experiences the force (C).
  E – electric field ($N.C^{-1}$)
  F – Electrostatic force (N)



- **Worked example:**
  Charge B experiences a force of 2 N due to charge A.
  Determine the electric field at point B.

+2 μC -5 μC

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

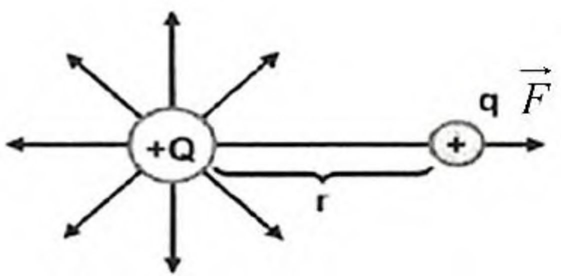
$E = \frac{2}{5 \times 10^{-6}}$

$E = 4 \times 10^{5}\ NC^{-1}$ to the right

ELECTRIC FIELD PATTERN

Electric field at distance r from point charge Q

- If a test charge q is placed at a distance r from a charge Q, the magnitude of the electrostatic force F that Q and q are exerting on each other is:
- The test charge placed at a point in electric field will experience a force; the magnitude of the force experienced will depend on the distance of the test charge(q) away from the charge(Q) setting the field`



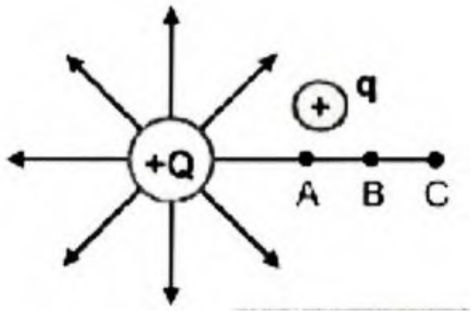
$\mathbf{E} = \frac{kQ}{r^2}$

E is the electric field ($N.C^{-1}$)

Q is the charge setting the field (C)

r is the distance (m)

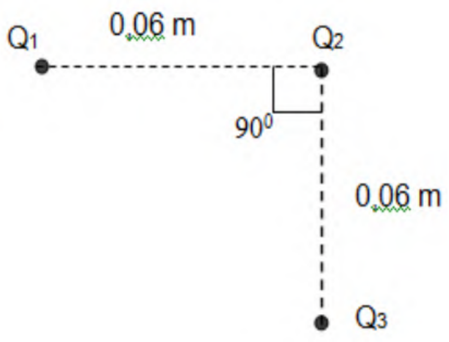
The strength of the electric field at different points is dependent on the position of a test charge in the field. The greater the distance between the two charges in the field, the smaller the force experienced by a test charge.



+q experiences a greater force at A than at C. Therefore, E is stronger at A than at C

WORKED EXAMPLE 1

Three point charges Q_1, Q_2 and Q_3 are placed in vacuum as shown in the diagram below. Charge Q_1 has a charge of $+6 \times 10^{-6}$ C, Q_2 has a charge of $+3 \times 10^{-6}$ C, and Q_3 has a charge of $+6 \times 10^{-6}$ C.

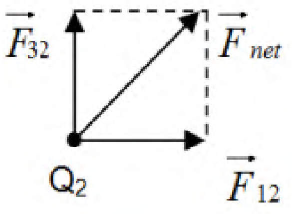


1.1	State Coulomb's Law in words.	(2)
1.2	Draw a free body diagram to show the forces acting on the point charge Q_2 and find the resultant force that acts on Q_2 graphically. Ignore gravitational force.	(3)
1.3	Calculate the magnitude of the resultant force that acts on point charge Q_2.	(6)
		[11]

SOLUTION 1

1.1 Coulomb's law states that the magnitude of the electrostatic force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.

1.2



1.3

$$F_{net} = \sqrt{(F_{12})^2 + (F_{32})^2}$$

$$F_{net} = \sqrt{\left(\frac{kq_1q_2}{(r_{12})^2}\right)^2 + \left(\frac{kq_3q_2}{(r_{32})^2}\right)^2}$$

$$F_{net} = \sqrt{\left(\frac{9\times10^9\times6\times10^{-6}\times3\times10^{-6}}{(0.06)^2}\right)^2 + \left(\frac{9\times10^9\times6\times10^{-6}\times3\times10^{-6}}{(0.06)^2}\right)^2}$$

$$F_{net} = \sqrt{\left(\frac{162\times10^{-3}}{3,6\times10^{-3}}\right)^2 + \left(\frac{162\times10^{-3}}{3,6\times10^{-3}}\right)^2}$$

$$F_{net} = \sqrt{(45)^2 + (45)^2}$$

$$F_{net} = 63,64N$$

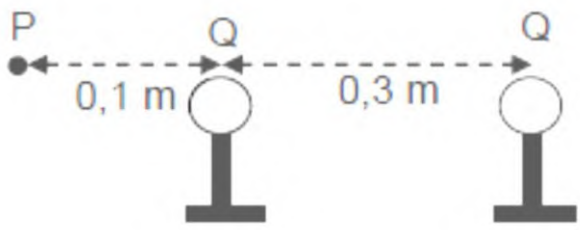
WORKED EXAMPLE 2

Two small identical metal spheres on insulated stands carry charges of +4,2 × 10^{-9} C and -6,8 × 10^{-9} C respectively. They are placed at a distance of 0,3 m apart.

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

2.2 Calculate the magnitude of the electrostatic force that the one charge exerts on the other. (3)

The two spheres are allowed to touch and are then returned to their original positions.



2.3 Calculate the number of electrons that were transferred. (3)

2.4 Define electric field at a point. (2)

2.5 Draw the electric field pattern between the two charged spheres. (2)

2.6 Calculate the magnitude of the net electric field at point **P** situated at 0,1 m to the left of the spheres, as shown in the diagram above. (5)

SOLUTION 2

2.1 The magnitude of the electrostatic force exerted by two-point charges (Q_1 and Q_2) on each other is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them (2)

2.2 $F = \frac{KQ_1Q_1}{r^2}$ ✓

$= \frac{(9\times10^9)(4,2\times10^{-9})(6,8\times10^{-9})}{(0,3)^2}$ ✓

$= 2,856\times10^{-4}$ N ✓ (3)

2.3 $Q_{new} = \frac{Q_1 + Q_2}{2}$

$= \frac{4,2\times10^{-9}+(-6,8\times10^{-9})}{2}$ ✓

$= -5,5 \times 10^{-9}$C

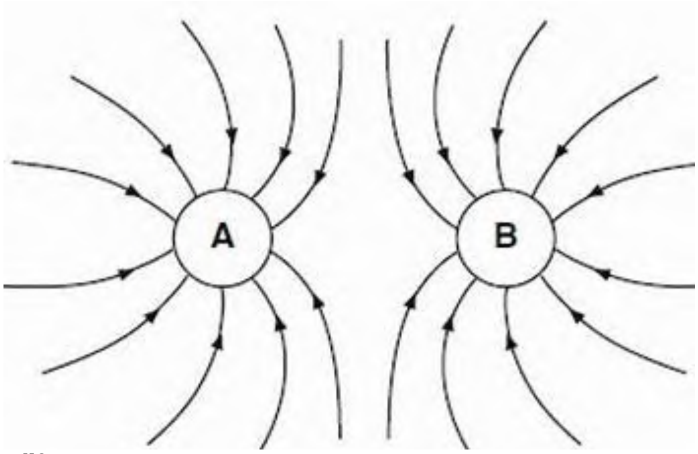
$n = \frac{\Delta Q}{e}$

$n = \frac{-5,5\times10^{-9}-4,2\times10^{-9}}{-1,6\times10^{-19}}$ ✓

$n = 6,0625 \times 10^{10}$electrons✓ (3)

2.4 It is the electrostatic force experienced per unit positive charge placed at that point. (2)

2.5 (2)



2.6 $E_{net} = \frac{KQ_1}{r^2} + \frac{KQ_2}{r^2}$ ✓

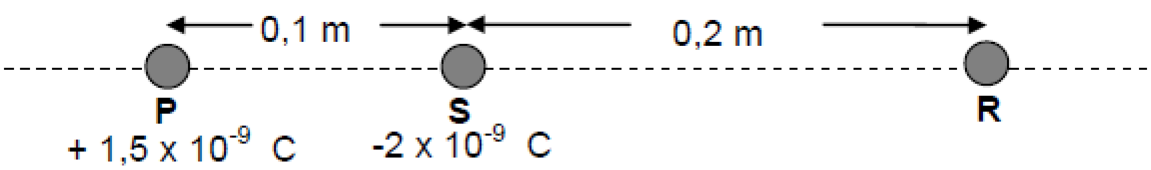
$E_{net} = \frac{(9\times10^9)(5,5\times10^{-9})}{(0.4)^2}$ ✓ $- \frac{(9\times10^9)(5,5\times10^{-9})}{(0.3)^2}$ ✓

$E_{net} = -2,41 \times 10^2$

$E_{net} = 2,41$ N·C^{-1} ✓ *left* ✓ (5)

WORKED EXAMPLE 3

Two point charges, P and S, are placed a distance 0,1 m apart. The charge on P is +1,5 x 10^{-9} C and that on S is -2 x 10^{-9} C. A third point charge, R, with an unknown positive charge, is placed 0,2 m to the right of point charge S, as shown in the diagram below.



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

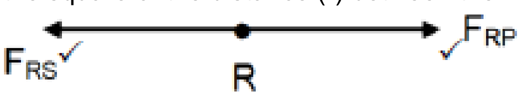
3.2 Draw a labelled force diagram showing the electrostatic forces acting on **R** due to **P** and **S**. (2)

3.3 Calculate the magnitude of the charge on **R**, if it experiences a net electrostatic force of 1,27 x 10^{-6} N to the left. Take forces directed to the right as positive (7)

SOLUTION 3

3.1 The magnitude of the electrostatic force exerted by two-point charges (Q_1 and Q_2) on each other is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them (2)

3.2 (2)



3.3 To the right as positive✓ (1)

(6)

$$F = k\frac{Q_1Q_2}{r^2} \checkmark$$

$$F_{netR} = F_{PR} + F_{SR}$$

$$F_{net} = \frac{kQ_1Q_2}{r^2} + \frac{kQ_1Q_2}{r^2}$$

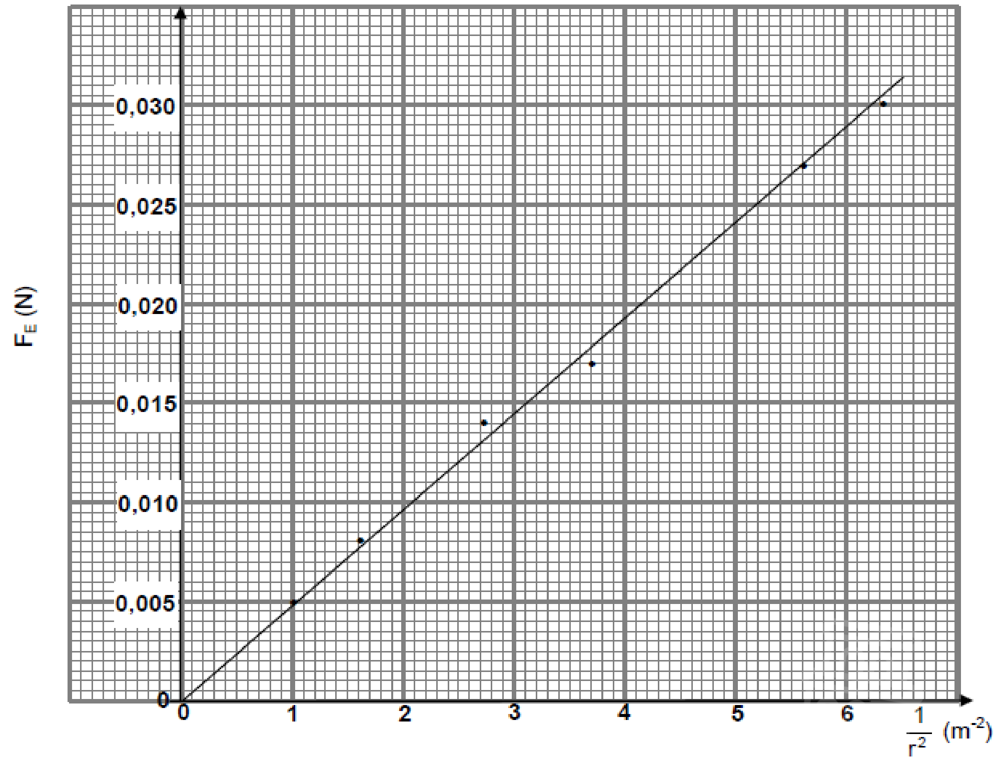
$$-1{,}27 \times 10^{-6} \checkmark = \left\{\frac{(9\times10^9)(1{,}5\times10^{-9})(Q)}{(0{,}3)^2} \checkmark - \frac{(9\times10^9)(2\times10^{-9})(Q)}{(0{,}2)^2} \checkmark\right\}$$

$-1{,}27 \times 10^{-6} = 150Q - 450Q$ ✓ ∴ $4{,}23 \times 10^{-9}$ C ✓

WORKED EXAMPLE 4

In an experiment to verify the relationship between the electrostatic force, F_E, and distance, r, between two **identical**, positively charged spheres, the graph below was obtained.

Graph of F_E versus $\frac{1}{r^2}$



4.1 Write down the dependent variable of the experiment. (1)

4.2 What relationship between the electrostatic force F_E and the square of the distance, r^2, between the charged spheres can be deduced from the graph? (1)

4.3 Use the information in the graph to calculate the charge on each sphere. (6)

SOLUTION 4

4.1 F_E/Electrostatic force (1)

4.2 The electrostatic force is inversely proportional to the square of the distance between the charges. (1)

4.3 (6)

$$\text{Slope} = \frac{\Delta F_E}{\Delta \frac{1}{r^2}} \checkmark = \frac{0{,}027 - 0}{5{,}6 - 0} \checkmark = 4{,}82 \times 10^{-3}\ \text{N·m}^2$$

$$\text{Slope} = F_E r^2 = kQ_1Q_2 = kQ^2 \checkmark \therefore 4{,}82 \times 10^{-3} \checkmark = \underline{9 \times 10^9\ Q^2} \checkmark \quad \therefore Q = 7{,}32 \times 10^{-7}\text{C} \checkmark$$

[16]

ELECTROSTATICS ACTIVITIES

QUESTION 1 (MULTIPLE CHOICE)

1.1 Two identical small metal spheres on insulated stands carry equal charges and are a distance *d* apart. Each sphere experiences an electrostatic force of magnitude F. The spheres are now placed a distance *d* apart. The magnitude of the electrostatic force each sphere now experiences is:

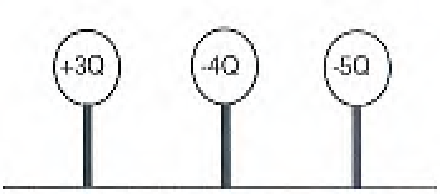
A. $\frac{1}{2}F$

B F

C 2F

D 4F (2)

1.2 Three spheres with charges of +3Q, -4Q and -5Q respectively are placed on isolated stands as shown in the diagram below.



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

The charge on each sphere after contact is….

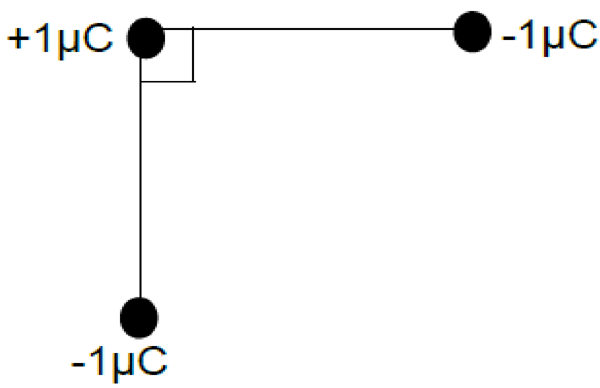
A Q

B -2Q

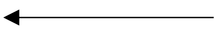
C -3Q

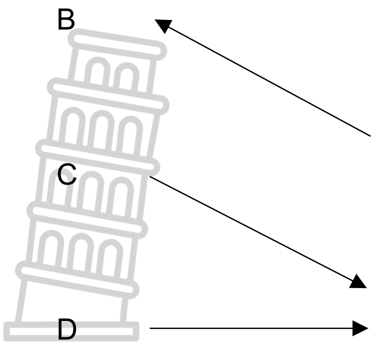
D 6Q (2)

1.3 Three point-charges of magnitude +1 μC, -1 μC and -1 μC are placed in a vacuum to form a right-angle as shown in the diagram below.



The net force acting on the + 1 μC can by represented by …

A 



(2)

1.4 The magnitude of the electric field at a point P from a positive point charge q is x N·C^{-1}. Which ONE of the statements below regarding this electric field is CORRECT?

A A + 1 C charge placed at P will experience a force of magnitude x N directed away from q.

B The force on a + 2 C charge placed at P will have a magnitude ¼ x N directed away from q.

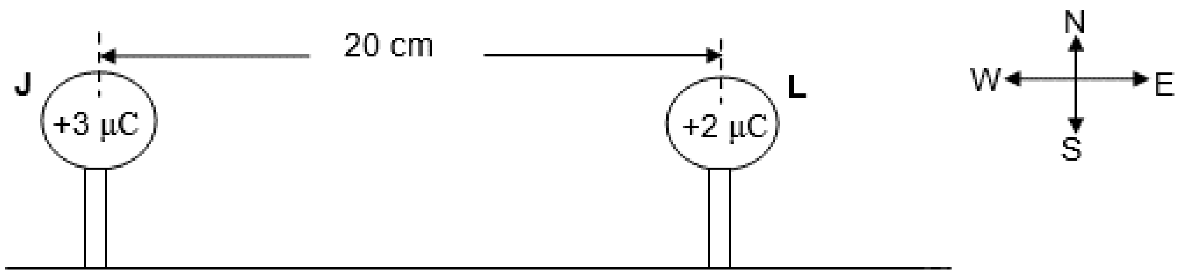
C A + 1 C charge placed at P will experience a force of magnitude x N directed towards q.

D The force on a + 2 C charge placed at P will have a magnitude ¼ x N directed towards q. (2)

[8]

QUESTION 2

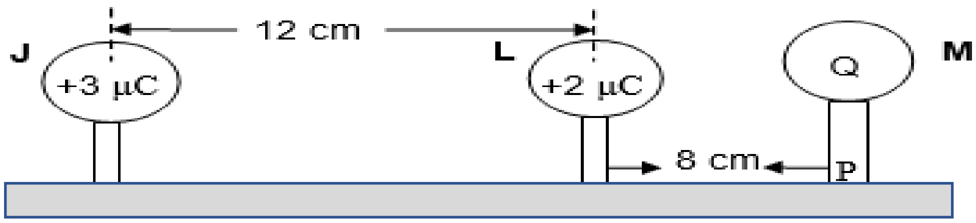
Two metal spheres, **J** and **L** placed on wooden stands, carry charges +3 µC and +2 µC respectively. The diagram is not drawn according to scale.



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

2.2 Calculate the electrostatic force experienced by sphere **L** as a result of sphere **J**. (4)

Sphere **L** is now placed 12 cm away from sphere **J**. Another sphere **M** with a charge of -8 µC is brought into contact with sphere **L**. **After contact**, sphere **M** is placed on a wooden stand **P**, 8 cm from sphere **L**, as shown in the diagram.



2.3.1 What is the charge (Q) of sphere **M** after contact with sphere **L**? (1)

2.3.2 Calculate the number of electrons transferred between sphere L and sphere **M** after contact. (3)

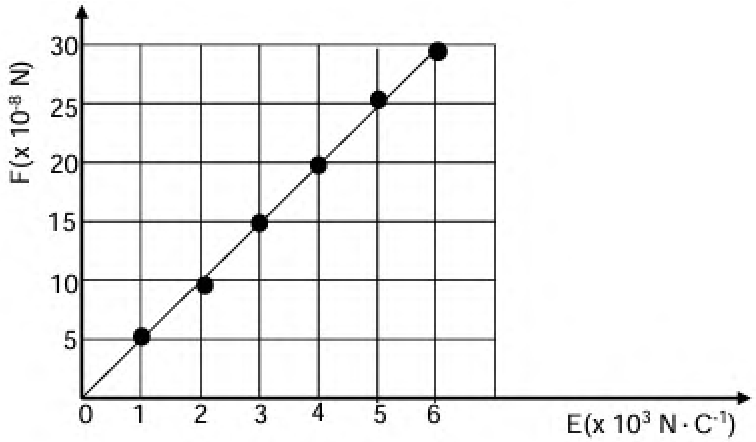
2.3.3 Draw the electric field pattern due to the charge of sphere **J** and sphere **L** after contact. (3)

2.4 Calculate the net electric field strength on sphere L **due** to sphere J **and** sphere **M** after contact. (6)

[19]

QUESTION 3

3.1 The relationship between the electrostatic force (F) experienced by a test charge and the magnitude of the electric field (E) the charge is placed in, is investigated. The results obtained are shown in the graph below.



3.1.1 For this investigation, write down the independent variable. (1)

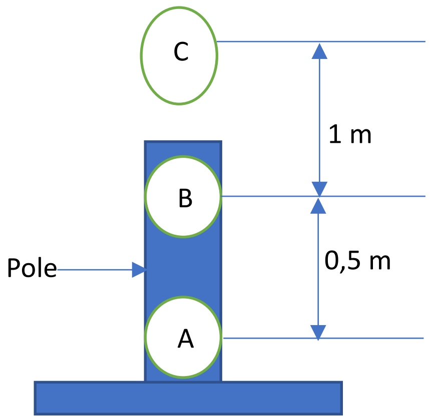
3.1.2 State, in words, the relationship between F and E as depicted by the graph. (1)

3.1.3 Write down the NAME of the physical quantity represented by the gradient of this graph. (1)

3.1.4 Calculate the value of the gradient of the graph. (3)

3.1.5 Hence, write down the magnitude of the test charge that is used. (1)

3.2 Two small charged spheres (A and B) are fixed 0,5 m apart on a vertical pole. The upper sphere, B, carries a fixed charged of $-3,0 \times 10^{-6}$ C, and the lower one, A, carries a charge of $+8,0 \times 10^{-6}$ C.
A 0,03 kg small sphere, C, carrying an unknown charge Q_c, is suspended 1 m above sphere B, as shown in the diagram.



3.2.1 Draw a diagram that shows the electric field pattern between spheres A and B. (3)

3.2.2 Draw a labelled free-body diagram showing all the forces acting on Sphere C. (3)

3.2.2 Calculate the charge on sphere C. (5)

3.3 A small metal sphere M carries a charge of $+2,4 \times 10^{-9} C$

3.3.1 Sketch the electric field pattern associated with sphere M (2)

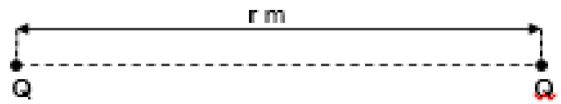
$\mathbf{3,2 \times 10^{10}}$ electrons are now transferred to sphere M.

3.3.2 Calculate the electric field at a point 0,125 m from the sphere M. (6)

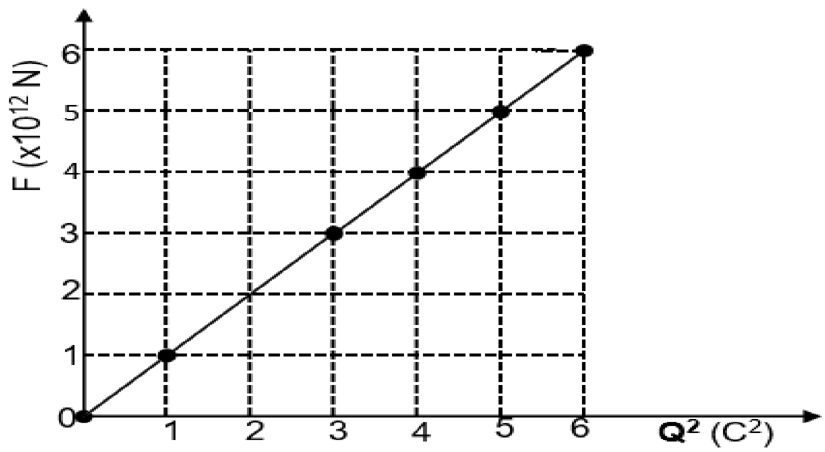
[26]

QUESTION 4

4.1 An investigation is conducted with pairs of IDENTICAL point charges, all placed a distance **r** meters from each other, as shown in the diagram below.



The graph below shows the relationship between the electrostatic FORCE **F**, exerted by one point charge on the other, and the PRODUCT of the two charges, $\mathbf{Q^2}$.



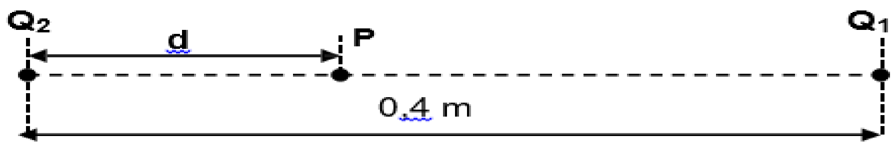
4.1.1 For this investigation, write down the controlled variable. (1)

4.1.2 Write down the relationship between the electrostatic force **F** and the product of the two-point charges, $\mathbf{Q^2}$. (1)

4.1.3 **Using the graph**, calculate the value of the gradient of the graph. (3)

4.1.4 Using the mathematical expression of Coulomb's law and the answer to **QUESTION 4.1.3**, calculate the distance **r** between the charges. (4)

4.2 Two-point charges, $\mathbf{Q_1}$ = +8 μC and $\mathbf{Q_2}$ = +2 μC, are separated by a distance of 0,4 m, as shown in the diagram below.



4.2.1 Define *electric field at a point* in words. (2)

The two-point charges are allowed to touch and returned to their original positions.

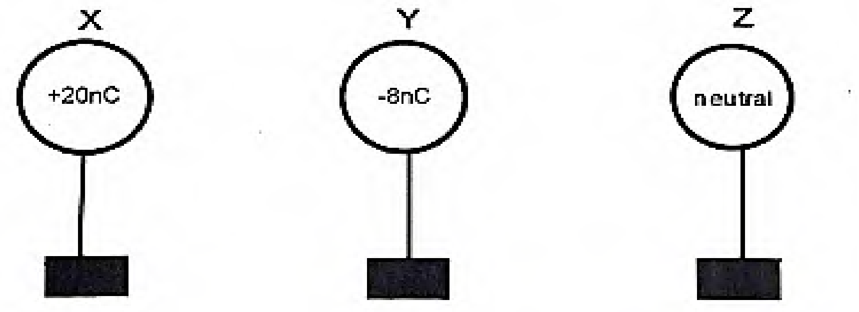
4.2.2 Calculate the distance **d** between point **P** and point charge Q_2, as shown in the diagram above. (4)

4.2.3 Calculate the number of electrons transferred from one charge to the other when they come into contact. (4)

[19]

QUESTION 5

Three small identical spheres **X**, **Y** and **Z** are mounted on insulated stands as shown. **X** carries a charge of +20nC, **Y** carries a charge of -8nC and **Z** is neutral.



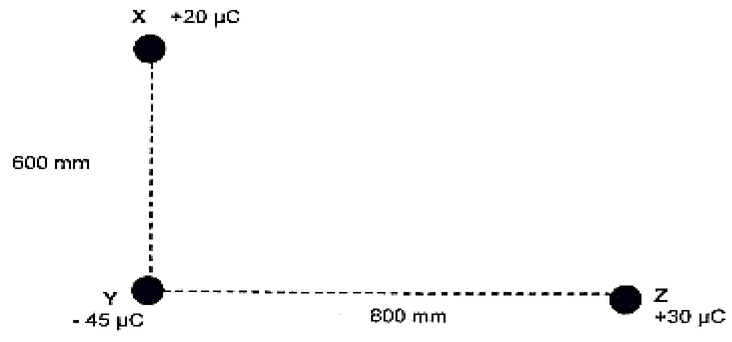
5.1 Give a reason why the metal spheres are mounted on insulated stands (1)

5.2 Spheres **X** is first brought into contact with sphere **Y**, Sphere **X** is moved and then brought into contact with sphere **Z** and then separated.

5.2.1 Calculate the net charge on each sphere on each sphere after they are separated (3)

5.2.2 Which of the three spheres undergoes a small net increase in mass? Give a reason for the answer (2)

5.3 Three point charges, **X**, **Y**, and **Z** of magnitudes +20 uC, -45 uC and +30 uC respectively are placed so that they form a right angle as shown below. **X** and **Y** are 600 mm apart, whilst **Y** are 800 mm apart.

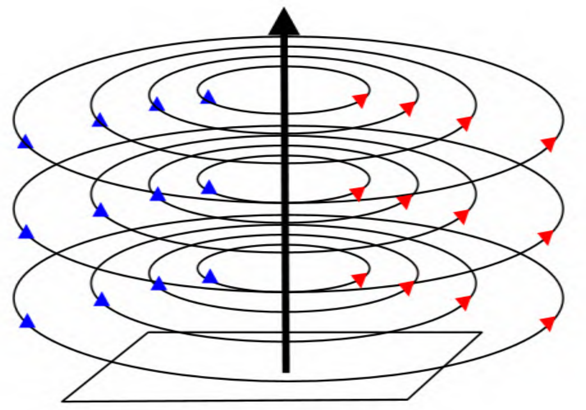


5.3.1 Calculate the magnitude of the net electrostatic force exerted on **Y** by **X** and **Z**. Point charge **Y** is now removed. (5)

[11]

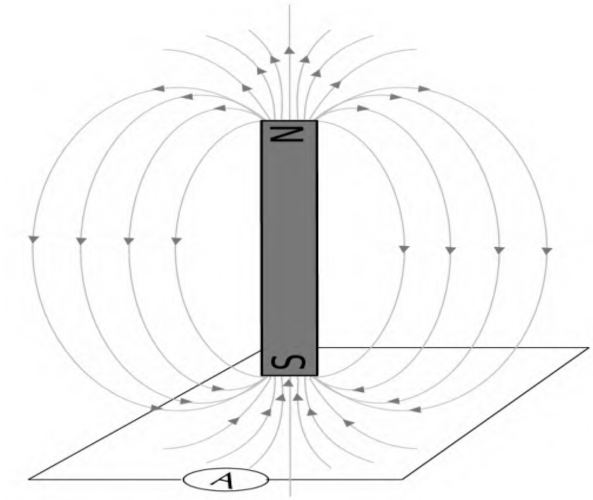
ELECTROMAGNETISM
NOTES

- **Electromagnetism** is the study of the relationship between electric and magnetic fields.
- The magnetic field produced by an electric current is always oriented perpendicular to the direction of the current flow.
- The following sketch shows what the magnetic field around a wire looks like when the wire has a current flowing in it. We use $\vec{B}$ to denote a magnetic field and arrows on field lines to show the direction of the magnetic field.



- The direction of the current in the conductor (wire) is shown by the central arrow. The circles are field lines and they also have a direction indicated by the arrows on the lines.
- **The Right-hand rule** says that the magnetic field lines produced by a current-carrying wire will be oriented in the same direction as the curled fingers of a person's right hand (in the "hitchhiking" position), with the thumb pointing in the direction of the current flow.

- Electromagnetic induction Faraday discovered that when he moved a magnet near a wire a voltage was generated across it.
- If the magnet was held stationary no voltage was generated. Thus, the voltage only existed while the magnet was moving. We call this voltage the induced emf (Ɛ).
- A circuit loop connected to a sensitive ammeter will register a current if it is set up as shown in the following figure which indicates the upward- and downward movement of the magnet: Magnetic flux Before we move onto the definition of Faraday's law of electromagnetic induction and examples, we first need to spend some time looking at the magnetic flux.



For a loop of area A in the presence of a uniform magnetic field, $\vec{B}$, the magnetic flux (Φ) is expressed as:
$\Phi = BA\cos\theta$,
where:
θ = the angle between the magnetic field, B, and the normal to the loop of area;
A = the area of the loop; and
B = the magnetic field.
The S.I. unit of magnetic flux is the weber (Wb).

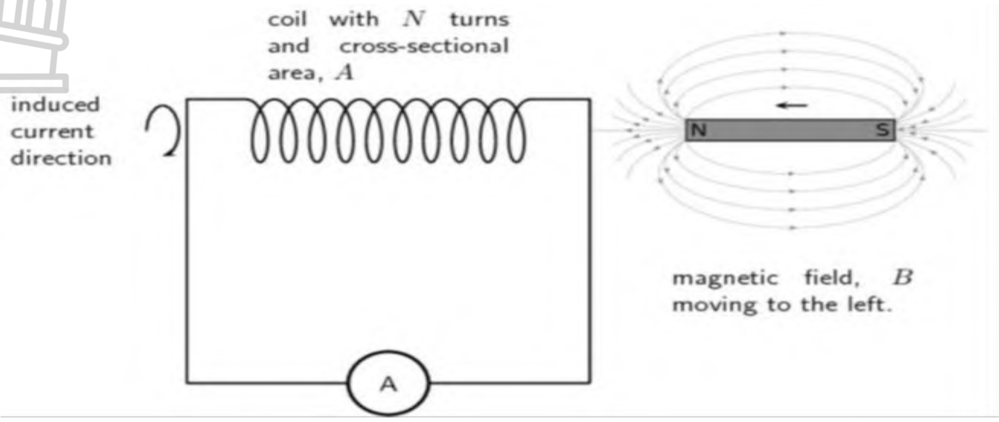
Environmental impact

In South Africa we have many power lines, which carry electrical power all over the country. Unfortunately this can have a negative impact on the wildlife, particularly birds. Birds may be physically harmed by power lines due to electrocution or physically colliding with the power lines. Large birds are especially at higher risk of colliding with the power lines. Each year thousands of birds are killed from collisions. The power lines also potentially interfere with nearby radio signals, as they can generate similar signals.

Faraday's Law of electromagnetic induction

- The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor. This can be stated mathematically as:
$$\varepsilon = \frac{-N\Delta\phi}{\Delta t}$$
- Where $\varphi = B \cdot A$ and B is the strength of the magnetic field. N is the number of circuit loops. A magnetic field is measured in units of teslas (T).
- The minus sign indicates direction and that the induced emf tends to oppose the change in the magnetic flux.

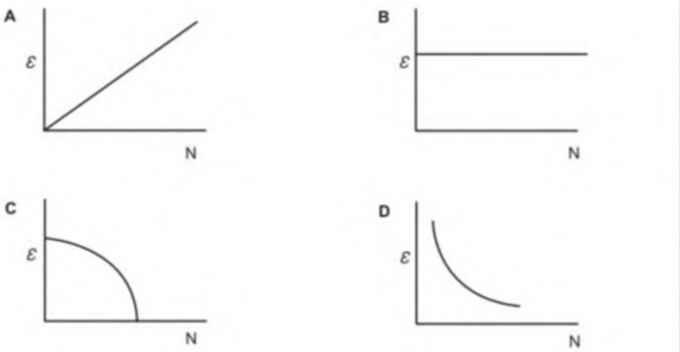
- When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field).
- When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change.



WORKED EXAMPLES

QUESTION 1 MULTIPLE CHOICE QUSTIONS [10 MARKS]

1.1. Consider the emf induced in a coil. Which of the following graphs correctly describes the relationship between the induced emf and the number of turns in the coil?



(2)

1.2 A circular coil is placed inside a magnetic field and rotated clockwise to induce an emf. Which ONE of the following changes will increase the induced emf ?

A Rotating the coil slower

B Decreasing the number of turns/ windings of the coil.

C Increasing the speed of rotation of the coil.

D Changing the polarity of the magnets. (2)

1.3. The magnetic flux linkage through a coil depends on…

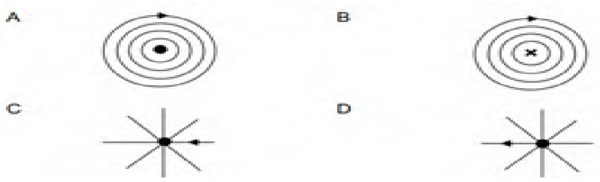
A The thickness of the wire in the coil.

B The angle between the coil and the magnetic field.

C The direction of the magnetic field.

D The material the coil made of. (2)

1.4. Which ONE of the sketches below represents the CORRECT magnetic field pattern around a straight current-carrying conductor?



(2)

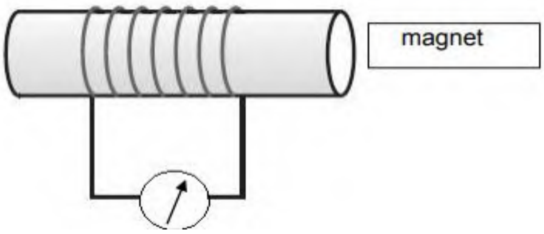
1.5 When a current, passes through a straight conductor a field is generated around the conductor. Which ONE of the following combinations is correct for the **nature of the field** and the **orientation of the field**?

	NATURE OF THE FIELD	ORIENTATION OF THE FIELD
A	Magnetic	Perpendicular to the conductor
B	Electric	Perpendicular to the conductor
C	Magnetic	Parallel to the conductor
D	Electric	Parallel to the conductor

(2)

QUESTION 2 [11 MARKS]

2.1 The arrangement of apparatus to demonstrate Faraday's law of electromagnetic induction is shown below.



2.1.1 State Faraday's law of electromagnetic induction in words. (2)

2.2.2 State TWO ways in which the deflection on the galvanometer can be increased. (2)

2.2 A coil with area 0,6 m^2 is held with its axis coinciding with the direction of a magnetic field of strength 0,4 T.

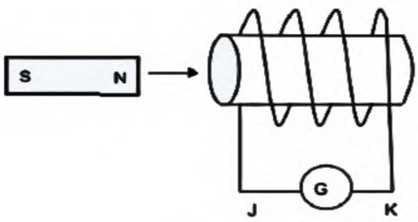
2.2.1 Calculate the magnetic flux linkage. (3)

In order to produce an emf of 9 V, the area of the coil, with its axis coinciding with the direction of a magnetic field, is halved from 0, 6 m^2 to 0, 3 m^2 in 2 minutes.

2.2.2 Calculate the number of turns in the coil. (4)

QUESTION 3 [11 MARKS]

3.1 The setup of the apparatus below was used to demonstrate the Faraday's Law of electromagnetic induction.



3.1.1. What will be observed on the Galvanometer when the bar magnet is held stationary inside the solenoid? Give a reason for the answer. (2)

3.1.2. What is the direction of the induced current through the Galvanometer? Choose from **J** to **K** or from **K** to **J.** (1)

3.2 A magnetic field with a field strength of 0, 5 T passes through a conducting loop of area 10 cm^2 in such a way that the field lines are at 70^0 to the plane of the loop.

3.2.1 Calculate the magnetic flux linkage. (3)

3.2.2 Calculate the average emf that will be induced across the ends of coil if it is removed from the field in 0,2 s. (3)

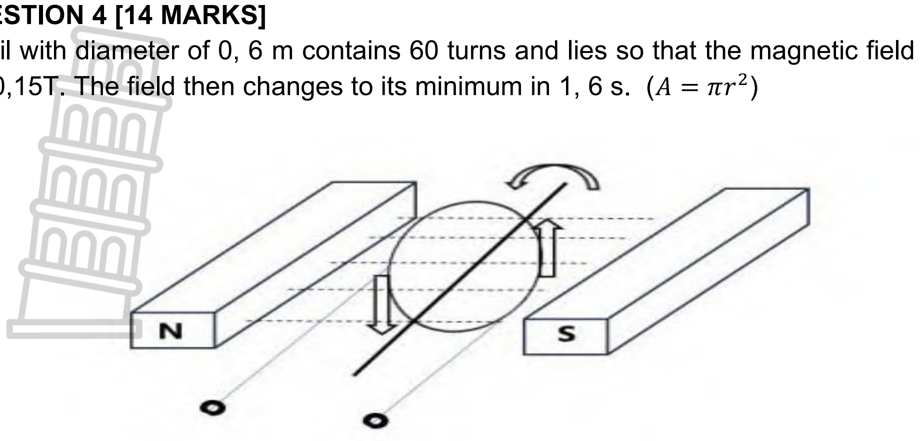
3.3 A circular coil is placed inside the magnetic field and rotated clockwise to induce an emf. How will the following changes influence the magnitude of the induced emf?
Choose from INCREASES, DECREASES or REMAINS THE SAME

3.3.1 Changing the polarity of the magnet (1)

3.3.2 Increases the speed of rotation of the coil (1)

QUESTION 4 [14 MARKS]

A coil with diameter of 0, 6 m contains 60 turns and lies so that the magnetic field strength is at maximum of +0,15T. The field then changes to its minimum in 1, 6 s. $(A = \pi r^2)$



4.1 State Faraday's Law of Electromagnetic Induction in words. (2)

4.2 Calculate: (4)

4.2.1. the change in the magnetic flux in the loop. (3)

4.2.2. the average induced emf in the loop in 1,6 s. (3)

4.3. If the coil is now rotated in 1, 8 s, how would it change the induced emf ? Write only INCREASE, DECREASE OR REMAIN THE SAME. Explain your answer. (2)

SOLUTIONS FOR WORKED EXAMPLES

1.1 A ✓✓

1.2 C ✓✓

1.3 B ✓✓

1.4 B ✓✓

1.5 A ✓✓ **[10]**

2.1.1 The magnitude of the induced emf (in a conductor) is equal to the rate of change of magnetic flux linkage. ✓✓ (2)

2.1.2 Move the magnet quickly inside the coil. ✓ (2)

Use a stronger magnet ✓

2.3.1 Φ= BA cosθ ✓

Φ= (0,4) (0,6) $\cos 0^0$ ✓ (3)

Φ = 0.24 Wb ✓

2.3.2 Φ = BAcos 0^0

$\Phi_{1/2}$ = (0,4)(0,3) cos 0^0✓

Φ = 0,12 Wb

$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$✓

$9 = -N\frac{(0{,}12-0{,}24)}{120}$✓ (4)

N = 9000 turns✓ [11]

QUESTION 3

3.1.1 The magnitude of the induced emf across the ends of a conductor is directly proportional to rate of change in the magnetic flux linkage with the conductor. ✓✓ (2)

3.1.2 No deflection / zero reading ✓ (2)

No change in the magnetic flux linkage. ✓

3.1.3 K to J✓ (1)

3.2.1 Φ= BA cosθ ✓

Φ= (0,5) (0,001) $\cos 20^0$ ✓

Φ = $4{,}70 \times 10^{-4}$ Wb ✓ (3)

3.2.2 $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$✓

$= \frac{-1(04,70 \times 10^{-4})}{0,2}$✓

$= 2,35 \times 10^{-3}$ V ✓ (3)

3.3.1 REMAIN THE SAME✓ (1)

3.3.2 INCREASES✓ (1)

QUESTION 4

4.1 The magnitude of the induced emf (in a conductor) is equal to the rate of change of magnetic flux linkage. ✓✓ (2)

4.2

4.2.1. Φi= BA cosθ ✓

=(0,15) πr^2Cos θ

= (0,15)(π) X 0,3²Cos 0°✓

= 4,24 x10^{-2} Wb

ΔΦi= Φi- Φf

=0-4,24x10^{-2}

= -4,24x10^{-2} Wb

4.2.2. $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$✓

$= \frac{(-60)(-4.24 \times 10^{-2})}{1,6}$✓

= 1.59 V✓ (5)

4.3. DECREASES✓ (3)

The emf is inversley proportional to the time of rotation, ✓thus if the time increases the emf will decrease✓0.

ELECTRODYNAMICS

PRACTICE ACTIVITIES

QUESTION 1 [9 MARKS]

A coil with 200 windings and a surface area of $2,8 \times 10^{-3}$m² is rotated at constant speed in a constant magnetic field of 2, 5 T. An emf of 3,5V is induced in the coil.

1.1. Consider the following statement: The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor.

Name the law represented by the above statement. (1)

1.2. Calculate the :

1.2.1. Change in magnetic flux if the angle of the coil related to the magnetic field changes from 0^0 to 90^0. (3)

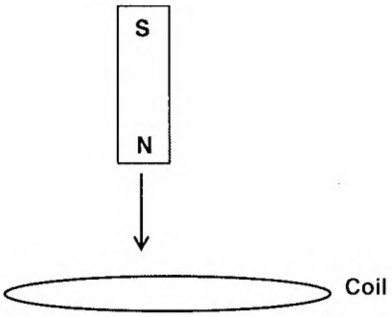
1.2.2. Time it takes the coil to rotate from 0^0 to 90^0. (3)

1.3 By what factor will the induced emf change if a coil with 100 windings is used under the same conditions? (2)

QUESTION 2 [13 MARKS]

2.1. State Faradays Law of electromagnetic induction in words. (2)

2.2. A bar magnet is dropped vertically downwards through a circular conducting loop, as shown below. An emf is induced in the circuit.



The direction of the induced current is views from above.

2.2.1. State the direction of the induced current. Choose from clockwise or anticlockwise. (2)

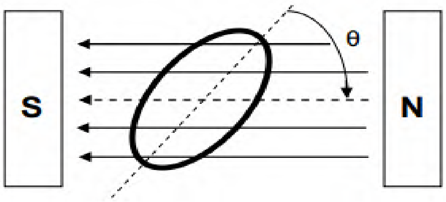
2.2.2. Explain why an emf is induced across the ends of the coil. (2)

2.3. A flat of wire has an area of 0,020m^{2}and consists of 50 turns. At 1=0 s, the coil is oriented so that the normal to its surface makes an angle of 00 to a constant magnetic field of magnitude 0, 15 T. the coil is then rotated in a time of 0, 10 s along its axis so that the normal to the surface makes an angle of 60^0 to the magnetic field.
Calculate the average induced emf in the coil. (5)

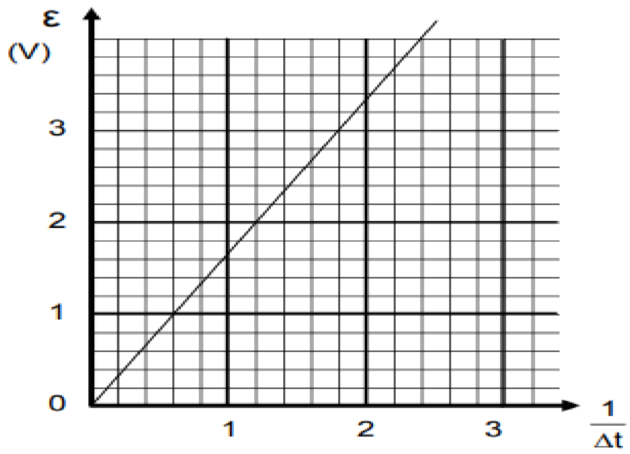
2.4. Explain the meaning of the minus sign in the equation for Faradays law of electromagnetic induction.
$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ (2)

QUESTION 3 [11 MARKS]

An induction coil of area 48, 6 cm^2 and 200 windings is rotated clockwise in a constant magnetic field of magnitude 2, 4 T. Refer to the diagram below.



The graph below shows how the induced emf varies with the inverse of time.



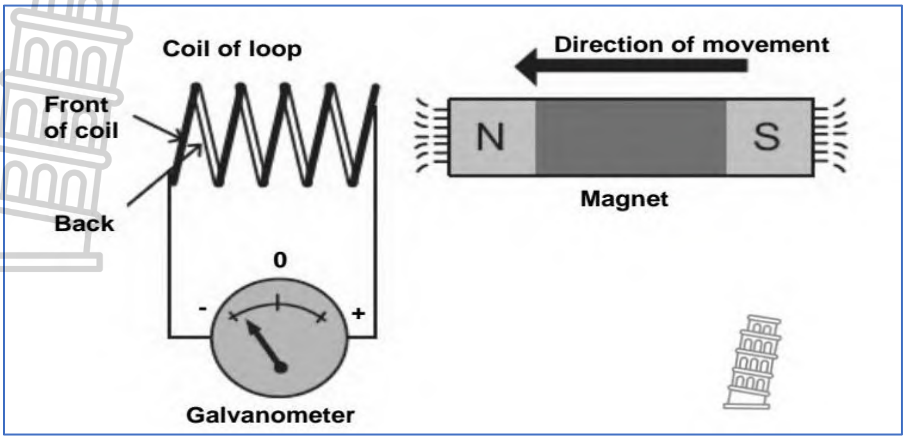
3.1 State Faraday's law in words (2)

3.2 Use the information in the graph to calculate the change in magnetic flux when the emf is 3 V (4)

3.3 The coil rotates through an angle θ to a position where the magnetic flux becomes zero.
Calculate angle θ. (5)

QUESTION 4 [10 MARKS]

A magnet is brought near a solenoid or coil as shown in the diagram below.



4.1. State Faradays law of Electromagnetic induction. (2)

4.2. Why does the galvanometer deflect as the magnet is brought close to the coil? (1)

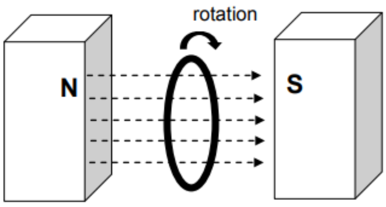
4.3. What rule can be used to predict the direction of the induced current? (1)

4.4. Give THREE ways in which the strength of the induced current can be increased. (3)

4.5. A coil with 200 windings (turns) s rotated so that the magnetic flux linkage with each winding changes from 5 x 10^{-4} Wb to 1 x 10^{-4} Wb in 0,2 s. (3)
Calculate the induced emf in the coil.

QUESTION 5 [13 MARKS]

A circular coil with 250 windings (turns) and a radius of 0, 04 m, is rotated clockwise inside a magnetic field with a field strength of 3, 2 T.



5.1 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the field. (3)

5.2 If the coil rotates clockwise through 25°, and the potential difference induced is 2, 8 V, calculate the time in which this rotation took place. (4)

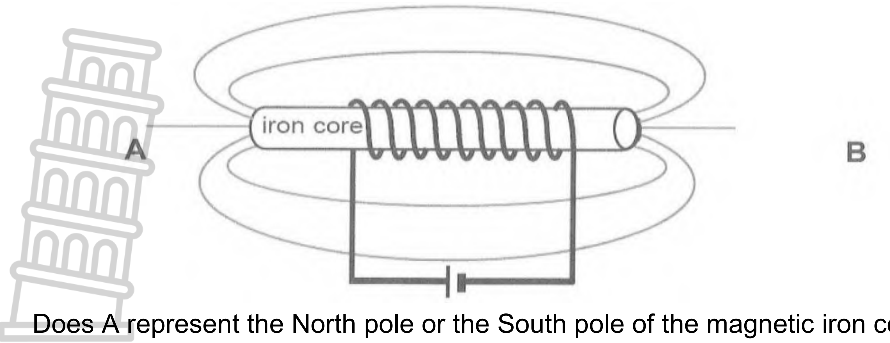
5.3 Which law can be used to explain the phenomenon described in QUESTION 5.2? Name and state the Law. (3)

5.4 5.4.1 If the circular coil is replaced with a square coil with a side length of 0, 04 m, and the same movement is made in the same amount of time, will the induced emf be the same as, larger than or smaller than the circular coil? Write down only THE SAME AS, LARGER THAN or SMALLER THAN. (1)

5.4.2 Explain the answer to QUESTION 5.4.1 (2)

QUESTION 6 [10 MARKS]

6.1 The sketch below shows a current carrying solenoid that is wrapped around a soft iron Core.

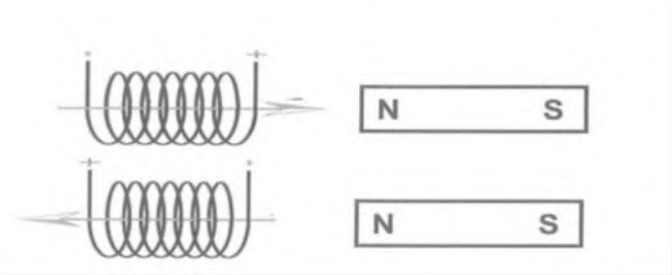


Does A represent the North pole or the South pole of the magnetic iron core? (1)

6.2

6.2.1 Is the magnetic field direction outside the core from A to B or from B to A (1)

6.3. A coil is moved into and out of the magnetic field of a bar magnet as shown below so that the rate of change of magnetic field is <u>$\Delta\phi$=0,6, T.s^{-1}</u>



The area through which the field links with the coil is given by A=0,4 m^2

6.3.1. State Faradays law of electromagnetic induction in words. (2)

6.3.2. Calculate the magnitude of the average emf generated in the coil, if the coil has 8 turns. (4)

6.3.3. If the experiment is repeated with a new coil that has twice as many turns, what would the new emf be? (2)

ELECTRIC CIRCUITS

Grade 11 concepts

- **Ohm's law**

The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature. $R = \frac{V}{I}$

Graphical representation of Ohm's law

Ohmic resistors	**non-ohmic resistors**
Resistors that obeys ohms law	resistors that do not obey ohms law

- **Power**

Is the rate at which work is done (or energy is transferred)

- The following formulae can be used to calculate Power $P = \frac{W}{\Delta t}$

$$P = VI$$
$$P = I^2R$$
$$P = \frac{V^2}{R}$$

- **Energy**

is the ability to do work
formulas to be used when calculating energy

$$W = VI\Delta t$$
$$W = I^2R\Delta t$$
$$W = \frac{V^2}{R}\Delta t$$

- **EMF**

is the maximum energy provided by a battery per unit charge passing through it.

- **Internal resistance**

Real batteries are made from materials which have resistance. This means that real batteries are not just sources of potential difference (voltage), but they also possess internal resistance. If the total potential difference source is referred to as the emf, ε, then a real battery can be represented as an emf connected in series with a resistor r. The internal resistance of the battery is represented by the symbol r.

$$V' = Ir$$
$$Emf = I(R + r)$$

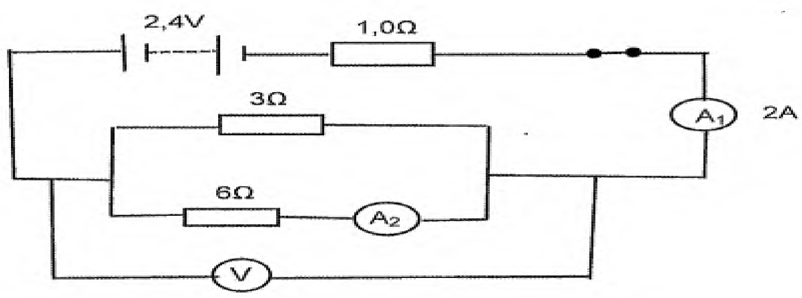
Cost of electricity

To calculate the cost of electricity, the energy must be expressed in Kilowatt hour(kWh).
The kilowatt-hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour.
1 kWh is an amount of electrical energy, also known as one unit of electricity.

Cost = Energy x Cost per unit

WORKED EXAMPLE 1

The battery of EMF 2,4V and negligible internal resistance is connected in a circuit as shown below.
A current of 2A registers on ammeter A_1



1.1 State the Ohms law in words. (2)
1.2 Calculate the effective resistance of the circuit. (3)
1.3 Calculate the reading on
 1.3.1 The voltmeter (3)
 1.3.2 The ammeter A_2 (3)
1.4 Calculate the amount of energy (KWh) that is transferred to the circuit in 48 hours. (5)
1.5 The 3Ω resistor is now replaced by a 6Ω resistor. How will this affect each of the following (choose from INCREASES, DECREASES, OR REMAIN THE SAME).
 1.5.1 The reading on A_1 . Explain the answer (3)
 1.5.2 The reading on A_2 (1)

[20]

Solutions

1.1 The current in a metal is directly proportional to the potential difference across the ends of the conductor, provided the temperature remains constant. ✓✓

1.2 $\frac{1}{Rp} = \frac{1}{R1} + \frac{1}{R2}$

$\frac{1}{Rp} = \frac{1}{6} + \frac{1}{3}$ ✓

R_p = 2 Ω✓

Effective Resistance = $R_P + R_s$ = 2 + 1 = 3Ω ✓

1.3.2 $R_p = \frac{V}{I}$ ✓

V= 0.8× 2 = 1.6V ✓✓

1.3.3 R = $\frac{V}{I}$ ✓ = 6 = $\frac{1.6}{I}$ ✓ I= 0.27 A ✓

1.4 P = VI ✓

= 2,4 × 0,8 ✓
= 1,92W = 0,00192 KW ✓
W = Pt
= 0,00192 × 48✓
= 0,09216 KWh ✓

1.5.1 Decrease. ✓ Resistance of circuit increases, from Ohms Law, R is inversely proportional to the current. ✓✓

1.5.2 Increases

Worked examples 2✓

Learners investigate to verify Ohm's Law. They measure the current through a resistor for different potential differences across its ends, ie the potential difference was chosen as the independent variable. The results obtained are tabulated below:

Potential Difference (V)	Current strength (A)
21.4	0.80
35.8	1.20
56.0	1.90
72.04	2.30
98.04	3.20
124.04	4.12

2.1 State Ohm's Law (2)

2.2 The dependant variable in this was the current

2.2.1 Name one quantity that was controlled in this investigation. (1)

2.2.2 State how the quantity in Question 2.2.1 was kept constant (1)

2.3 Using the information in the table and the graph sheet provided, draw a graph of current versus potential difference. (5)

2.4 Calculate the gradient of the graph. (4)

2.5 What quantity does the gradient of the graph represent? (1)

2.6 Hence determine the resistance of the resistor. (2)

[16]

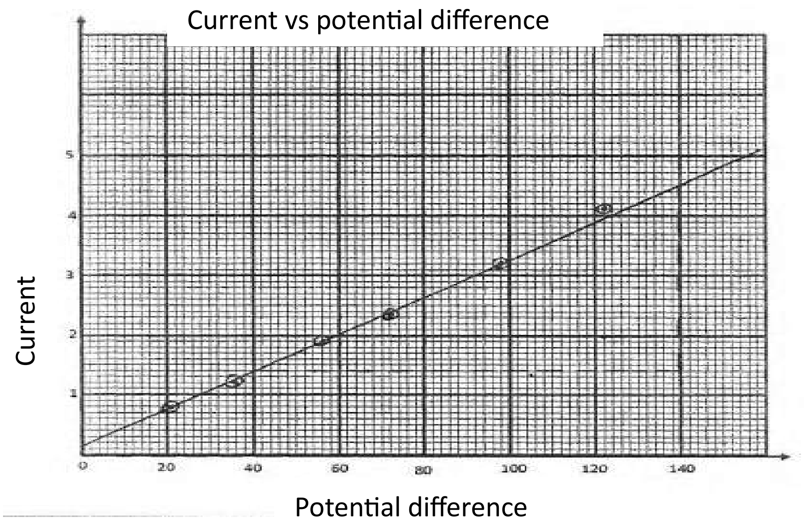
Solutions

2.1 The potential difference across the conductor is directly proportional to the current in the conductor at constant temperature. ✓✓

2.2.1 Resistance / Temperature of the resistor✓

2.2.2 Do not keep the circuit on for long periods of time. ✓

2.3



suitable scale used on X and Y axes	✓
X and Y axes correctly labelled	✓
correct plotting of points	✓
best fit curve drawn joining points	✓

2.4 Gradiant (1/R) = $\frac{\Delta I}{\Delta V}$ ✓

$= \frac{4.5-1.4}{140-40}$ ✓✓

$=0.031\Omega$✓

2.5 Inverse of resistance/ $\frac{1}{R}$ ✓

2.6 $\frac{1}{R}= 0{,}031$

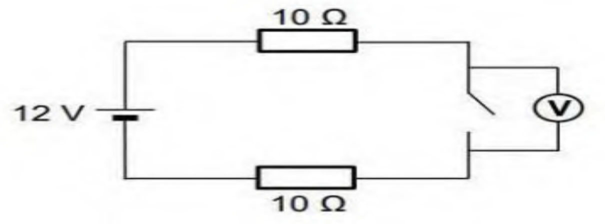
R =32,26 Ω ✓✓

ELECTRIC CIRCUITS MCQ QUESTIONS

QUESTION ONE

FOUR possible answers provided to the following questions only one answer that is correct. Choose the correct answer write only the correct letter next to question number

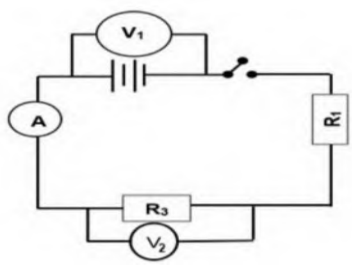
1.1 In the circuit shown below two identical resistors are connected to 12V cell and the switch is open the reading on v will be:



A) 0 V
B) 6 V
C) O,6 V
D) 16 V (2)

1.2 The unit for electric power is
A) N C^{-1}
B) J.s^{-1}
C) Kg.m.s^{-1}
D) N.s (2)

1.3 The potential difference across the battery in the circuit diagram below is 10 V. The internal resistance of the battery can be ignored Two voltmeter V_1 and V_2 are connected in the circuit as shown in the diagram below the reading on V1 and V2 will be: (2)



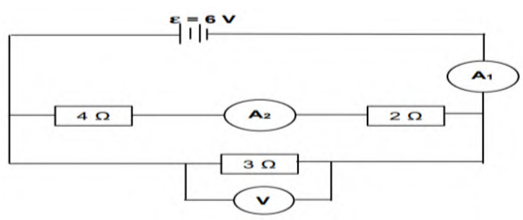
	Voltmeter 2	Voltmeter 1
A)	10	0
B)	0	10
C)	0	0
D)	10	10

1.4. Current is the same in
A) Series connection
B) Parallel connection
C) Combination of parallel and series connection
D) Two resistor in parallel (2)

ELECTRIC CIRCUITS STRUCTURED QUESTIONS

Question one

In the circuit diagram below the battery has emf of 6 V and negligible internal resistance.

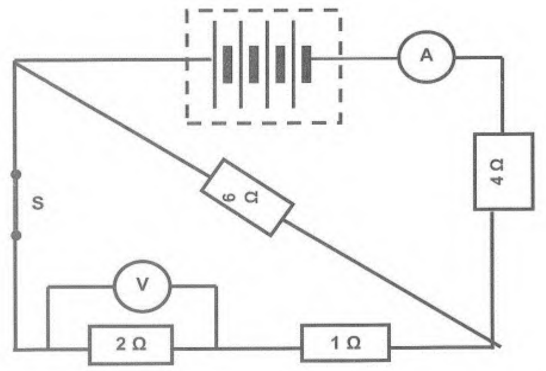


1.1 Calculate the:
1.1.1 Effective resistance in the circuit (3)
1.1.2 Reading on ammeter A1 (1)
1.1.3 Reading on ammeter A2 (3)
1.1.4 Power dissipated by the 4 Ω resistor (3)
1.2 What is the reading on voltmeter V? No calculation is required. (1)
1.3 A kettle is rated 1 500 W. Calculate how much a learner will pay for electricity for using the kettle for 4 hours. Eskom charges 1 kWh electricity at R2,05. (4)
[17]

Question two

You are given four identical resistors, each of magnitude “R” and battery of Emf “v” volts.

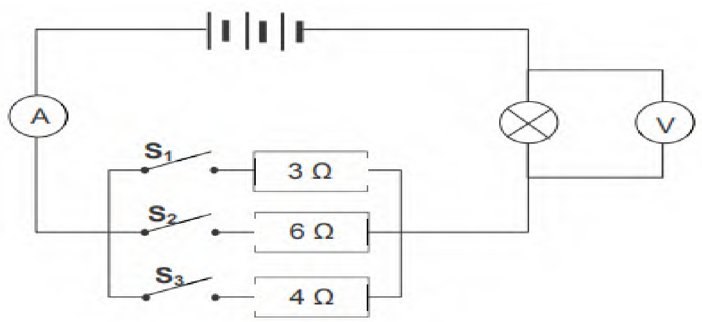
2.1 Sketch an appropriate circuit diagram, use all the above components, to show how you would connect them to obtain a total resistance of R in the circuit. (2)
2.2 Use the relevant calculations to show that the total resistance in your circuit in 2.1 is equal to R. (3)
2.3 The circuit diagram below shows a battery of known Emf with neglible internal resistance, connected as shown below.



The reading on voltmeter is 4V. Calculate :
2.3.1 The effective resistance in the circuit. (3)
2.3.2 The current flowing through the 1Ω resistor. (3)
2.3.3 The reading on the ammeter. (4)
2.3.4 The Emf of the battery (3)
2.4 The switch S is now opened
2.4.1 How will the energy dissipated by the 4Ω resistor change if the time is in operation remains constant ? State whether it will increase , decrease or remain the same. (1)
2.4.2 Briefly explain your answers using relevant formulae. (2)
[20]

Question three

Three resistors , of 3Ω, 4Ω and 6Ω, and a bulb are connected in a circuit, as shown below. Initially all the switchesz , S_1 , S_2,and S_3 are open. The internal resistance of the battery and the resistance of the connecting may be ignored



3.1 State the Ohms’ law in words. (2)

3.2 Switch S_1 is now closed and the voltmeter and ammeter readings are recorded. The voltmeter and ammeter readings, when both switch S_1 and switch S_2 are closed, are then recorded, as well as the readings when all three switches, S_1 ,S_2 , and S_3 , are closed. The results are shown in the table below

SWITCHES CLOSED	VOLTMETER READING (V)	AMMETER READING (A)
S_1	4,8	2,4
S_1 and S_2	6	3
S_1, S_2 and S_3	7,2	3,6

3.2.1 Explain the increase in the ammeter reading as more switches are closed. (2)

3.3 Calculate the :

3.3.1 Resistance of the bulb. (3)

3.3.2 Potential difference of the battery (4)

3.4 Define the term power. (2)

3.5 Calculate the power dissipatedin the 6Ω resistor when ONLY SWITCHES S_1 and S_2 are closed. (4)

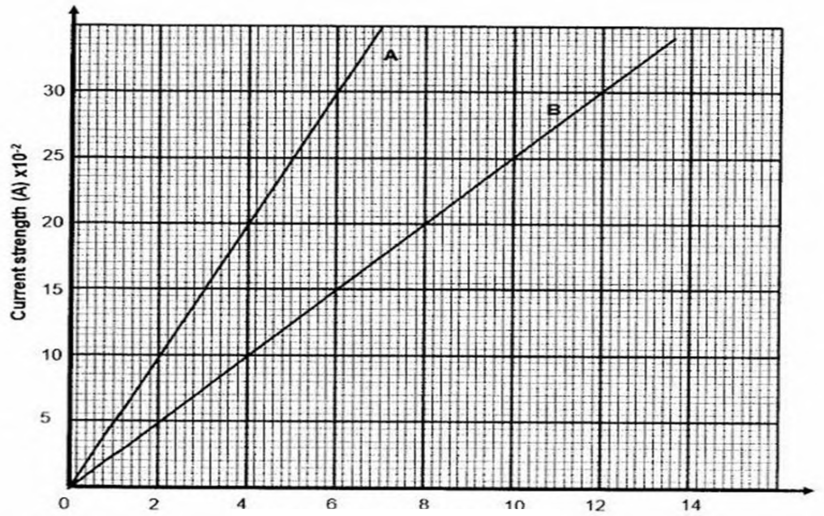
3.6 How will the BRIGHTNESS of the bulb be affected as more switches in the circuit are closed? Write only INCREASES, DECREASES or REMAINS THE SAME. (1)

3.7 Explain the answer to question 3.6. (2)

[21]

Question four

Two grade 11 learners conduct two separate expiriments (Expiriment A and Expiriment B) to verify the relationship between the potential difference across a resistor and the current trough resistor. They each used the following components to set up their circuits : battery, an ammeter, a resistor of unkown resistance, a voltmeter, a switch conducting wire and rheostat



Potential difference (V)

4.1 Write down the law investigated in the expiriment above (1)

4.2 What is a function of rheostat (1)

4.3 State one precaution that the learners would have to take to ensure that the temperature of their resistors remains constant (1)

4.4 Draw circuit diagram to show how the learners should connect the given components in the circuit (4)

4.5 **Consider graph B**

4.5.1 What is the relationship between the current and the potential difference across resistor? (1)

4.5.2 What does the gradient of the graph represent ? (1)

4.5.3 What is the current trough the resistor when the potential difference across the resistor is 6 V? (1)

4.5.4 Using the graph calculate the resistance of the resistor in expiriment B (4)

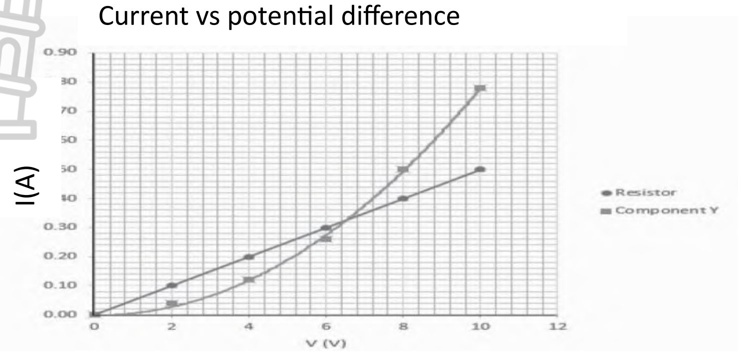
4.6 **Consider graph A and B**

4.6.1 Which experiment used a resistor with higher resistance ? (1)

4.6.2 Give a reason for your answer (2)
[18]

Question five
The variation with potential difference V of the current I in a component Y and in a resistor R are shown in the graph. The current is plotted on the y axis and the potential difference is plotted on the x axis

Current vs potential difference



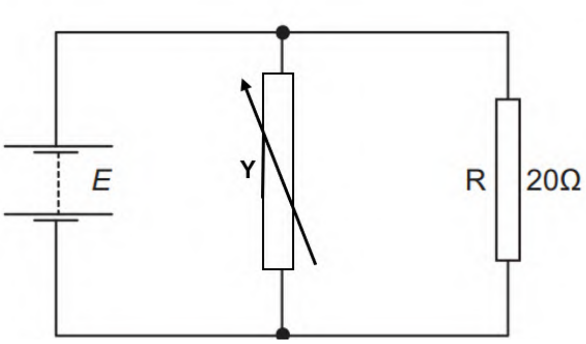
V(V)

5.1.

5.1.1 Use the graph to explain how it can be deduced that resistor R has a constant resistance of 20 Ω. (3)

5.1.2 Is component Y an ohmic conductor? Give a reason for your answer. (2)

5.2 The component Y and the resistor R are connected in parallel.



A power pack (or a battery with a variable voltage E) with negligible internal resistance is connected across the parallel combination. Use data from the graph to determine:

5.2.1 The current in the battery for an voltage of 4,0 V. (3)

5.2.2 The total resistance of the circuit for a voltage of 8,0 V (3)

5.2.3 The electrical energy used in R with a voltage of 8,0 V for 20 s. (4)
[15]

ATOMIC COMBINATIONS

DEFINITIONS

- Chemical bond – a mutual attraction between two atoms resulting from the simultaneous attraction between their nuclei and the outer electrons.
- Intramolecular bond – bond which occurs between atoms within molecules
- Lewis dot diagram – a structural formula in which valence electrons are represented by dots or crosses.
- Valence electrons – the electrons in the highest energy level of an atom in which there are electrons.
- Covalent bond – the sharing of electrons between two atoms to form a molecule.
- Ionic bond – a transfer of electrons and subsequent electrostatic attraction
- Metallic bond – metallic bonding as the bond between positive ions and delocalized valence electrons in a metal
- Molecule – a group of two or more atoms covalently bonded and that function as a unit.
- Bonding pair – a pair of electrons that is shared between two atoms in a covalent bond.
- Lone pair – a pair of electrons in the valence shell of an atom that is not shared with another atom.
- Electronegativity – a measure of the tendency of an atom in a molecule to attract bonding electrons.
- Non-polar covalent bond – a bond in which the electron density is shared equally between the two atoms.
- Polar covalent bond – a bond in which the electron density is shared unequally between the two atoms.
- Bond energy of a compound – the energy needed to break one mole of its molecules into separate atoms.
- Bond length – the average distance between the nuclei of two bonded atoms

MOLECULAR STRUCTURE

- The structure mainly depends on the type of chemical bond (force) that exists between the atoms that the molecule consists of.

RULES FOR BOND FORMATION

Different atoms:

- each with an unpaired valence electron, can share these electrons to form a chemical bond
  example: two H atoms form a H_2 molecule by sharing an electron pair
- with paired valence electrons, called lone pairs, cannot share these 4 electrons and cannot form a chemical bond
  example: no bond forms between 2 He atoms
- with unpaired valence electrons, can share these electrons and form a chemical bond for each electron pair shared (multiple bonds can be formed)
  example: two O atoms form an O_2 molecule

Atoms with an empty valence shell can share a lone pair of electrons from another atom to form a coordinate bond or a dative covalent

- example: in NH_4^+ the lone pair of nitrogen from NH_3 is shared with H^+

CHEMICAL BONDS

A chemical bond is the net electrostatic force that two atoms sharing electrons exert on each other.

- Bonding occurs when valence electrons are shared between two atoms or transferred from one atom to another.
- Valence electrons correspond to the group number of an element in the Periodic table
- Valence electrons: Valence electrons or outer electrons are the electrons in the highest energy level of an atom in which there are electrons.
- The type of bond that forms is dependent on the electronegativity difference (ΔEN) between the atoms.
- Electronegativity is a measure of the tendency of an atom in a molecule to attract bonding electrons. If one atom has a greater electronegativity than another, the electrons will be pulled more towards one atom than another. Such a shift of electrons creates negative and positive charge distributions inside the molecule.

  - ΔEN = 0: Non-polar (pure) covalent
  - ΔEN < 1: Weakly polar covalent
  - ΔEN >1: polar covalent
  - ΔEN > 2,1: Ionic (transfer of electrons)
  - ΔEN > 3: purely ionic

Types of bonds and molecules

- Non-polar bond: a bond in which the electron density is shared equally between the two atoms
  Example: H – H
- EN (H) = EN (H): Bonding electrons are evenly shared. Charge is evenly distributed and no dipole formed.
  ΔEN = 2,1 – 2,1 = 0
- Polar bond: a bond in which the electron density is shared unequally between the two atoms.

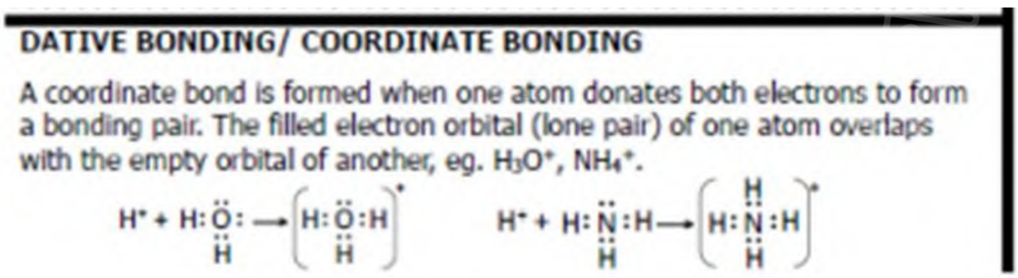
- Example: H – Cl
- EN (Cl) > EN (H): Electrons shift towards chlorine. Chlorine is slightly negative (δ−) and hydrogen is slightly positive (δ+).
  ∆EN = 3,0 – 2,1 = 0,9
- Polar molecule: A molecule over which charge is distributed unevenly.
  Example: H_2O
- Non-polar molecule: A molecule over which the charge is evenly distributed.

Covalent Bonding (Between non-metals)

- Covalent bonding involves the sharing of electrons between two atoms to form a molecule.
- The covalent bond may be non-polar, weakly polar or polar.
- A non-polar (pure) covalent bond is a bond in which the electron density is shared equally between the two atoms.
  example:
  Two chlorine atoms are joined by a non-polar covalent bond (Cl – Cl)
  EN for chlorine atom is 3,0.
  ∆EN = 3,0 – 3,0 = 0

- In a weakly polar covalent bond there is an unequal sharing of electrons
  example:
  A hydrogen atom and a bromine atom are joined by a weakly polar bond
  (H – Br)
  EN for hydrogen is 2,1 and EN for Br is 2,8.
  ∆EN = 2,8 – 2,1 = 0,7

- A polar covalent bond has an unequal sharing of electrons leading to a dipole forming
- example:
  A hydrogen atom and an oxygen atom are joined by a polar covalent bond
  (H_2O)
  EN for oxygen atom is 3,5.
  ∆EN = 3,5 – 2,1 = 1,4
- bonds between them. If two pairs of electrons are shared, a double bond is formed, e.g. between two O atoms to form H_2O.
- Atoms with an empty valence shell can share a lone pair of electrons from another atom to form a coordinate covalent or dative covalent bond, e.g. in NH^{+4} the lone pair of nitrogen is shared with H^+ and in H_3O^+ the lone pair of oxygen is shared with H^+.



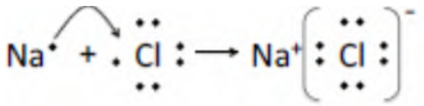
Ionic Bonding (between metals and non-metals)

- metal atom gives electron or electrons to non-metal atom
- metal forms a positive ion and positive ion is called a cation
- non-metal forms a negative ion and negative ion is called an anion
- electrostatic attraction of ions leads to formation of giant crystal lattice

Example:

Show how the ionic bond is formed between the sodium and the chlorine atoms.

1. $Na - 1e^- \rightarrow Na^+$ (Na atom loses one electron)
2. $Cl + 1e^- \rightarrow Cl^-$ (Clatom gains one electron)
3. $Na^+ + Cl^- \rightarrow NaCl$ (electrostatic attraction between the two ions)

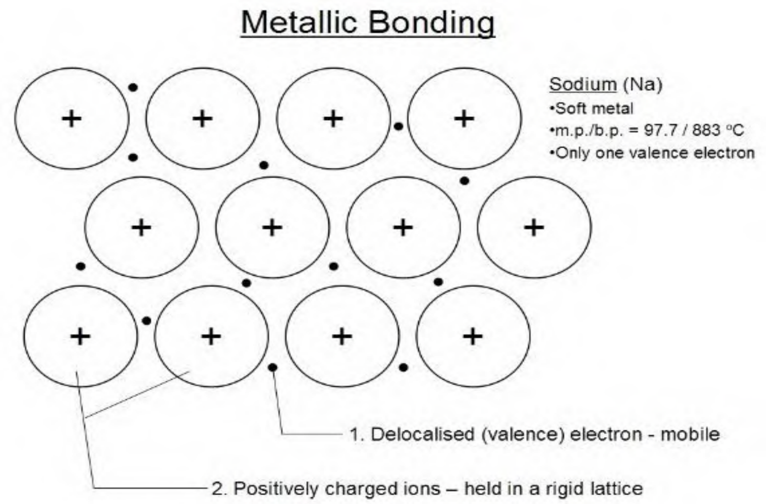


Metallic Bonding (between metals)

-Metallic bonding forms between the positive metal kernels and the sea of delocalized electrons.

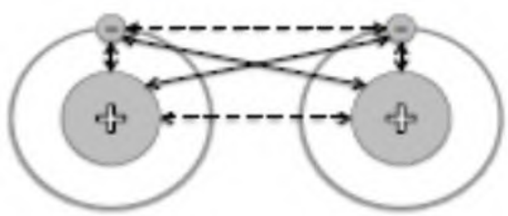
-The metal atoms release their valence electrons to surround them.

-There is a strong but flexible bond between the positive metal kernels and a sea of delocalised electrons



BOND ENERGY

- Bond energy is required to break one mole of its molecules into separate atoms.



- There are various attractive and repulsive forces at play between the two atoms during bonding.
- Attractive forces between the protons of one atom and the electrons of another.
- Attractive forces between the protons and electrons from the same atom.
- A repulsive force between the protons from each atom.
- A repulsive force between the electrons from each atom.
- The net electrostatic forces will determine bond strength, which can be quantified as the bond energy. This is the energy required to break the bond, or it is the energy released when bonds are formed.

FACTORS INFLUENCING BOND STRENGTH

*Bond length

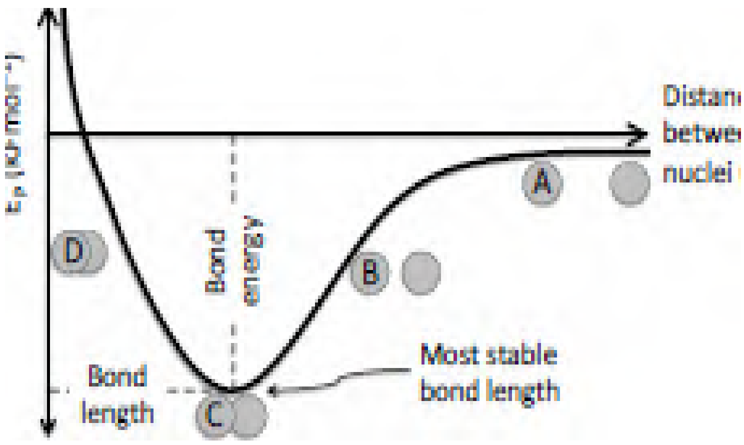
The shorter the length of the bond, the stronger the bond.

*Atom size

The smaller the atoms, the stronger the bond.

*Bond order
The more bonds (double, triple bonds etc.) between the atoms, the stronger the bond.
BOND LENGTH
Bond length: The average distance between the nuclei of two bonded atoms.
As the atoms get closer, the attractive forces get stronger until the minimum possible potential energy is reached (bond energy). The distance between the nuclei of the atoms at the minimum potential energy is the bond length. If the two atoms get closer than the bonding length, they will be forced apart by the repulsive forces, increasing the potential energy.

FACTORS INFLUENCING BOND LENGTH
*Atom size- The smaller the atoms, the shorter the bond.
*Bond order -The more bonds (double, triple bonds etc.) between the atoms, the shorter the bond.
*Difference in electronegativity (ΔEN). The greater the ΔEN, the shorter the bond.
Process of bond formation
*Atoms are infinitely separated; potential energy is nearly zero.
*As the atoms move closer, the forces of attraction and repulsion increase until the forces of attraction dominate.
*The lowest, most stable energy state reached, chemical bond forms.
*Atoms move too close, forces of repulsion increase, potential energy increases



WORKED EXAMPLE 1
Both aluminium fluoride ($A\ell F_3$) and phosphorus trifluoride (PF_3) contain fluorine. Aluminium fluoride is a colorless solid in the production of aluminum, whilst phosphorus trifluoride is a poisonous, colorless gas.

1.1 Explain the difference between a covalent bond and ionic bond (2)
1.2 Name the type of chemical bond between particles in:
- 1.2.1 $A\ell F_3$ (1)
- 1.2.2 PF_3 (1)

1.3 Draw a lewis structure for:
- 1.3.1 $A\ell F_3$ (3)
- 1.3.2 PF_3 (2)

1.4 Write down the molecular shape of PF_3. (1)

1.5 The melting point of $A\ell F_3$ is 1 291°C and that of PF3is -151°C.Fully explain this difference in melting point. (4)

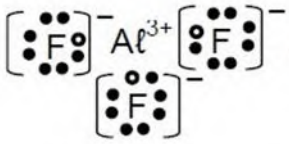
[14]

SOLUTIONS
1.1 A covalent bond is a sharing of electrons between two atoms, whilst, ionic bond forms when there is a transfer of electrons from one atom to another (non-metal to metal) and oppositely charge atoms attract each other. √√ (2)

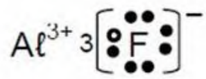
1.2 1.2.1 Ionic bond √ (1)

1.2.2 Covalent bond √ (1)

1.3 1.3.1

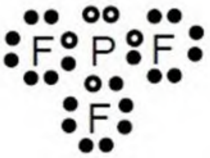


✓✓ OR/OF



(3)

1.3.2



✓✓

(2)

1.4 Pyramidal ✓ (1)

1.5 The ionic bonds between the aluminum fluoride are stronger than the dipole-dipole forces in between phosphorus fluoride molecules. ✓ ✓

More energy is needed to overcome ionic bond in AlF_3 than intermolecular forces in PF_3 ✓ ✓ (4)

[14]

WORKED EXAMPLE 2

2. Hydrogen fluoride (HF) is used in the manufacturing of refrigerants, herbicides, pharmaceuticals and gasoline. Hydrogen fluoride (HF) can be prepared by treating calcium fluoride with sulphuric acid, according to the following balanced equation.

$$CaF_2 + H_2SO_4 \rightarrow CaSO_4 + 2HF$$

2.1 Draw a Lewis diagram for:

2.1.1 HF (2)

2.1.2 CaF_2 (2)

2.2 Define a polar covalent bond (2)

2.3 Which of the product will likely be:

2.3.1 A gas at room temperature (1)

2.3.2 A crystalline solid at room temperature (1)

2.4 Define the term electronegativity (2)

2.5 Use electronegativity to determine the types of bonds in CaF_2 (2)

2.6 Will HF be a polar or non-polar molecule? (1)

2.7 Explain your answer in question using calculation (2)

[15]

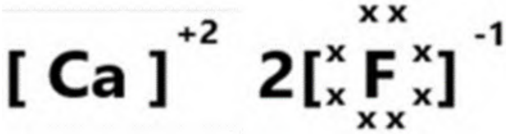
SOLUTION

2.1 2.1.1

✓✓

(2)

2.1.2



✓✓ (2)

2.2 A polar covalent bond is a bond in which the electron density is shared unequally between the two atoms✓✓ (2)

2.3 2.3.1 HF/Hydrogen fluoride ✓ (1)

2.3.2 $CaSO_4$/Calcium sulfate✓ (1)

2.4 Electronegativity is a measure of the tendency of an atom in a molecule to attract bonding electrons. ✓✓ (2)

2.5 $\Delta EN = 4 - 1 = 3$ ✓
Ionic bond ✓ (2)

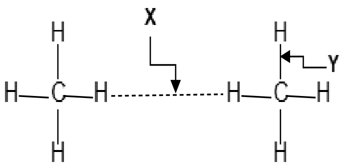
2.6 Polar molecule ✓ (1)

2.7 $\Delta EN = 4 - 2{,}1 = 1{,}9$ ✓ polar bond ✓
Thus, the molecule is polar (2)

[15]

MULTIPLE CHOICE QUESTIONS

1.1 The diagram below is used to demonstrate the differences between interatomic bonds (chemical bonds) and intermolecular forces.



A X is stronger than Y
B X is an interatomic bond
C X is an intermolecular force
D Y is an intermolecular force (2)

1.2 Which ONE of the following bonds will have the highest bond energy?
A H – H
B C – H
C C = C
D C ≡ C (2)

1.3 Consider the following compounds and their respective boiling points.

COMPOUNDS	BOILING POINT (°C)
He	-268,9
HBr	-66
HF	19,5

The correct arrangement for the decreasing strength of the intermolecular forces of the given compounds is …
A HF, He, HBr.
B HBr, He, HF.
C HF, HBr, He.
D He, HBr, HF.
(2)

1.4 Consider the substances **P**, **Q** and **R**. **P** dissolves in **Q** but not in **R**.
The MOST LIKELY bonds or intermolecular forces in substances **P**, **Q** and **R** are :

	P	Q	R
A	Ionic bonds	Dipole-dipole forces	London forces
B	London forces	Dipole-dipole forces	Ionic bonds
C	Dipole-dipole forces	London forces	Ionic bonds

D	Ionic bonds	London forces	Dipole-dipole forces

(2)

1.5 The intermolecular forces holding the molecules in ice together are …

A ion-dipole forces.

B Van der Waals forces.

C covalent bonds.

D hydrogen bonds. (2)

[10]

LONG QUESTIONS

QUESTION 2

Consider the following compounds.

O_2; H_2O; H_3O+

2.1 Define the term *molecule.* (2)

2.2 Draw the Lewis structures for:

2.2.1 O_2 (2)

2.2.2 H_2O (2)

2.3 The H_3O^+- ions forms when the oxygen atom in H_2O donates its lone pair of electrons into the vacant orbital of H^+.

2.3.1 Write down the NAME of the type of bond described by the underlined phrase. (2)

2.3.2 Draw the Lewis structure for the H_3O^+-ion. (2)

2.4 Which molecule is polar, H_2O or O_2? Explain your answer. (2)

[12]

QUESTION 3

3.1 Draw a Lewis diagram of methane. (2)

3.2 What is the name of the special kind of bond found inside the methane molecule? (1)

3.3 Answer the following questions about magnesium chloride:

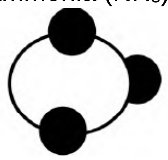
3.3.1 Make a Lewis diagram to indicates the transfer of electrons between magnesium and chlorine (4)

3.3.2 Magnesium chloride is ionic substance. Prove this statement with relevant calculation (2)

[9]

QUESTION 4

4 Ammonia (NH_3) is represented in the diagram below.



4.1 Write down the number of valence electrons for nitrogen (1)

4.2 Draw the Lewis structure for ammonia (3)

4.3 Write down the molecular shape of the ammonia molecule (1)

4.4 Explain why ammonia does not have a trigonal planar shape. (2)

4.5 Is ammonia a polar or non-polar molecule? (1)

4.6 Refer to the structure and difference in electronegativity to explain the answer to QUESTION 4.5. (2)

When a hydrogen ion reacts with an ammonia molecule, it forms the ammonium ion.

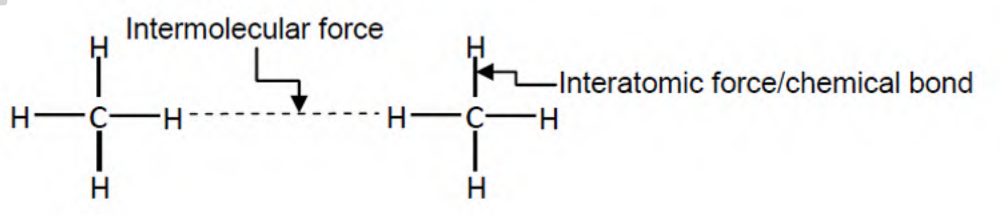
4.7 By referring to the ammonium ion, explain what is a dative covalent bond (2)

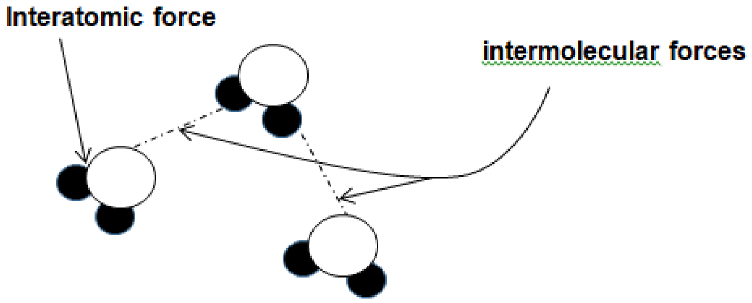
[12]

INTERMOLECULAR FORCES

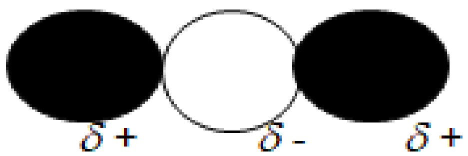
- Intermolecular forces are forces of attraction between molecules in a substance.
- Intermolecular forces are weak forces of attraction between molecules or between atoms of noble gases
- Intermolecular forces are not the same as intramolecular bonds.
- Intramolecular (interatomic) bonds exist between atoms in a molecule.
- The intermolecular forces are **weaker** than interatomic forces.

Examples of intermolecular forces and intramolecular (interatomic)forces



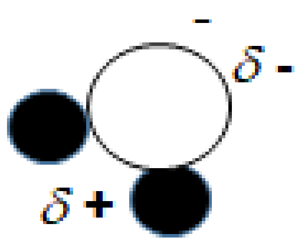


- Molecules can be **polar** or **non-polar**.
- The polarity of a molecule is determined by two factors:
    - The difference in electronegativity between the bonding atoms.
    - The geometry (shape) of a molecule
- **Non-polar molecules** have no dipoles (positive and negative ends) e.g., CO_2



Polar molecule

- In polar molecule there are ∂+ and ∂- ends e.g., H_2O and the geometry of the water molecule is angular (bent).

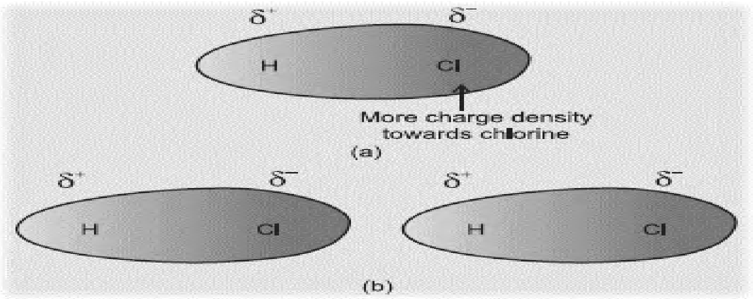


- H_2O molecule has H-end being ∂+ and O-end being ∂-, it has **dipoles.** The molecule is polar

- **Non-polar bonds:**
  - H_2 is non-polar because the two atoms are identical, there is even or symmetrical distribution of charge, this makes H_2 a non-polar molecule.

TYPES OF INTERMOLECULAR FORCES

- Different intermolecular forces (Van der Waals forces) ARE
  - Mutually induced dipole forces or London forces: Forces between non-polar Molecules
  - Dipole-dipole forces: Forces between two polar molecules
  - Dipole-induced dipole forces: Forces between polar and non-polar molecules
  - Hydrogen bonding: Forces between molecules in which hydrogen is covalently bonded to nitrogen, oxygen, or fluorine – a special case of dipole-dipole forces
  - Ion-dipole forces: Forces between ions and polar molecules



INTERMOLECULAR FORCES AND PHYSICAL PROPERTIES (factors affecting intermolecular forces)

Boiling point and melting point

- Intermolecular forces dictate several properties, such as melting points, boiling points, solubility of substances, vapour pressure, viscosity etc.

- Boiling point is the temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the higher the boiling point.

- Melting point is the temperature at which the solid and liquid phases of a substance are at equilibrium. The stronger the intermolecular forces, the higher the melting point.

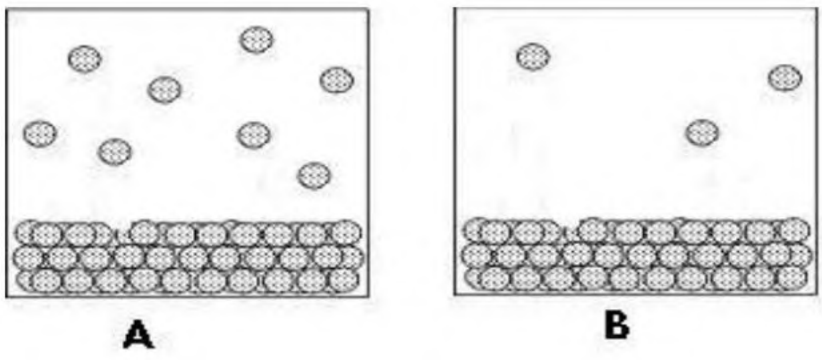
- A liquid with high boiling point, like water (H_2O, b.p. 100 °C), exhibits stronger intermolecular forces compared to a liquid with low boiling-point, like hexane (C_6H_{14}, b.p. 68,73 °C).

Solubility

- Solubility is the property of a solid, liquid, or gaseous chemical substance (solute) to dissolve in a solid, liquid, or gaseous solvent to form a homogeneous solution.
- Miscible liquids have similar polarities.
- For example, methanol and water are miscible and are both polar and capable of hydrogen bonding.
- When methanol and water are mixed, they interact through intermolecular hydrogen bonds of comparable strength to the methanol–methanol, and water–water interactions; thus, they are miscible.
- Likewise, nonpolar liquids like hexane and bromine are miscible with each other through dispersion forces.
- The chemical axiom “like dissolves like” is useful to predict the miscibility of compounds.
- For example, nonpolar hexane is immiscible in polar water. Relatively weak attractive forces between the hexane and water do not adequately overcome the stronger hydrogen bonding forces between water molecules.

Vapor Pressure

- Vapor pressure is the pressure exerted by a vapour at equilibrium with its liquid in a closed system. The stronger the intermolecular forces, the lower the vapour pressure.
- At the surface, some molecules of a liquid have enough kinetic energy to break their attractive forces with neighbouring molecules.
- These molecules escape from the liquid phase and form a gas above the surface of the liquid. If there is a lid, pressure develops.

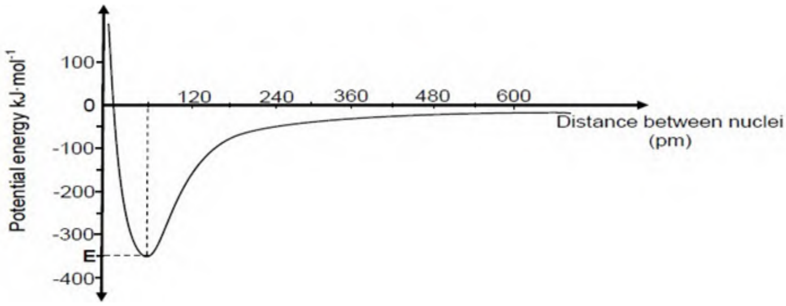


- In the picture above, A has more gas, meaning gas molecules are breaking away from the liquid state easier than molecules in B.
- The intermolecular forces must be weaker in A than in B.
- Molecules in A are less attracted to each other than molecules in B.
- Intermolecular forces in A are weaker than those in B

WORKED EXAMPLES

QUESTION 1

The graph below shows the change in energy that takes place when a hydrogen (H) atom approaches a bromine (Br) atom.



1.1 Define the term *bond length* (2)

1.2 From the graph, write down the:

1.2.1 Bond length, in pm, of the H-Br bond (2)

1.2.2 Energy,in kJ mol^{-1} (1)

1.2.3 Name of the potential energy represented by E (2)

1.3 How will the bond length of H-F bond compare to that of H-Br bond?
Write down EQUAL TO, SHORTER THAN, LONGER THAN. Give a reason for your answer (2)

[9]

SOLUTION

1.1 The average distance between nuclei of two bonded atoms in a molecule. (2)

1.2 1.2.1 60 (pm) ✓✓ (2

1.2.2 350 ($kJ.mol^{-1}$) ✓✓ (2)

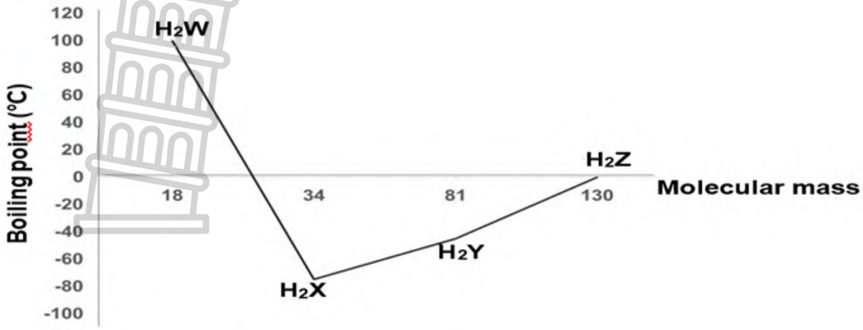
1.2.3 Bond energy✓ (1)

1.3 Shorter than,√ F atoms are smaller than Br atoms and come closer to H atom.√ (2)

[9]

QUESTION 2

The graph below shows the relationship between the boiling points of the hydrides of the Group 16 elements and molecular mass.



2.1 Define the term *boiling point*. (2)

2.2 Consider the boiling points of hydrides, excluding H_2W.

2.2.1 What is the relationship between molecular mass and boiling points of compounds? (2)

2.2.2 Explain the trend in boiling points. Refer to molecular mass, intermolecular forces and energy to explain your answer. (3)

2.3 H_2W does not follow the trend in boiling points for the 16 hydrides.

2.3.1 Identify the compound H_2W (1)

2.3.2 Name the types of intermolecular forces found in this compound (2)

2.3.3 Explain why the boiling point is higher than expected (2)

[12]

SOLUTION

2.1 The temperature at which the vapour pressure of a substance equals atmospheric pressure (2)

2.2 2.2.1 As the molecular mass increases, the boiling point increases. ✓✓ (2)

2.2.2 As the molecular mass increases, ✓ the strength of the intermolecular forces increases. ✓ Therefore more energy is needed to overcome/ weaken the intermolecular forces. ✓(No mark if BROKEN is used instead of overcome or weaken.) Thus the boiling point increases. (3)

2.3 2.3.1 water✓ (1)

2.3.2 Hydrogen Bond✓ (2)

2.3.3 Hydrogen bonds are stronger than dipole-dipole forces ✓ therefore more energy is needed to overcome/weaken the forces. ✓ Thus the boiling point is higher than expected. (2)

[12]

ACTIVITIES: INTERMOLECULAR FORCES

QUESTION 1

Which intermolecular forces are found in:

1.1 hydrogen fluoride (HF) (1)

1.2 methane (CH4) (1)

1.3 potassium chloride in ammonia (KCl in NH3) (1)

1.4 krypton (Kr) (1)

[4]

QUESTION 2

Refer to the table below and answer questions that follow.

	distance	Melting Point	Boiling Point	Relative molecular/ atomic mass

	Sodium	97,79	882,8	23
	Bromine (Br2)		58,8	160
	Hydrogen chloride (HCℓ)	-1 14,2	-85,1	36,5
	Water (H20)		100	18

2.1 Define the term *boiling point*. (2)

2.2 By referring to the forces present in hydrogen chloride, explain the difference between intermolecular forces and interatomic forces. (2)

2.3 Which of these substances will be a liquid at +50 0 C? (1)

2.4 Refer to intermolecular forces and energy and explain why the boiling point of HCℓ is lower than the boiling point of H20 (4)

2.5 NaCℓ dissolved in 1-120.

2.5.1 Write down the name the intermolecular forces between NaCl and 1-120. (1)

2.5.2 Are the intermolecular forces stated in QUESTION 2.5.1 weaker or stronger than those of H20 molecules. (1)

2.6 Refer to TYPE of INTERMOLECULAR FORCES, MOLECULAR MASS, STRENGTH of INTERMOLECULAR FORCES and ENERGY to explain the big difference in boiling points of Br2 and HCl. (4)

[15]

QUESTION 3

The table below shows the relationship between the melting points of three molecules:

Molecule	Melting point (°C)
CH4	-182,5
CF4	-150
CCℓ4	-23

3.1 Define the term *melting point.* (2)

3.2 Explain the trend in melting points of the molecules in the above table by referring to the intermolecular forces and energy involved. (4)

3.3 Which molecule in the table will have the highest vapour pressure at a given temperature? Explain the answer by referring to the data in the table. (2)

3.4 Water (H2O) is a smaller molecule than CCℓ4, but water has a higher melting point than CCℓ4. Explain this observation by referring to the type of intermolecular forces involved. (2)

3.5 Write down the name of intermolecular force that will exist in a mixture of H2O and CCℓ4. (2)

[12]

QUESTION 4

In the table below the boiling points of four hydrogen halides are given.

Hydrogen halides	A	B	C	D
	HF	HCℓ	HBr	HI
Boiling points (˚C)	19,4	-85	-67	-35,5

4.1 Define the term *boiling point*. (2)

4.2 What is the relationship between strength of the intermolecular forces and boiling point? (1)

4.3 Which of the hydrogen halides (A, B, C or D) in the table above has the …

4.3.1 highest vapour pressure? (Refer to the boiling point in the table above to give a reason for the answer.) (2)

4.3.2 strongest intermolecular forces? (1)

4.4 Draw a line graph to represent the boiling points of the hydrogen halides. Label the axes clearly and give the graph a heading. (6)

4.5 Compare compound A and B. Refer to the TYPE and STRENGTH of the intermolecular forces and ENERGY needed to explain the difference in boiling points between hydrogen halides. (4)

[16]

QUANTITATIVE ASPECT OF CHEMICAL CHANGE

- The mole is the SI unit for the amount of substance (describe as mole)
- The Mole is a name for a specific number. The Mole is the SI unit for quantity of substance.
- One mole is the amount of a substance having the same number of particles as there are atoms in 12 g carbon-12 (define a mole).

Abbreviation of units – the official SI abbreviation of the unit mole is mol.
The mole - mass relationship is summarised in the formula:

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

Where: n: number of moles of substance in mol
m: mass of sample of substance in g
M: molar mass of substance in g·mol^{-1}

Worked Example 1
Calculate the number of moles of water in 100 g of water.

Solution
$n = \frac{m}{M} = \frac{100}{16+(2\times1)} = 5{,}56$ mol

Worked Example 2
Calculate the molar mass of a 5 mol substance with a mass of 295,5 g.

Solution
$n = \frac{m}{M}$
$5 = \frac{295{,}5}{M}$ (cross multiply and let M be the subject of the formula
$M = \frac{295}{5} = 58{,}5$ g·mol^{-1}

Worked Example 3
Calculate mass of NH_3 with 0,15 mol:

Solutions
Molar mass of NH_3
$M_{NH_3} = 14 + 3(1) = 17$ g·mol^{-1}
$n = \frac{m}{M}$
$0{,}15 = \frac{m}{17} = 2{,}55$ g

Practice Exercises
1. Calculate the number of moles in:
(i) 213 g of Cl_2 (ii) 128 g of SO_2

(i) 39,5 g $KMnO_4$ (iv) 20,5 g of $Ba(OH)_2$

2. Calculate the mass of:
   (i) 0,2mol of NH_3 (ii) 0.7 mol of O_2
   (iii) 2,5mol of $Mg(OH)_2$ (iv) 3,5mol of Fe

3. Calculate the molar mass for each of the following:
   (i) Ca (ii) $MgCl_2$
   (iii) CO_2 (iv) $CaCO_3$

Relationship Derived from Balanced Chemical Equation

4Fe(s)	+	$3O_2(g)$	→	$2Fe_2O_3(s)$
Iron	+	oxygen	→	iron(iii) oxide
4 atoms Fe	+	3 molecules O_2	→	2 formula units of Fe_2O_3
4 mol Fe	+	3 mol O_2	→	2 mol of Fe_2O_3
223,4 g Fe	+	96 g O_2	→	319 g of Fe_2O_3
319,4 g reactants			→	319,4 g products

The Mole and the Gases

Avogadro's Law:
Avogadro determines that: One mole of any gas occupies the same volume at the same temperature and pressure.

<u>1 mole of ANY gas at STP is occupies a volume of 22,4 dm^3</u>

For the reactions at STP, gas volumes will be according to their molar ratio:

N_2	+	$2O_2$	→	$2NO_2$
1 mol	+	2 mol	→	2 mol
1(22,4 dm^3)	+	2(22,4dm^3)	→	2(22,4dm^3)

- The molar volume of ANY gas at STP is given the symbol V_m
  (i.e. V_m = 22,4 dm^{3}mol^{-1})

NOTE: STP stands for Standard Temperature (273 K) and Pressure ($1,01\times10^5$ Pa).

- For any gas at STP, $n = \frac{V}{V_m}$
- Where: n: number of moles of gas
  V: volume of gas sample
  V_m: molar volume of gas (22,4 dm^{-3}·mol^{-1})
- The volume of the gas sample (V) must always be measured in dm^3
  (1 dm^3 = 0,001 m^3 = 1000 cm^3)

Worked Example 4
4.1) Determine the volume of 0,2 moles of H_2 at STP.
4.2) Determine the mass of 60 cm^3 of NH_3 at STP.
Solutions

$$4.1\ n = \frac{V}{V_m}$$

$$0,2 = \frac{V}{22,4}$$

V_m = 0,448 dm^3
4.2) convert units first

V = <u>60</u> = 0,06 dm^3

$$1000$$

$$n = \frac{V}{V_m} = \frac{0,06}{22,4} = 0,0027 \text{ mol}$$

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

$$0,0027 = \frac{m}{17}$$

$$m = 0,046 \text{ g}$$

The Mole and Concentrations of Solutions

- Solutions are homogeneous (uniform) mixture of solute and solvent.
- Solute and solvent can be a gas, liquid or solid.
- The most common solvent is liquid water (called aqueous solution).
- Concentration is the mount of solute per litre of solution.
- Concentration can be calculated with $c = \frac{n}{V} = \frac{m}{MV}$

Where: c: concentration ($mol{\cdot}dm^{-3}$)
n: number of moles (mol)
V: volume (dm^3)
m: mass (g)
M: molar mass ($g{\cdot}mol^{-1}$)

Worked Example 5

5.1) Calculate the concentration of a solution of calcium chloride made by dissolving 5,55 g of dry $CaCl_2$ crystals in enough water to make 750 cm^3 of solution.

5.2) What mass of copper (II) sulphate must be dissolved in 200 ml water to yield a 0,4 $mol{\cdot}dm^{-3}$ solution?

Solutions

5.1) $c = \frac{m}{MV} = \frac{5,55}{(111)(0,75)} = 0,067 \text{ mol}{\cdot}dm^{-3}$

5.2) $c = \frac{m}{MV}$

$0,4 = \frac{m}{(159,5)(0,2)}$

$m = 12,76 \text{ g}$

The Mole and Percentage Composition of Substances

- The subscripts in a chemical formula give the mole ratio in which the elements combine.
- The mole ratio enables one to calculate the percentage composition, of the elements in the compound.

Empirical formula of compounds.

- The empirical formula of a compound gives the simplest mole ratio in which the elements of the compound combine.

Empirical formula simply tells us the ratio of the different elements in a compound, not number of atoms of each element in molecule.

STEPS TO FIND THE EMPIRICAL FORMULA

STEP 1
Find the mass
Convert the % mass into grams by assuming 100 g of a given sample.

↓

STEP 2
Convert the moles of each element by using the n=$\frac{m}{M}$

↓

STEP 3
Determine the empirical formula by diving each number of moles by the smallest number of moles to get the simplest whole number ratio.

Worked Example 6
In a combustion reaction, 0,48 g of Mg ribbons is burnt. The amount of MgO produced is 0,8 g. Calculate the empirical formula for MgO.

Solution

Steps	Magnesium	Oxygen
Step 1: mass (g)	0,48	0,80 – 0,48= 0,32
Step 2: mol (n = $\frac{m}{M}$)	n = $\frac{m}{M}$ = $\frac{0.48}{24}$ = 0,02	n = $\frac{m}{M}$ = $\frac{0.32}{16}$ = 0,02
Step 3: Atom ratio (divide by smallest number in ratio)	$\frac{0,02}{0,02}$ = 1	$\frac{0,02}{0,02}$ = 1

∴ the empirical formula is MgO

Worked example 7
The action of bacteria on meat and fish produces a stinking compound called cadaverine. The compound has a composition of 58,77% C; 13,81% H and 27,42% N by mass.
Determine the empirical formula of cadaverine.

Solution
In 100 g of compound, we have 58,77 g C; 13,81 g H; and 27,40 g N

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

$$n(C) = \frac{58,77}{12} \checkmark = 4,8975 \text{ mol C}$$

$$n(H) = \frac{13,81}{1} \checkmark = 13,81 \text{ mol H}$$

$$n(N) = \frac{27,40}{14} \checkmark = 1,9571 \text{ mol N}$$

mole ratio = C: H: N

$= \frac{4,8975}{1,9571} : \frac{13.81}{1,9571} : \frac{1,9571}{1,9571}$

$= (2,50: 7,06: 1,00) \quad x\ 2$ ✓

Nearest whole number ratios = 5: 14: 2 ✓

∴ empirical formula is $C_5H_{14}N_2$ ✓

Empirical Formula to Molecular Formula

- Molecular formula is the actual ratio of atoms in a molecular mass.
- The molecular formula can be calculated from the empirical formula and the relative molecular mass.

STEP 1
Find the molar mass of the empirical formula.

↓

STEP 2
Divide the given molar mass by the molar mass of the empirical formula that was calculated.

↓

STEP 3
Determine the molecular formula by multiplying all subscripts in the empirical formula by the whole number that you calculated in step 2.

Worked Example 8

Butene has the empirical formula CH_2.The molecular mass of butene is 56 g·mol^{-1} determine the molecular formula of butene.

Solution

Empirical formula given: CH_2

Step 1 calculate $M(CH_2)$= 12+2(1) = 14 g·mol^{-1}

Step 2 find ratio number = $\frac{\text{molecular formula mass}}{\text{empirical formula mass}} = \frac{56}{14} = 4$

Step 3 multiply each subscript of the empirical formula by 4: $C_{(1x4)}H_{(2x4)}$

Molecular formula is C_4H_8

Limiting Reactant

- In a reaction between two substances, one reaction is likely to be used up completely before the other and this limit the amount of product formed.
- The amount of limiting reactant will determine:
  - ✓ The amount of product formed.
  - ✓ The amount of other (excess) reactant used.

Determining Limiting Reactants

- ✓ Calculate the number of moles of each element.
- ✓ Determine the ratio between reactants.
- ✓ Determine limiting reactant using the ratio.

NOTE: If one reactant is in excess, it means that there is more than enough of it. If there are only two reactants and one is in excess, it means that the other is the limiting reactant.

Worked example 9

A nitrogen sample of mass 8,4 g reacts with 1,5 g of hydrogen. The reaction is represented with the unbalanced equation below.

$$N_2(g) + H_2(g) \rightarrow NH_3(g)$$

9.1) Write down a balanced reaction equation.

9.2) Determine:

9.2.1) The limiting reactant

9.2.2) The mass of ammonia that can be produced

Solutions

9.1) $N_2 + 3H_2 \rightarrow 2NH_3$

9.2.1) $n(N_2) = \frac{m}{M} = \frac{8,4}{28} = 0,3$ mol

$n(H_2) = \frac{m}{M} = \frac{1,5}{2} = 0,75$ mol

N_2 : $3H_2$

1 : 3

0,3 : x

$\therefore n(H_2) = 0,9$ mol

If all nitrogen is used, 0,9 mol of hydrogen is needed, however, only 0,75 mol of hydrogen is available. The hydrogen will run out first therefore hydrogen is the limiting reactant.

9.2.2) Since hydrogen is the limiting reactant, it will determine the mass of ammonia produced:

$3H_2$: $2NH_3$

3 : 2

0,75 : x = 0,5 mol

$n(NH_3) = \frac{m}{M}$

m = (0,5)(17)

= 8,5 g

Percentage Purity

- Sometimes chemicals are not pure, and one needs to calculate the percentage purity.
- Only the pure component of the substance will react.
- For impure sample of a substance:

$$\text{Percentage purity} = \frac{\text{mass of pure substance}}{\text{mass of impure substance}} \times 100\ \%$$

STEPS TO DETERMINE THE PERCENTAGE PURITY

- ✓ Determine moles of a product.
- ✓ Balance the equation.
- ✓ Determine the ratio between reactants and products.
- ✓ Using the ratio, determine the number of moles of reactants.
- ✓ Determine the mass of pure substance.
- ✓ Calculate the percentage purity of the sample.

Percentage Yield

- The percentage yield shows how much product is obtained compared to the maximum possible mass.

- Some of the product may be lost due to evaporation into the surrounding air, or to a little being left in solution. This results in the amount of produced being less than maximum theoretical amount you would expect.
- We can express this by the percentage yield:

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\%$$

- Percentage yield is usually determined using mass but can also be determined with mol and volume.

STEPS TO DETERMINE THE PERCENTAGE YIELD

- ✓ Determine the moles of reactant
- ✓ Balance the equation.
- ✓ Using the ratio from the balance equation, determine the numbers of moles of product.
- ✓ Determine the theoretical mass of product.
- ✓ Calculate the percentage yield.

Worked Example 10

An excess of $Pb(NO_3)_2$ reacts with 0,75 g of KI according to the reaction:

$$Pb(NO_3) + KI \rightarrow PbI_2 + KNO_3$$

After titration and drying, a mass of 0.583 g of PbI_2 is measured.
Determine the percentage yield of PbI_2

Solution

Step 1: (balance chemical equation)

$Pb(NO_3) + 2KI \rightarrow PbI_2 + 2KNO_3$

Step 2: (convert all given information to mole)

$$n(KI) = \frac{m}{M} = \frac{0{,}75}{166} = 4{,}52 \times 10^{-3}\,\text{mol}$$

Step 3: (use stoichiometric ratio)

From the balance equation:

(n)KI : (n)PbI_2

2 : 1

4.52×10^{-3} : ?

$$(n)PbI_2 = \tfrac{1}{2}(4{,}52 \times 10^{-3}) = 2{,}26 \times 10^{-3}\text{ mol}$$

Step 4: (convert the number of moles to mass)

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

$$2{,}26 \times 10^{-3} = \frac{m}{461}$$

$$m = 1{,}04\text{ g}$$

Step 5: (percentage yield)

$$\text{Percentage yield} = \frac{\text{actual yield mass}}{\text{theoretical yeild mass}} \text{X}100$$

$$= \frac{0{,}583}{1{,}04} \text{x}100$$

$$= 56{,}1\%$$

Worked Example 11

A sample of $NaNO_3$(s) of mass 4,25 g was heated and 500 cm^3 of O_2(g) was collected at STP. The chemical reaction that takes place is:

$2NaNO_3(s) \rightarrow 2NaNO_2(g) + O_2(g)$

Calculate the:

10.1) Theoretical volume of O_2(g) that was formed

10.2) Percentage yield of O_2(g)

Solutions

11.1)) $M(NaNO_3) = 23+14+16\times3 = 85\ g\cdot mol^{-1}$

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

$$n = \frac{4,25}{85}$$

$$= 0,05\ mol$$

$n(NaNO_3) : n(O_2)$

2 : 1

$$n(O_2) = \frac{0,05}{2}$$

$$= 0,025\ mol$$

Volume of oxygen produced:

$V(O_2) = nV_m$

$V(O_2) = 0,025 \times 22,4$

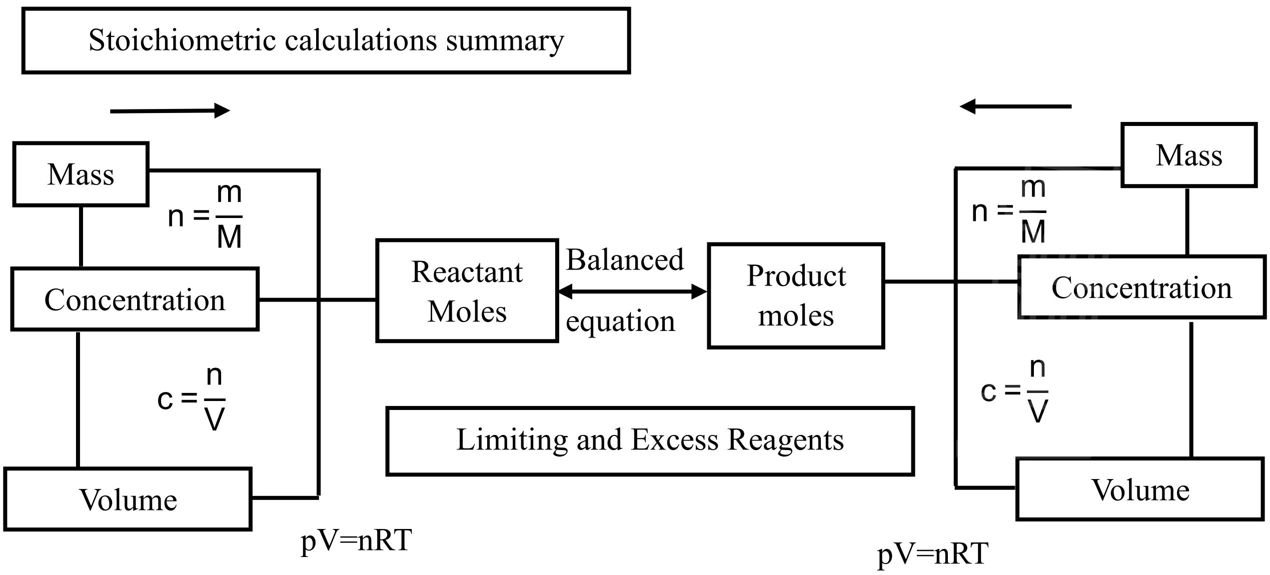
$= 0,56\ dm^3$

11.2)

$$\%yield = \frac{\text{Actual Volume}}{\text{Theoretical Volume}} \times 100\%$$

$$= \frac{0,50}{0,56} \times 100\%$$

$$= 89,29\%$$



ACTIVITIES – QUANTITATIVE ASPECTS
QUESTION 1: MULTIPLE-CHOICE QUESTIONS

Choose the answer and write only the letter (A–D) next to the question numbers.

1.1 ….of a gas is the volume of one mole of a gas at STP.
A. Molar mass
B. Molar volume
C. Atomic weight
D. Molar weight (2)

1.2 Equal volumes of all gases at the same temperature and pressure contain the same number of…
A. protons.
B. neutrons.
C. electrons.
D. molecules. (2)

1.3 How many moles of chloride ions are present in 111 g of calcium chloride?
A. 0,5
B. 2
C. 1
D. 1,47 (2)

1.4 What amount of oxygen gas (in moles) contains 1,8 x 10^{22} molecules?
A. 0,03
B. 33,34
C. 1,2 X 10^{24}
D. 1,08 X0^{46} (2)

1.5 The molecular formula of a compound is $C_6H_{12}O_2$
A. C_3H_6O
B. $C_3H_{12}O_2$
C. $C_{12}H_{24}O_4$
D. C_2H_4O (2)
[10]

QUESTION 2 – CONCENTRATION

2.1 Learners prepare a solution of sodium hydroxide (NaOH) in water by placing 8 g of sodium hydroxide (NaOH) in a volumetric flask and adding water to produce 250 cm^3 of solution after stirring.

2.1.1 Define the term *concentration*. (2)
2.1.2 Calculate the concentration of sodium hydroxide (NaOH) in solution. (4)

2.2 Sodium azide (Na_3N) is used in car airbags. For the airbag to inflate, the following reaction must take place:

$$2Na_3N\ (s) \longrightarrow 6Na\ (s) + N_2\ (g)$$

Calculate the volume of nitrogen gas (N_2) that would be produced at STP if 55 g of sodium azide reacts completely. (5)
[11]

QUESTION 3 – EMPIRICAL FORMULA

3.1 Methyl propanoate is an organic compound with the following percentage composition:

54,55% C; 9,09% H; 36,36% O

The molar mass of the compound is 88 g·mol^{-1}

3.1.1 Define the *empirical* formula. (2)
3.1.2 Determine, by calculation, the empirical formula. (6)
3.1.3 Determine the molecular formula. (2)

3.2 In order to determine the empirical and molecular formulae of a compound, C_xH_y, a certain mass of compound is burnt completely in excess oxygen to produce 47,1 g CO_2 and 19,35 g H_2O as the only products.

3.2.1 Use relevant calculations to determine the empirical formula of the compound. (8)
3.2.2 Determine by calculations, the values of x and y if molar mass of the compound is 28 $g \cdot mol^{-1}$. (2)

[20]

QUESTION 4 – COMPLEX STOICHIOMETRIC CALCULATIONS

4.1 A sample of IMPURE calcium carbonate (limestone) of unknown mass required a continuous supply of strong heat to decompose according to the following equation:

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

Upon completion of the reaction, 11.76g of CaO was obtained, and the percentage purity of calcium carbonate was found to be 80%.
Calculate the mass of impure calcium carbonate. (6)

4.2 During a chemical reaction, 7,62 g potassium was added to a test tube containing 4,34 g molten sulphur. The potassium and the sulphur reacted to form a potassium sulphide according to the following balanced equation:

$$2K_{(S)} + S_{(s)} \rightarrow K_2S_{(S)}$$

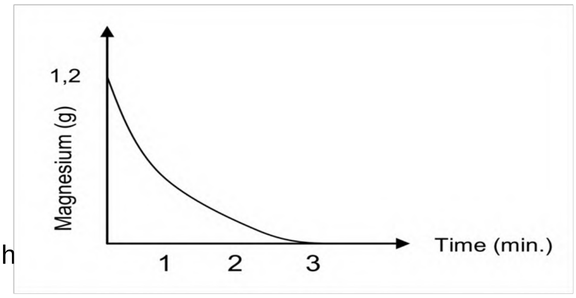
4.2.1 Calculate the number of moles of potassium. (3)
4.2.2 Determine the limiting reagent. (5)
4.2.3 Calculate the mass of K_2S produced (3)

4.3 During the reaction in an experiment, a learner adds 500 cm^3 of hydrochloric acid (HCℓ) with a concentration of 0,36 $mol \cdot dm^{-3}$ to 1,2 g of magnesium in a test tube.
She records the change in the mass of magnesium as the reaction proceeds at regular intervals. The balanced chemical equation for the reaction is:

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

The mass change of magnesium graph is shown on the graph below.

Use the graph



4.3.1 Identify the limiting agent in the reaction. Give a reason for your answer. (2)
4.3.2 Calculate the number of moles of unreacted hydrochloric acid in 3 minutes. (5)

4.4 An excess of $Pb(NO_3)_2$ reacts with 0,75 g of KI according to the reaction:

$$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$$

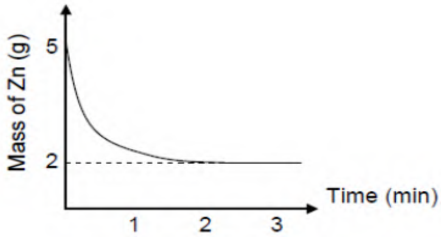
After titration and drying, a mass of 0,583 g of PbI_2 is measured.

Determine the percentage yield of PbI_2 (6)

4.5 Zinc reacts with sulphuric acid according to the reaction below.

$$Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$$

The mass of zinc is recorded during the experiment and is shown on the graph below. The reaction stops after 2 minutes.



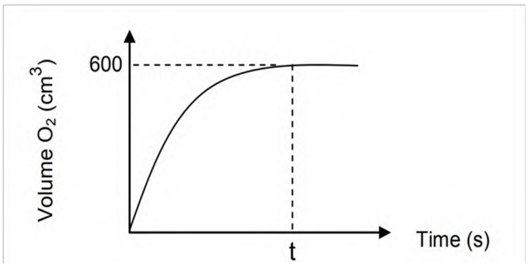
4.5.1 Name the substance that is the limiting reagent.
Give a reason for your answer. (2)

4.5.2 Calculate the initial concentration of the sulphuric acid if 50 cm³ of the acid was used. (5)

4.6 Decomposing hydrogen peroxide in the presence of a catalyst at a specific pressure and room temperature is given by the unbalanced chemical equation below:

$$H_2O_2 \longrightarrow H_2O + O_2$$

Oxygen gas is collected, and the volume is recorded over time (s). The results are then used to draw the graph below.



Take the molar gas volume (V_m) to be 24,45 dm³ at room temperature and standard pressure.

4.6.1 Balance the equation given above. (2)

4.6.2 Using the information from the graph, calculate the mass of hydrogen peroxide that decomposed. (5)

[44]

QUESTION 5 – PERCENTAGE PURITY

15 g of impure $Mg(OH)_2$ was reacted with excess phosphoric acid to produce 16 g of $Mg_3(PO_4)_2$ according to the following balanced equation:

$$3Mg(OH)_2\ (s) + 2H_3PO_4\ (aq) \rightarrow Mg_3(PO_4)_2\ (s) + 6H_2O\ (l)$$

5.1 Calculate the percentage purity of the $Mg(OH)_2$. (5)

5.2 If 20 g of the same impure $Mg(OH)_2$ was used in the above reaction, how will each of the following be affected?
Choose from INCREASES, DECREASES, or REMAINS THE SAME.

5.2.1 The mass of $Mg_3(PO_4)_2$ produced. (1)

5.2.2 The percentage purity of the $Mg(OH)_2$. (1)

5.3 Explain the answer to QUESTION 5.2.2. (2)

5.4 A 5 g of impure magnesium carbonate ($MgCO_3$), is added to 9,033 x 10^{22} molecules of hydrochloric acid (HCl), according to the following balanced equation:

$$MgCO_3 + 2HCl \rightarrow MgCl_2 + CO_{2(g)} + H_2O_{(l)}$$

The reaction is allowed to proceed until all the pure magnesium carbonate Completely reacts. The excess hydrochloric acid is neutralised by adding 55 cm^3 of sodium hydroxide solution of concentration 0,8 $mol·dm^{-3}$. The balance equation for neutralisation reaction is:

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Calculate the:

5.4.1 Initial number of moles of hydrochloric acid (3)

5.4.2 Percentage purity of magnesium carbonate (8)

[20]

QUESTION 6

The fizz produced when an antacid dissolve in water is caused by the reaction between sodium hydrogen carbonate ($NaHCO_3$) and citric acid ($H_3C_6H_5O_7$). The balanced equation for the reaction is:

$$3NaHCO_3(aq) + H_3C_6H_5O_7(aq) \rightarrow Na_3C_6H_5O_7(aq) + 3CO_2(g) + 3H_2O\ (l)$$

6.1 Write down the formula of the substance that causes the fizz when the antacid dissolves in water. (1)

6.2 A certain antacid contains 1,8 g of $H_3C_6H_5O_7$ and 3,36 g of $NaHCO_3$. The antacid is dissolved in 100 cm^3 distilled water in a beaker.

6.2.1 Define 1 mole of a substance. (2)

6.2.2 Calculate the number of moles of $NaHCO_3$ in the antacid. (3)

6.2.3 Determine, using calculations, which substance is the limiting reagent. (4)

6.2.4 Calculate the mass of the reactant in excess. (3)

6.2.5 Calculate the mass decrease of the beaker contents on completion of the reaction. (3)

[16]

QUESTION 7

7.1 Compound **Q** (C_XH_Y) reacts with oxygen according to the balanced equation:

$$\mathbf{P}\ C_XH_Y + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$$

The molar mass of compound **Q** is 58 $g·mol^{-1}$.

7.1.1 Define *empirical formula*. (2)

7.1.2 Use the principle of conservation of mass and determine the value **P**. (3)

The percentage composition of compound Q is:

Carbon	Hydrogen
82,76%	17,24%

7.1.3 Determine the molecular formula of compound **Q**. (5)

7.2 5 g of sodium carbonate (Na_2CO_3) reacts with 250 cm^3 of hydrochloric acid ($HC\ell$).

$$Na_2CO_3(s) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + H_2O(\ell) + CO_2(g)$$

The percentage of hydrochloric acid ($HC\ell$) that reacted with sodium carbonate (Na_2CO_3) is 76%.

7.2.1 Define the term *limiting reagent*. (2)

Calculate the:

7.2.2 Amount of hydrochloric acid that reacted with sodium carbonate (4)

7.2.3 Volume of carbon dioxide that was produced (4)

Take the molar gas volume at room temperature as 24,24 dm^3

7.2.4 The hydrochloric acid that was used in the reaction was obtained by diluting 100 cm^3 HCℓ to 250 cm^3 hydrochloric acid (HCℓ) solution.
Calculate the concentration of the concentrated hydrochloric acid (HCℓ).

(4)
[24]

ENERGY AND CHEMICAL CHANGE

Enthalpy: The total energy of a system.
Heat of Reaction (∆H): The energy absorbed or released per mole in a chemical reaction.
Energy is absorbed to break bonds; energy is released when bonds form.

- Exothermic reactions: Reactions that release energy.
  - Bond forming is exothermic.
- Endothermic reactions: Reactions that absorb energy.
  - Bond breaking is endothermic.

Calculating Changes in Enthalpy from Bond Energies
Change in Enthalpy (∆H) = Energy needed to break bonds – Energy released when bonds form

$$\Delta H = Energy_{absorbed} - Energy_{released}$$

If ∆H < 0 (negative): Exothermic reaction If ∆H > 0 (positive): Endothermic reaction

Calculating Energy Required from Change in Enthalpy
Energy released = n x *∆H (where* n represents number of moles (mol))

Examples of Exothermic and Endothermic reactions
Exothermic Reactions

- *Respiration:* Energy is released for the organism to carry out its life processes.
  $C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O$
- *Combustion of fuels* (Wool, coal, petrol, alcohol): Energy is released into the surroundings as "heat of combustion".
- *Heat/ hot patches*: Energy is released to dilate blood vessels to promote blood flow and help relax muscles.

Endothermic Reactions

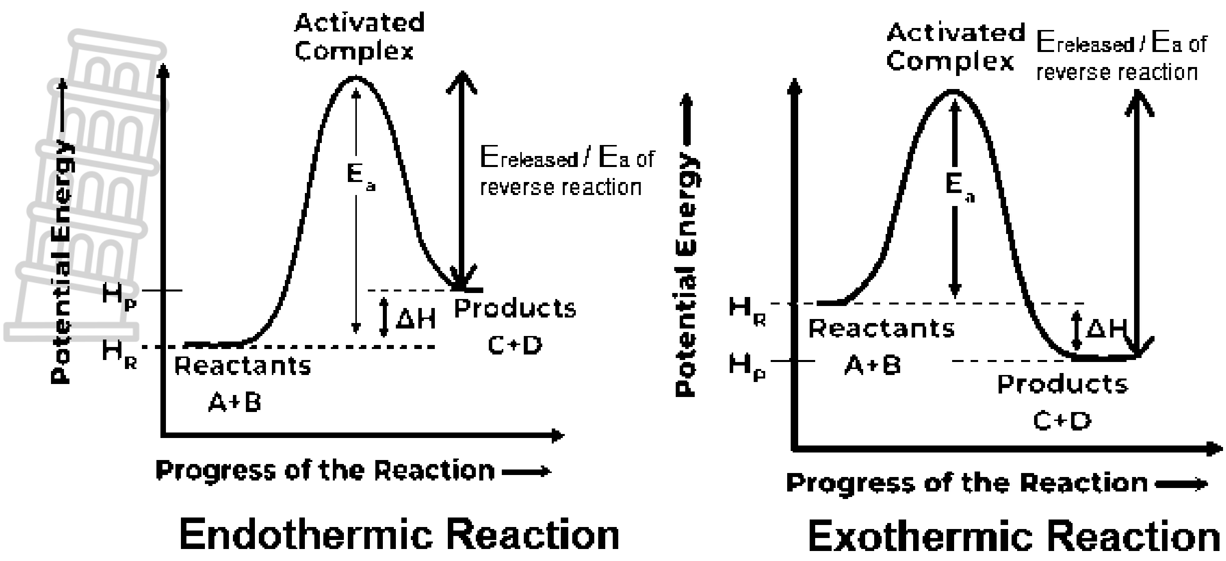
- *Photosynthesis:* Light energy from the sun is absorbed by the plant.
  $CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
- *Cold patches/ packs*: Heat energy is absorbed when cooling injuries and reduces swelling.

Activation energy: The minimum energy required for a reaction to take place.
Activated complex: The unstable transition from reactants to products.
Catalyst/ Positive Catalyst: A chemical substance that speeds up a chemical reaction (without itself being used up in the reaction) by lowering the activation energy.

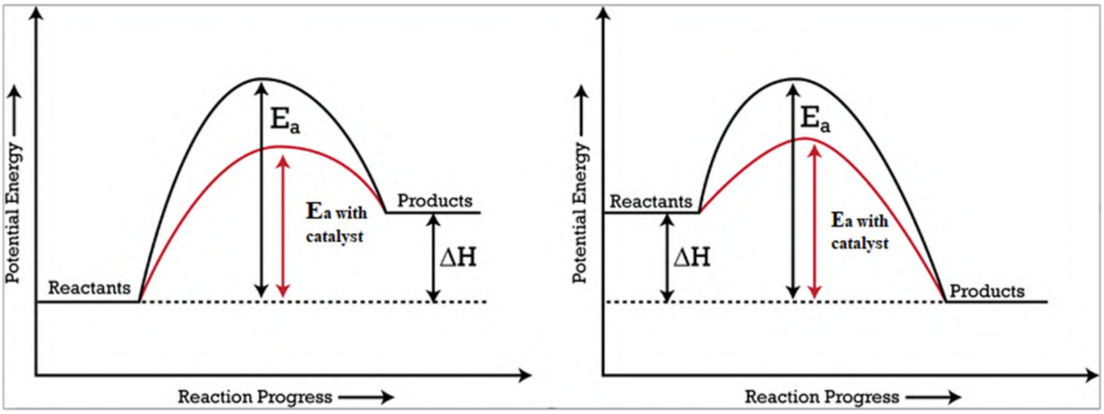
Energy Graphs/ Profiles

$$\Delta H = H_{products} - H_{reactants}$$

N.B. ∆H does not change with the addition of a catalyst, *ONLY* activation energy and energy of the activated complex is decreased.



Forward reaction: *The reaction of the reactants to form products. (Left to Right)*
Reverse reaction: *The reaction of the products to form reactants. (Right to Left)*
If the forward reaction is endothermic, the reverse will be exothermic and vice versa.
ΔH will be the same but with opposite signs.



WORKED EXAMPLES
WORKED EXAMPLE 1.

Consider the following reaction and bond energy values:

$3H_2$ + N_2 → $2NH_3$ (H – H 436 kJ.mol^{-1}, N ≡ N 946 kJ.mol^{-1}, N – H 389 kJ.mol^{-1})

1.1. Calculate the enthalpy change by making use of bond energy values. (4)

Energy absorbed = 3(H – H) + (N ≡ N)
Energy absorbed = 3(436) + 946 ✓= 2254 kJ.mol^{-1}
Energy released = 6(N – H)
Energy released = 6 (389) ✓= 2334 kJ.mol^{-1}
Δ H = 2254 – 2334 ✓= - 80 kJ.mol^{-1} ✓

1.2. Identify whether the reaction is exothermic or endothermic. Provide a reason for your answer. (2)

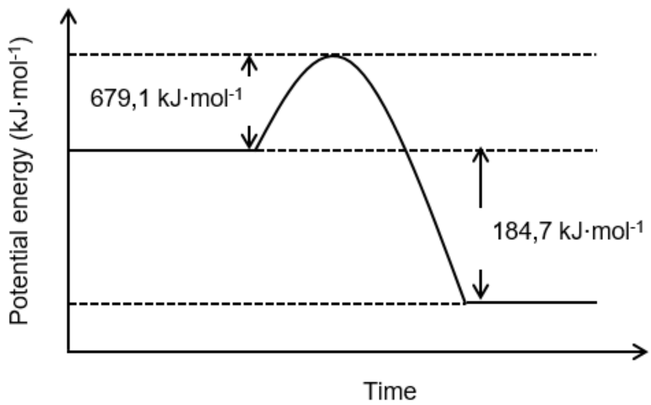
Exothermic✓Δ H < 0 / Δ H is negative✓

1.3. Determine the energy released when 10 g of N_2 completely reacts. (5)

$n=\frac{m}{M}$ ✓ $=\frac{10}{28}$ ✓ =0,357142857 mol
$Energy_{released}$ =nΔH ✓
$Energy_{released}$ =(0,357142857)(80)✓=28,57 kJ ✓

WORKED EXAMPLE 2.

The diagram shows the potential energy changes during the following chemical reaction: $2\ H_{2\ (g)} + C\ell_{2\ (g)} \rightarrow 2\ HC\ell_{\ (g)}$



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

Exothermic ✓ Enthalpy of products is less than enthalpy of reactants ✓

2.2. What is the total bond energy (H_2 and $Cℓ_2$) of the reactants? Give a reason for the answer. (3)

679,1 kJ·mol^{-1} ✓

The energy needed to break all the bonds ✓✓ / Activation energy

2.3. Determine the energy released by the bond formation of the HCℓ molecule. (2)

Bond formation/ = 184,7 + 679,1 ✓= 863,8 kJ·mol^{-1} ✓

2.4. What effect will adding a catalyst have on the value 184,7 kJ·mol^{-1}? Write down only INCREASE, DECREASE or NO EFFECT. Give a reason for the answer. (2)

No effect. ✓

Catalyst only has an effect on the activation energy and no effect on the heat of the reaction ✓

WORKED EXAMPLE 3.

The decomposition of hydrogen iodide into hydrogen and iodine can be represented as follows: $2HI(g) \rightarrow H_2(g) + I_2(g)$ $\Delta H = +21$ kJ.mol^{-1}

3.1 Calculate the amount of energy needed to decompose 50 g of HI. (5)

$n = \frac{m}{M}$ ✓ $= \frac{50}{128}$ ✓ $= 0,390625$ mol

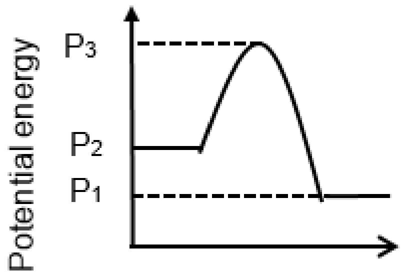
ΔH per mol HI $= -\frac{21}{2}$ ✓ $= 10,5$ kJ.mol^{-1}

$Energy_{required} = n\Delta H$

$Energy_{required} = (0,390625)(10,5)$ ✓ $= 4,10$ kJ ✓

MULTIPLE CHOICE QUESTIONS

1 When sulphuric acid reacts with water, the temperature of the reaction mixture increases. Which ONE of the following correctly describes the heat of the reaction (ΔH) between sulphuric acid and water from the graph below? (2)



A $P_3 - P_2$
B $P_1 - P_2$
C $P_3 - P_1$
D $P_2 - P_1$

2 The activation energy for the forward reaction of the reaction below is 230 kJ.mol^{-1}. $A_2 + B_2 \rightarrow 2C$ $\Delta H = +150$ kJ.mol^{-1} (2)

What is the activation energy of the reverse reaction in $kJ.mol^{-1}$?

A 380
B 230
C 150
D 80

3 In a chemical reaction, the difference between the potential energy of the products and the potential energy of reactants is equal to: (2)

A Enthalpy of the reaction
B Rate of reaction
C Enthalpy change of reaction
D Total potential energy of the particles

[6]

QUESTION 1

1. The equation for combustion of butane gas is given below.

$$\text{butane (g)} + 13O_2 \rightarrow 8CO_2(g) + 10H_2O \qquad \Delta H<0$$

1.1. Define the term *activation energy* . (2)

1.2. Is the combustion reaction of butane *exothermic* or *endothermic*? Give a reason for the answer, (2)

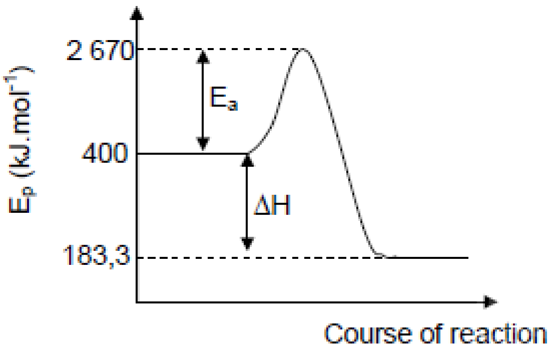
1.3. Draw a sketch graph of potential energy versus course of the reaction for the reaction. (3)
Clearly indicate the following on the graph:
- Activation energy
- Heat of reaction (ΔH)
- Reactants and products

[7]

QUESTION 2

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

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



2.1. Define activated complex. (2)

2.2. Give reason why this reaction is exothermic. (1)

2.3. What is the total bond energy of $NH_3 and\ O_2$ (the reactants) give reason for your answer. (3)

2.4. Determine the energy released by bond formation of NO and H_20 (2)

2.5. Calculate the heat of reaction. (3)

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

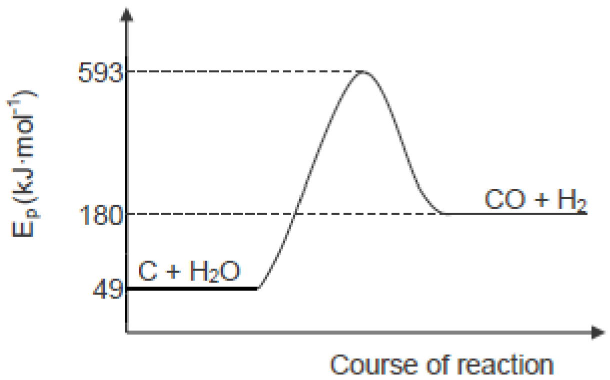
[13]

QUESTION 3 (8 MARKS)

3. The balanced equation for the reaction of carbon with steam is as follows:

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

The graph below, NOT drawn to scale, represents the change in potential energy of substances during the reaction.



3.1. Define heat of reaction. (2)

3.2. Is the reaction ENDOTHERMIC or EXOTHEMIC? Give a reason for the answer. (2)

3.3. Use the information on the graph and write down the value of the

3.3.1 Activation energy. (2)

3.3.2. Heat of reaction. (2)

[8]

QUESTION 4 (10 MARKS)

4. Learners study ENDOTHERMIC and EXOTHERMIC reactions by conducting experiments **I** and **II** in which the reactions shown in the table below take place.

EXPERIMENT	BALANCED EQUATION
I	$2\ H_2O_2\ (\ell) \rightarrow 2\ H_2O\ (\ell) + O_2(g)$
II	$2\ H_2O\ (\ell) \rightarrow 2\ H_2\ (g) + O_2\ (g)$

The learners measured the initial and the final temperatures of the reaction mixtures. They also obtained activation energies for the reactions from a data table.
The learners represented their findings in a table as shown below.

EXPERIMENT	Initial (˚C)	Final (˚C)	Activation energy (kJ/mol)
I	24	36	75
II	24	18	237

4.1. Define ENDOTHERMIC reaction (1)

4.2. In which experiment (**I** and **II**) is the reaction EXOTHERMIC? Explain your answer. (2)

4.3. Is the heat of reaction, ΔH, POSITIVE or NEGATIVE for an EXOTHERMIC reaction? (1)

4.4. Write down the general name of a substance that can be added to the reaction mixture in the experiment(**II**) to reduce the activation energy. (1)

4.5. Both reactions produce the same number of moles of oxygen gas. (2)
How does the mass of H_2O_2 used in experiment **I** compare the mass of H_2O used in experiment **II** ?
Write down only SMALLER THAN, LARGER THAN or THE SAME.

4.6. Draw a potential energy versus time graph for the reaction in experiment **II.** (3)
The following must be shown on the graph.

- Heat of reaction (ΔH)
- Activation energy (E_a)

[10]

QUESTION 5

5. Consider the decompositions reaction of dinitrogen pentoxide:

$$2N_2O_5(g) \rightarrow 2N_2O_4(g) + O_2(g)$$

The table below shows the different energies for the above reaction.

Heat the of reactants (H_r)	26,6 kJ·mol^{-1}
Activation energy (E_a)	6,73 kJ·mol^{-1}
Heat of the reaction (ΔH)	-7,28 kJ·mol^{-1}

5.1. Define the term catalyst. (2)

5.2. Is the above reactions ENDOTHERMIC or EXOTHERMIC? Give reason for your answer. (2)

5.3. Calculate the heat of products. (2)

5.4. Draw the potential energy versus course of the reaction graph for the above reaction. On the graph indicate values for: (5)

- Heat of reactants($H_{reactants}$)
- Heat of products($H_{products}$)
- Energy at the activated complex
- Heat of reaction (ΔH)

5.5. On the same graph drawn in QUESTION 5.4, use a dotted line and draw the shape of the graph when a catalyst is added to the original reaction. (2)

[13]

TYPES OF REACTIONS

1. ACIDS AND BASES

Define acids and bases according to Arrhenius and Lowry-Brønsted:

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.

Lowry-Brønsted theory:

An acid is a proton/H^+ ion donor.

A base is a proton/H^+ ion acceptor.

Common acids: hydrochloric acid, nitric acid, sulphuric acid and ethanoic acid (acetic acid).

Common bases: ammonia, sodium carbonate (washing soda), sodium hydrogen carbonate, sodium hydroxide (caustic soda) and potassium hydroxide.

1.1. Strength of acid and base

STRONG ACIDS

$HC\ell$ – Hydrochloric acid monoprotic)

HNO_3 – Nitric acid (monoprotic

H_2SO_4 – Sulphuric acid (diprotic

H_3PO_4 – Phosphoric acid (triprotic)

WEAK ACIDS

CH_3COOH – Acetic acid

$(COOH)_2$ – Oxalic acid

STRONG BASES

$NaOH$ – Sodium hydroxide

KOH – Potassium hydroxide

$LiOH$ – Lithium hydroxide

$Ba(OH)_2$ – Barium hydroxide

WEAK BASES

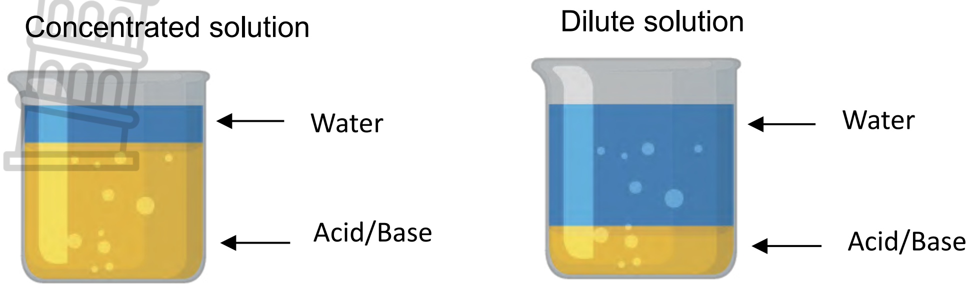
NH_3 – Ammonia

$Zn(OH)_2$ – Zinc hydroxide

Na_2CO_3 – Sodium carbonate

- Strong acids ionise completely in water to form a high concentration of H_3O^+ ions.
- Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions.
- Strong bases dissociate completely in water to form a high concentration of OH^- ions.

- Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^- ions.
    - **<u>Concentrated and dilute acids/bases</u>.**
- Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to volume of water.
- Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to volume of water.



Dilutions : $C_1V_1 = C_2V_2$ **$V_2 = V_1 + V_{water}$ (Note: to calculate V_2)**

Example:

Calculate how much water must be added to 30 cm^3 of a 0.2 mol.dm^{-3} HCl solution to change the concentration to 0.03 mol.dm^{-3}.

Solution

$C_1V_1 = C_2V_2$

$0.2 \times 0.03 = 0.03V_2$

$V_2 = \frac{0.006}{0.03}$

$V_2 = 0.2dm^{-3}$ therefore the volume of water to be added is:$V_2 = V_1 + V_{H_2O}$

$V_{H_2O} = V_2 - V_1$=0.2-0.03

$V_{H_2O} = 0.17dm^3$

- **<u>Reaction equations of aqueous solutions of acids and bases</u>.**

Examples:

<u>Ionisation equations.</u>

HCℓ(g) + H_2O(ℓ) → H_3O^+(aq) + Cl^-((aq) (HCℓ is a monoprotic acid.)
NH_3(g) + H_2O(ℓ) → NH_3 (aq) +OH^-(aq)
H_2SO_4(aq) + 2H_2O(ℓ) → 2H_3O^+ (aq) + HSO_4^- *(aq)* (H_2SO_4 is a diprotic acid.)

<u>Dissociation equations</u>

$NaOH_{(aq)} + H_2O \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$
$KOH_{(aq)} + H_2O \rightarrow K^+_{(aq)} + OH^-_{(aq)}$
$Mg(OH)_{2(aq)} + H_2O \rightarrow Mg^{2+}_{(aq)} + 2OH^-_{(aq)}$

- **<u>Identifying conjugate acid-base pairs.</u>**

When the acid, HA, loses a proton, its conjugate base, A$^-$, is formed. When the base, A$^-$, accepts a proton, its conjugate acid, HA, is formed. These two are a conjugate acid-base pair.

Example

(I) HCℓ(g) + H_2O(ℓ) → H_3O^+(aq) + Cl^-(aq)
Acid 1 Base 2 Acid 2 Base 1

(II) NH_3(g) + H_2O(ℓ) → NH_4^+(aq) + OH^-(aq)

Base 2 Acid 1 Acid 2 Base 1

(III) HSO_4^- aq) + $H_2O(\ell) \rightarrow H_3O^+$(aq) + SO_4^{2-} (aq)
Acid 1 Base 2 Acid 2 Base 1

(IV) $H_2SO_4(aq)$ + $H_2O(\ell) \rightarrow H_3O^+$(aq) + HSO_4^- (aq)
Acid 1 Base 2 Acid 2 Base 1

- **Ampholytes**

- Substance that can act as either acid or a base.
- Water is a good example of an ampholyte substance in reaction (I) water act as a base receiving a proton but in reaction (II) water act as an acid donating a proton when reacting with ammonia.
- HSO_4^- is also an ampholyte because in reaction (III) it act as an acid but in reaction (IV) it act as an base and accepts a proton.

- **Neutralisation reactions of common laboratory acids and bases**.

General equations

When an acid reacts with a metal hydroxide a salt and water are formed. The salt is made up of a cation from the base and an anion from the acid.

Acid + metal hydroxide (base) → salt + water

Eg. H_2SO_4 (aq) + $Mg(OH)_2$ (aq) →$MgSO_4$ (aq) + $2H_2O$ (ℓ)

$HC\ell$(aq) + NaOH(aq) → $NaC\ell$(aq) + $H_2O(\ell)$
$HC\ell$(aq) + KOH(aq) → $KC\ell$(aq) + $H_2O(\ell)$
HNO_3(aq) + NaOH(aq) → $NaNO_3$(aq) + $H_2O(\ell)$
HNO_3(aq) + KOH(aq) → KNO_3(aq) + $H_2O(\ell)$
H_2SO_4(aq) + 2NaOH(aq) → Na_2SO_4(aq) + $2H_2O(\ell)$

When an acid reacts with a metal oxide a salt and water are formed. An example is the reaction between magnesium oxide (MgO) and hydrochloric acid (HCl).

Acid + metal oxide → salt + water

E.g. $2HC\ell$(aq) + CaO(aq) → $CaC\ell_2$(aq) + $H_2O(\ell)$
$2HC\ell$(aq) + MgO(aq) → $MgC\ell_2$(aq) + $H_2O(\ell)$
$2HC\ell$(aq) + MgO(aq) → $MgC\ell_2$(aq) + $H_2O(\ell)$
$2HC\ell$(aq) + CuO(aq) → $CuC\ell_2$(aq) + $H_2O(\ell)$

When an acid reacts with a metal carbonate a salt, water and carbon dioxide are formed. An example is the reaction between calcium carbonate ($CaCO_3$) and $HC\ell$

Acid + metal carbonate → salt + water + carbon dioxide

E.g. $2HC\ell$ (aq) + $CaCO_3$ (s) → $CaC\ell_2$(aq) + H_2O (ℓ) + CO_2(g)
$2HC\ell$(aq) + Na_2CO_3(aq) → $2NaC\ell$(aq) + $H_2O(\ell)$ + CO_2(g)

- **Indicators**

An indicator is a compound that changes colour according to the pH of the substance. During titrations, the indicator needs to be selected according to the acidity/alkalinity of the salt that will be produced (see hydrolysis).

INDICATOR	COLOUR IN ACID	COLOUR IN BASE	COLOUR AT EQUIVALENCE POINT	PH RANGE OF EQUIVALENCE
Litmus	Red	Blue		4,5 - 8,3
Methyl orange	Red	Yellow	Orange	3,1 - 4,4
Bromothymol blue	Yellow	Blue	Green	6,0 - 7,6
Phenolphthalein	Colourless	Pink	Pale Pink	8,3 - 10,0

pH calculation

- Explain the pH scale as a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.
- Calculate pH values of strong acids and strong bases using pH = -log[H_3O^+].
- Explain the *auto-ionisation of water*, i.e. the reaction of water with itself to form H_3O^+ ions and OH^- ions.

To calculate the pH of a solution the concentration of H_3O^+ must be known or be determined. The reaction of water with itself produces H_3O^+ and OH^- ions, it is called the auto-ionisation of water. The equation is given below:

$H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + OH^-{}_{(aq)}$

neutral solution [H_3O^+] = [OH^-] = 1×10^{-7} mol·dm^{-3}

acidic solution [H_3O^+] > 1×10^{-7} mol·dm^{-3} and [H_3O^+] > [OH^-]

basic solution [H_3O^+] < $1\times10^{-7}$and [H_3O^+] < [OH^-]

Calculate pH values of strong acids and strong bases using pH = -log[H_3O^+].

Steps to calculate pH of acids

1. Write down a balanced equation for the ionisation reaction of the acid (reaction with water)
2. Use ratios to determine the concentration of [H_3O^+]
3. Substitute the concentration of [H_3O^+] in the formula pH = -log[H_3O^+]

Example 1

A few drops of bromothymol blue indicator are added to a potassium hydroxide solution in a beaker. A dilute sulphuric acid solution is now gradually added to this solution until the colour of the indicator changes.

Write down the:

1. Colour change of the indicator

Solution: green

Activity 1

1. Identify the conjugate acid base pair for the reactions below

1.1. $H_2CO_3 + H_2O \rightarrow H_3O^+ + HCO_3^-$ (2)

1.2. $H_2O + HCO_3^- \rightarrow H_3O^+ + CO_3^{2-}$ (2)

1.3. $H_2SO_4 + 2H_2O \rightarrow 2H_3O^+ + SO_4^{2-}$ (2)

Solutions 1

1.

1.1. H_2CO_3 is the conjugate acid of HCO_3^- (base) ✓ (2)

OH^- is the conjugate base of H_2O (acid) ✓

1.2. HCO_3^- is a conjugate acid of CO_3^{2-} base ✓ (2)

H_3O^+ is a conjugate acid of H_2O base. ✓

1.3. SO_4^{2-} is a conjugate base for H_2SO_4 acid✓ (2)

H_3O^+ is a conjugate acid for H_2O base✓

Activity 2

2. Calculate the pH of a 0,25 mol·dm^{-3} H_2SO_4 solution (4)

Solutions

2. $H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons 2H_3O^+(aq) + SO_4^{2-}(aq)$ (4)

0,25 mol·dm^{-3} 2(0,25) mol·dm^{-3} (**1:2 ratio**) ✓

(diprotic acid)

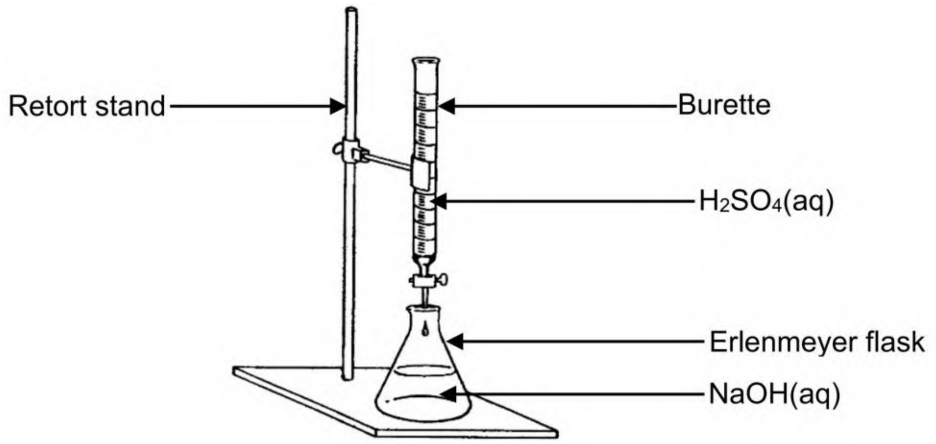
Marking criteria	**tick**
Ratio **1**(H_2SO_4)**: 2**(H_3O^+)	✓
Formula pH = -log [H_3O^+]	✓
Correct Substitution	✓
Correct Answer	✓

[H_3O^+] = 0,5 mol·dm^{-3}
pH = -log [H_3O^+] ✓
= -log (0,5) ✓
= 0,301✓

Activity 3

The reaction between a sulphuric acid (H_2SO_4) solution and a sodium hydroxide (NaOH) solution is investigated using the apparatus illustrated below.

3.



3.1 Write down the name of the experimental procedure illustrated above. (1)

3.2 What is the function of the burette? (1)

3.3 Define an acid in terms of the Arrhenius theory. (2)

3.4 Give a reason why sulphuric acid is regarded as a strong acid. (1)

3.5 Bromothymol blue is used as indicator. Write down the colour change that will take place in the Erlenmeyer flask on reaching the endpoint of the titration. Choose from the following: (1)

BLUE TO YELLOW YELLOW TO BLUE GREEN TO YELLOW

3.6 During the titration a learner adds 25 cm^3 of NaOH(aq) of concentration 0,1 mol·dm^{-3} to an Erlenmeyer flask and titrates this solution with H_2SO_4 (aq) of concentration 0,1 mol·dm^{-3} . The balanced equation for the reaction that takes place is:

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

3.6.1 Determine the volume of H_2SO_4(aq) which must be added to neutralise the NaOH(aq) in the Erlenmeyer flask completely. (4)

If the learner passes the endpoint by adding 5 cm^3 of the same H_2SO_4(aq) in excess, follow the questions below to calculate the pH of the solution in the flask.

3.6.2 Calculate initial number of moles of sulphuric acid (2)

3.6.3 Calculate the number of moles of sulphuric acid in excess (2)

3.6.4 Calculate the concentration of hydronium ion in excess (2)

3.6.5 Calculate the pH of the solution (3)

NB!! YOU CAN BE ASKED TO CALCULATE THE pH OF THE SOLUTION WITHOUT BEING GIVEN SUB-QUESTIONS. ENSURE YOU FOLLOW THE SAME ROUTINE.

3 **Solution**

3.1 Titration/Volumetric analysis ✓ (1)

3.2 To measure the (exact) volume of acid needed to reach endpoint/to neutralise the base. ✓ (1)

3.3 Acids produce hydrogen ions (H^+)/hydronium ions (H_3O^+) in solution/water. ✓✓ (2)

3.4 H_2SO_4 ionises completely. ✓ (1)

3.5 Blue to yellow✓ (1)

3.6.1

OPTION 1	OPTION 2
calculate moles of the known substance	$\frac{c_a v_a}{c_b v_b} = \frac{n_a}{n_b}$ ✓ $\therefore \frac{0.1 v_a}{(0.1)(25)} = \frac{1}{2}$ ✓ $\therefore v_a = 0.125 dm^3$ ✓
$c_b = \frac{n}{V}$ ✓ $\therefore 0.1 = \frac{n}{0.025}$ ✓ $\therefore n_b = 2.5 \times 10^{-3} mol$	
use ratio to find moles of a required substance	
$n_a = \frac{1}{2} n_b = \frac{1}{2}(2.5 \times 10^{-3})$ ✓ $= 1.25 \times 10^{-3} mol$	
calculate what is required	
$c_a = \frac{n}{V}$ $\therefore 0.1 = \frac{1.25\times10^{-3}}{V}$ $\therefore V = 0.0125 dm^3$ ✓	

3.6.2 $n = c \times v = 0.1 \times 0.0175$ ✓ $= 1.75 \times 10^{-3} moles$ ✓ (2)

3.6.3 $n_{excess} = n_{initial} - n_{reacted}$ (2)

$\therefore n_{excess} = 1.75 \times 10^{-3} - 1.25 \times 10^{-3}$ ✓

$\therefore n_{excess} = 5 \times 10^{-4} moles$ ✓

3.6.4 $[H_3O^+] = 2(c_a) = 2\left(\frac{5 \times 10^{-4}}{4.25 \times 10^{-2}}\right) = 2 \times 1.18 \times 10^{-2}$ ✓ $= 2.36 \times 10^{-2} mol.dm^3$ ✓ (2)

3.6.5 $\text{pH} = -\log [H_3O^+]$ ✓ (3)

$= \log(2.36 \times 10^{-2})$ ✓

$= 1.63$ ✓

ACIDS AND BASES

QUESTION 1: **Multiple choice questions**

1.1 Consider the equilibrium $H_2SO_4 + HSO_3^- \rightleftharpoons HSO_4^- + H_2SO_3$.
The two Lowry-Brønsted bases are: (*conjugates*)

A HSO_4^- and H_2SO_4

B HSO_3^- and HSO_4^-

C HSO_3^- and H_2SO_3

D HSO_4^- and H_2SO_3 (2)

1.2 Water can act as either an acid or a base. Which equation represents water reacting as an acid? (*donating proton*)

A $H_2O(\ell) + NH_3(g) \rightleftharpoons OH^-(aq) + NH_4^+(aq)$

B $H_2O(\ell) + HC\ell(aq) \rightleftharpoons H_3O^+(aq) + Cl^-(aq)$

C $H_2O(\ell) \rightleftharpoons H_2(g) + ½O_2(g)$

D $H_2O(\ell) + C(s) \rightleftharpoons CO(g) + H_2(g)$ (2)

1.3 Consider the following equilibrium: $HC_2O_4^- + HCO_3^- \rightleftharpoons H_2CO_3 + C_2O_4^{2-}$
Which ONE of the following CORRECTLY identifies the order of Lowry-Brønsted acids and bases in the above reaction? (*conjugates*)

A Base, acid, acid, base

B Acid, base, base, acid

C Acid, base, acid, base

D Base, acid, base, acid (2)

1.4 Which ONE of the reactions below will produce the salt sodium ethanoate (sodium acetate)? (*acid and base salts formation*)

A $HC\ell(s) + CH_3COOH(aq) \rightarrow$

B $CH_3COOH(aq) + H_2O(\ell) \rightarrow$

C $CH_3COOH(aq) + NaOH(aq) \rightarrow$

D $H_2CO_3(aq) + NaOH(aq) \rightarrow$ (2)

1.5 If base P is titrated against acid Q, the pH of the solution at the end point is 9.
Which ONE of the following combinations CORRECTLY represents base P and acid Q? (2)

	BASE P	**ACID Q**
A	KOH	HNO_3
B	$NaHCO_3$	HCl
C	NH_3	H_2SO_4
D	NaOH	CH_3COOH

[10]

QUESTION 2 (*conjugates and ampholytes*)

NH_4^+ ions are mixed with HCO_3^- ions.

2.1 Write a balanced equation for the reaction that takes place (3)

2.2 Define the term conjugate acid−base pair (2)

2.3 Identify the two bases in the above reaction (2)

2.4 The hydrogen sulphate ion can act as both an acid and a base. It reacts with water according to the following balanced equation.

$$HSO_4^- + H_2O \rightarrow H_2SO_4 + OH^-$$

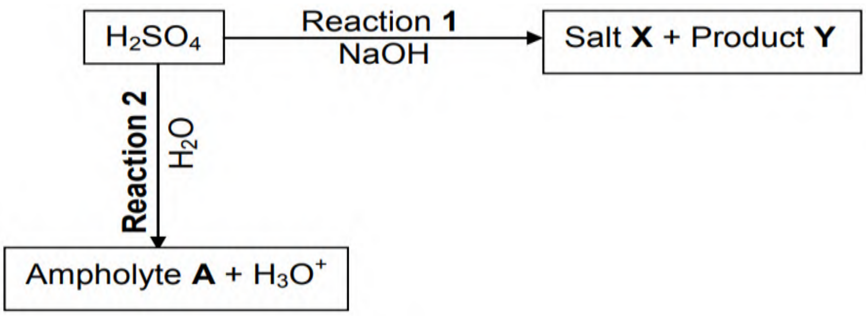
2.4.1 Write down ONE word for the underlined sentence (1)

2.4.2 Show with the aid of equations that HSO_4^- can act as a base or acid (4)

[12]

QUESTION 3 (*interpretation and stoichiometry calculations*)

3.1 Two reactions of sulphuric acid are shown in the diagram below.



3.1.1 Define a Lowry-Brønsted base. (2)

3.1.2 Write down a balanced equation for Reaction 1 (3)

3.1.3 Write down the NAME of the salt represented by X (2)

3.1.4 Write down the FORMULA of ampholyte A (2)

3.1.5 Write down the formulae of the TWO conjugate acid-base pairs in Reaction 2. (4)

3.2 A solution of sodium hydroxide (NaOH) is prepared by dissolving 6 g solid NaOH in 500 cm^3 water.
This solution reacts completely with 10 g impure ammonium chloride ($NH_4C\ell$) according to the equation below.

$NaOH(aq) + NH_4C\ell(s) \rightarrow NaC\ell(aq) + H_2O(\ell) + NH_3(aq)$

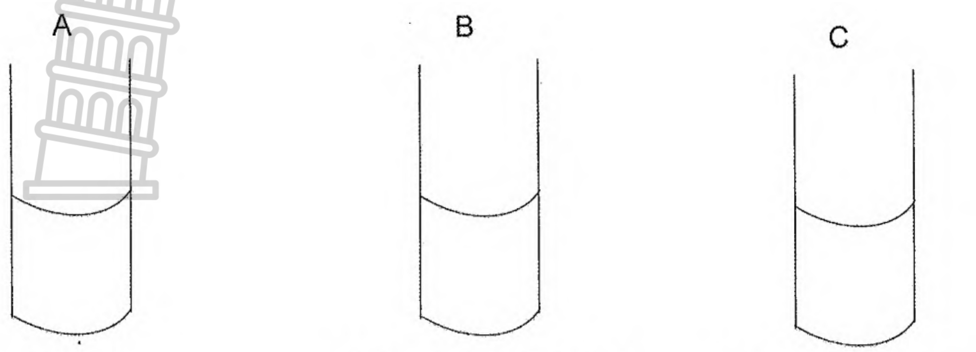
3.2.1 Calculate the concentration of the NaOH solution. (4)

3.2.2 Calculate the percentage impurities in the $NH_4C\ell$ (6)

[23]

QUESTION 4 (*Strength and titration stochiometry*)

Three test-tubes A ,B and C contain three solutions :HCl(aq), 0.12 mol.dm^{-3} CH_3COOH and 0.12 mol.dm^{-3} K_2CO_3 respectively as indicated below



HCℓ(aq) 0,12 mol.dm^{-3} CH_3COOH 0,12 mol.dm^{-3} K_2CO_3

4.1 Which of these solutions

4.1.1 Is a strong acid (1)

4.1.2 Is an organic acid (1)

4.1.3 Will turn red litmus paper blue (1)

4.2 Solution A is formed when hydrogen chloride gas is added in water

4.2.1 Write down the balanced equation for the reaction taking place here (3)

4.3 You are required to prepare 200 cm^3 of solution C. Calculate the mass of solute that must be used. (4)

4.4 In a titration ,25.10 cm^3 of solution B is neutralised by unknown volume of solution C in the presence of an indicator.

The following reaction takes place.

$$2CH_3COOH\,(aq) + KOH\,(aq) \rightarrow 2CH_3COOK(aq) + H_2O(\ell) + CO_2(g)$$

4.4.1 What is an indicator (1)

4.4.2 Calculate the volume of solution C that was neutralised (4)

4.5 Write down the balance equation for each of the following reactions using appropriate chemical formulae

4.5.1 Magnesium + solution A (4)

4.5.2 $MgO + H_2O \rightarrow$ (2)

4.6 You are required to prepare some sodium sulphate in the laboratory using acid and a base.

4.6.1 Name the acid and base that you would use. (2)

4.6.2 Write down the balanced equation for the reaction that will take place (3)

[26]

QUESTION 5 (pH calculations and diprotic acid)

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

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

5.2.1 Write down the FORMULA of the conjugate base of H_2CO_3(aq). (1)

5.2.2 Write down a balanced equation for the first step in the ionisation of carbonic acid. (3)

5.2.3 The pH of a carbonic acid solution at 25 °C is 3,4. Calculate the hydronium ions concentration in the solution. (3)

[9]

QUESTION 6 (pH calculations)

6.1 A laboratory technician prepares the following two dilute nitric acid solutions:

0,20 mol.dm^{-3} HNO_3 solution ……………………...(I)

0,30 mol.dm^{-3} HNO_3 solution ……………………...(II)

6.1.1 Distinguish between a *concentrated acid* and a *dilute acid*. (2)
6.1.2 Give a reason why nitric acid is classified as a strong acid. (2)
6.1.3 Determine the pH of solution (**I**) at 25 °C . (3)
[7]

IDEAL GASES AND THERMAL PROPERTIES

According to the Kinetic Molecular Theory (KMT), molecules of a gas:

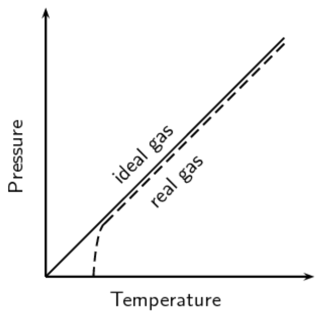
- Have the highest kinetic energy (move the fastest with different speeds)
- Are further apart, forces of attraction are very weak
- Easy to compress
- Exert pressure when they collide with each other and the sides of the container
  - Pressure is the force per unit area. $p=\frac{F}{A}$ (p ∝number of collisions)

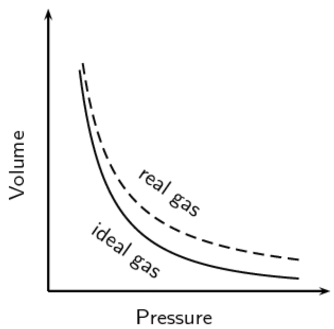
Ideal Gases
Molecules of an ideal gas:

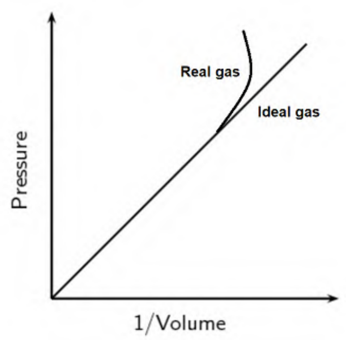
- Are identical and in constant motion
- Are very small and do not occupy a volume (Gas volume is determined by the volume of the container)
- Exert no forces on each other and the sides of the container, except when they collide with each other or the sides of the container
- Collisions are elastic (No energy is lost)
- Exert no pressure at 0K (0K – Absolute zero, the lowest possible temperature)

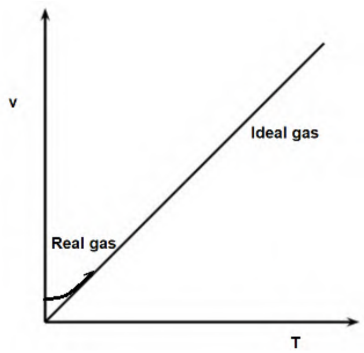
Temperature: The measure of the average kinetic energy of particles.
NB. T(K) = T(°C) + 273 T(°C) = T(K) – 273

Non-Ideal/ Real Gases deviate from ideal gas behaviour at: High Pressure and low temperature









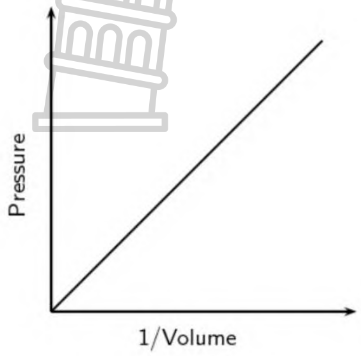
At **High Pressure** real gases occupy a volume. Gas molecules become compressed and are closer to each other. Forces of repulsion between molecules become strong. Volume is higher than predicted.
At **Low Temperature** gases liquefy. Forces of attraction between molecules become strong. Gas molecules occupy a volume, volume is higher than predicted.

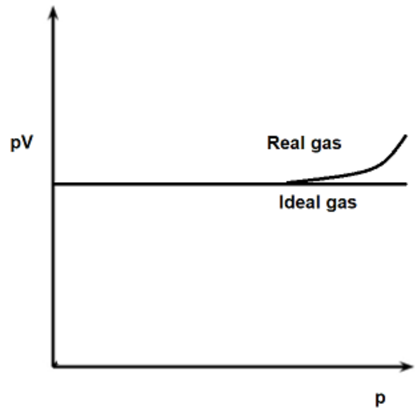
Real gases act like ideal gases at (1) High Temperature and (2) Low Pressure

At high temperature: The gas molecules have higher average kinetic energies, they move faster and further apart so that attractive forces become very weak.
At low pressure: Gas molecules move further apart, the forces of attraction are negligible, gas molecules will not contribute to the volume.

Boyle's Law
The pressure of an enclosed gas is inversely proportional to the volume it occupies at a constant temperature.

$p \propto \frac{1}{V}$

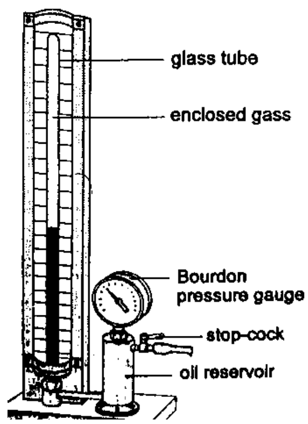




gradient=pV
k=pV
units of k=Pa × m^3
units of k=$N.m^{-2}$ × m^3
units of k =N.m
units of k=J

Boyle's Law Equation: $p_1V_1=p_2V_2$

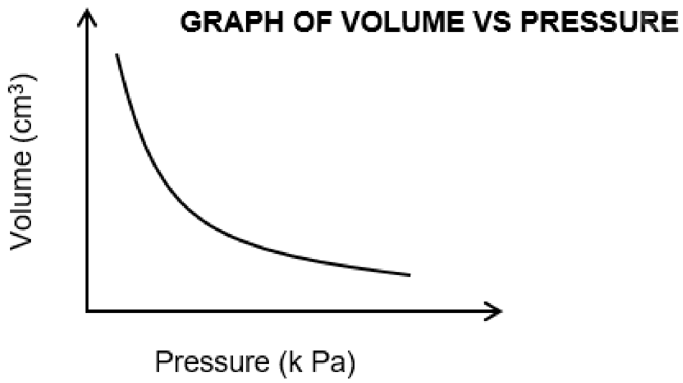
Common conversions:
kPa=1000 Pa $1cm^3=10^{-6}m^3$ $1dm^3=10^{-3}m^3$



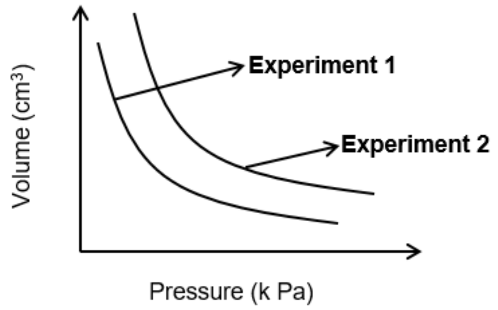
Boyle's Law Apparatus

WORKED EXAMPLES
WORKED EXAMPLE 1.
An experiment was conducted to investigate the relationship between pressure and volume of a fixed gas at a constant temperature of 20,5 °C.

The following graph was obtained from the results.



1.1. Write down the name of the law which formulates the pressure-volume relationship shown by the graph. (1)
Boyle's Law✓
1.2. Write down the investigative question for this experiment. (2)
What is the relationship between pressure and volume of enclosed gas at constant temperature?✓✓
1.3. The experiment is repeated at a different temperature. The results of the experiment are plotted on the same axis. (3)

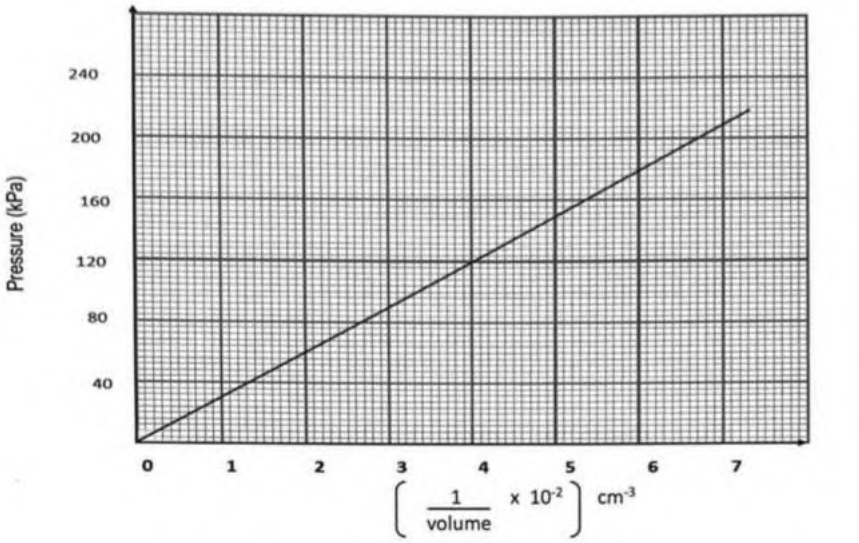


Which experiment (1 or 2) was carried out at a HIGHER temperature? Explain your answer.
Experiment 2 ✓
Kinetic energy of the molecules will be higher and they will move more freely ✓ *increasing the volume.* ✓

1.4. Explain why real gases deviate from ideal gas behaviour at high pressure. (2)
They occupy a volume ✓ *and intermolecular forces become significant.* ✓

WORKED EXAMPLE 2.

A group of learners perform an experiment to verify a gas law. The results are shown in the graph of pressure versus inverse of volume drawn below.



2.1. Write a suitable hypothesis for the experiment. (2)
As the volume of a fixed mass of gas increases, the pressure decreases. ✓✓

2.2. For this experiment, identify the following:

2.2.1 Two controlled variables (2)
Mass of gas ✓ *Temperature* ✓

2.2.2 Dependent variable (1)
Pressure ✓

2.3. Calculate the volume occupied by the gas when the pressure exerted by the gas is 200 kPa. (3)

At 200 kPa: $\frac{1}{V}=6{,}7 \times 10^{-2}$ ✓

$\therefore v=\frac{1}{6{,}7 \times 10^{-2}}$ ✓

$v=14{,}93 \text{ cm}^3$ ✓

2.4. Determine the pressure exerted by the gas when its volume is 11,11 cm³. (3)

$p_1V_1=p_2V_2$ ✓

$(120)(25)= p_2(11{,}11)$ ✓ *Or any other correct combinations from the graph)*

$p_2=270{,}03$ kPa ✓

2.5. State two properties of an ideal gas. (2)
Any two ✓✓
Are identical; Occupy no volume; Exert no forces on each other, except during collisions; All collisions are elastic

WORKED EXAMPLE 3.

A sealed gas syringe laying on a table contains 80 cm^3 of air. The plunger is air-tight, but moves freely. The atmospheric pressure is 100 kPa.

3.1 What is the pressure of the gas in the syringe? (1)

100 kPa ✓

3.2 What additional pressure has to be applied on the plunger so that the air is compressed to a volume of 50 cm^3 while the temperature remains constant? (3)

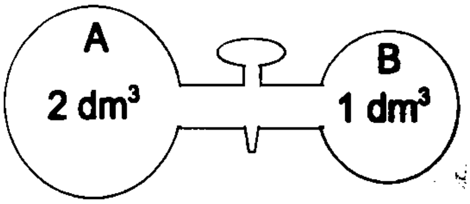
$p_1V_1=p_2V_2$ ✓

$(100)(80)= p_1(50)$ ✓

$p_1=160$ kPa ✓

WORKED EXAMPLE 4.

4.1 The diagram depicts two containers that are connected by a tube with a closed stopcock. Container A contains air at a pressure of 100 kPa. Container B is void of air. What will the pressure in both containers be when the stopcock is opened, while the temperature remains constant? (3)



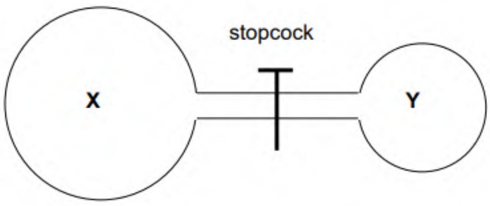
$p_1V_1=p_2V_2$ ✓

$(100)(2)= p_2(3)$ ✓

$p_2=66,67$ kPa ✓

MULTIPLE CHOICE QUESTIONS

1 The sketch shows two containers, X and Y, connected by a tube containing a closed stopcock. (2)



The volume of container X is V and contains a gas at a pressure p. Container Y is evacuated. The volume of the tube is negligible. When the stopcock is opened at constant temperature the pressure of the gas in container X changes to $\frac{3}{4}$ p. What is the volume of container Y?

A $\frac{1}{3}$ V

B $\frac{2}{3}$ V

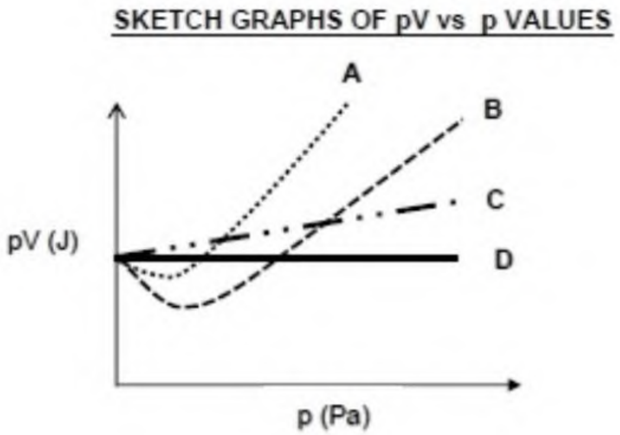
C $\frac{3}{4}$ V

D $\frac{4}{3}$ V

2 Air in a gas syringe is compressed to half its original volume while the temperature remains constant. Which one of the following combinations are CORRECT regarding the gas pressure and the average speed of gas particles? (2)

	Pressure	**Average Speed of Gas Particles**
A	Increases	Decreases
B	Decreases	Increases
C	Increases	Remains constant
D	Decreases	Remains constant

3 The graphs below for four gases: He, CO, CH_4 and an ideal gas are shown below. Which graph CORRECTLY depicts He gas? (2)



4 In an experiment to verify Boyle's Law, learners are advised to wait for the oil on the inside of the glass tube to run down the sides because … (2)

A it is a precaution to maintain constant temperature
B it allows for the pressure gauge to recalibrate
C it allows the oil to settle
D the gas needs to escape

5 The graph of p versus $\frac{1}{v}$ is a straight line through the origin. The relationship between p and v is … (2)

A a linear relationship
B directly proportional
C equivalent to each other
D inversely proportional

[10]

QUESTION 1

1. A certain amount of gas is sealed in a container of which the volume can change.
The relationship between the pressure and volume of the gas at 20 °C is investigated. The results of the experiment are given in the table below.

PRESSURE (kPa)	VOLUME (dm^3)
70	174
95	128
130	93,6
165	74
205	59
240	51
260	47

1.1. Name the gas law that is represented by the results of the experiment. (1)
1.2. Write down a hypothesis for the investigation. (2)
1.3. Draw a graph of volume versus pressure. (3)
1.4. Calculate the volume of the gas at 300 kPa. (3)
1.5. When the volume of the gas is measured at 300 kPa, it is 44 dm^3. Explain why the measured volume differs from the volume calculated in QUESTION 1.4. (2)

1.6. Which temperature condition will cause a gas to deviate from ideal behaviour? Write only HIGH or LOW. Explain your answer (3)

1.7. Calculate the number of moles of the gas in the container at the INITIAL pressure and volume. (4)

[18]

QUESTION 2

2. The relationship between pressure and volume of an enclosed gas at 25 °C is investigated. The results obtained are shown in the table below.

PRESSURE (kPa)	VOLUME (m^3)	$\frac{1}{V}$ (m^{-3})
50	0,121	8,2
80	0,076	13,2
125	0,049	20,6
140	0,043	23,1
175	0,035	28,8

2.1. State Boyle`s law in words (2)

2.2. Use the data in the table above to draw a graph of pressure (p) versus the inverse of the volume ($\frac{1}{v}$). (4)

2.3. Which physical quantity can be determined from the gradient of the graph? Give a reason for your answer. (2)

2.4. It is found that, at high pressures, the shape of the graph deviates from that of the graph obtained in question 2.2. Explain this deviation. (3)

[13]

QUESTION 3

3. A group of learners investigate the relationship between pressure and the volume of an enclosed gas at room temperature. They recorded their result in the table below:

Pressure (kPa)	Volume (cm^3)
100,33	7,34
102,2	7,21
103,93	7,09
X	6,97

3.1. For this investigation write down the :

3.1.1. Name of the gas law that is being investigated (1)

3.1.2. Controlled variable (1)

3.1.3. Relationship between pressure and volume of the gas as described by the first 3 data sets in the table. (2)

3.2. Calculate the value of **X.** (4)

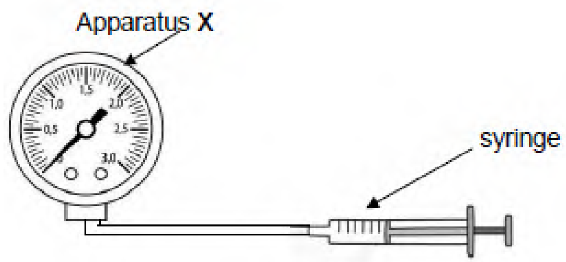
3.3. Write down TWO conditions under which real gases behave more like an ideal gas. (2)

3.4. Write down the NAME of a gas whose behaviour is close to that of an ideal gas, under the conditions mentioned on QUESTION 3.3. above. (1)

[11]

QUESTION 4

4. A group of learners investigate the relationship between the pressure and the volume of a gas. The gas syringe is connected to apparatus **X** as shown below.



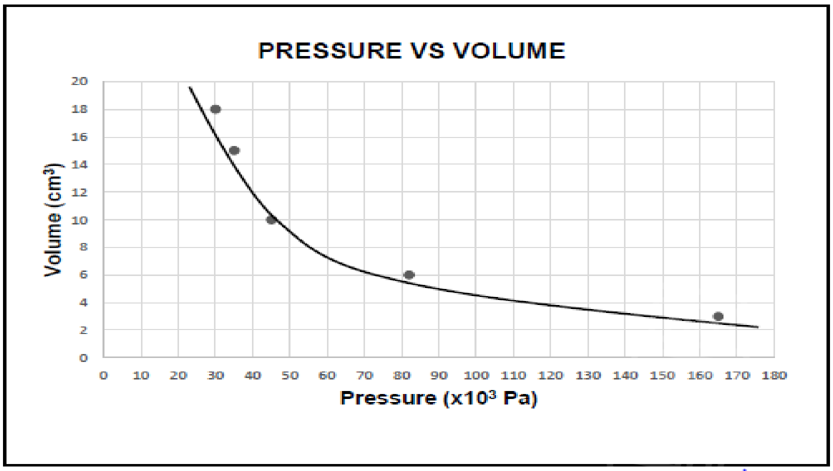
The learners vary the volume and record the pressure and volume. They calculated the inverse of the volume and recorded it with its pressure readings in the table shown below.

	Pressure (kPa)	1/volume (cm^{-3})
1	92,5	0,05
2	111	0,06
3	129,5	0,07
4	148	0,08

4.1. Write down the mathematical relationship between pressure and volume. (1)
4.2. For this investigation, write down ONE controlled variable. (1)
4.3. Give the name of apparatus **X**. (1)
4.4. Use the data in the table and draw a pressure against $\frac{1}{\text{volume}}$. (4)
4.5. Using the information from the graph write down the learner`s conclusion. (2)
4.6. Calculate the volume of the gas at pressure of 184 kPa. (4)
[13]

QUESTION 5

5. Learners investigated the relationship between pressure and volume of a gas. The graph below shows the results obtained during the investigation.



5.1. Name and state the law the experiment is based on. (3)
5.2. Write down the hypothesis for this investigation. (2)
5.3. Read and write down the pressure from the graph when the volume is 12 cm^3. (1)
5.4. Calculate the volume at 200 kPa. (4)
5.5. The above graph has been recopied, label it **A** on same set of axes and draw the graph to show how real gas will deviate at high pressure. Label this graph **B**. (3)
[12]

REDOX REACTIONS
Definitions and Key Concepts

Oxidation numbers of atoms in molecules

- Explain the meaning of oxidation number.
- Assign oxidation numbers to atoms in various ions and molecules, e.g. H_2O, CH_4, CO_2, H_2O_2 and HOCℓ, by using oxidation number guidelines or rules.

Redox reactions

- Describe a redox (oxidation-reduction) reaction as involving electron transfer.
- Describe a redox (oxidation-reduction) reaction as always involving changes in oxidation numbers.
- Identify a redox reaction and apply the correct terminology to describe all the processes:
  Oxidation: A loss of electrons. /An increase in oxidation number.
  Reduction: A gain of electrons. /A decrease in oxidation number.
  Reducing agent: A substance that is oxidised/that loses electrons/whose oxidation number increases.
  Oxidising agent: A substance that is reduced/that gains electrons/whose oxidation number decreases.

Balance redox reactions by using half-reactions from the Table of Standard Reduction Potentials (Tables 4A and 4B).

- An **electrolyte** is a substance of which the aqueous solution contains ions OR a substance that dissolves in water to give a solution that conducts electricity.
- **Electrolysis** is the chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change

Summary of notes

OIL: Oxidation is loss
RIG: Reduction is gain

LEO: Loss of electrons is oxidation
GER: Gain of electrons is reduction

In order to keep track of the electrons during a chemical reaction oxidation numbers are assigned to each element in the reaction. The oxidation number is similar to the valency of the element.

Rules for assigning oxidation numbers

1. Pure elements and diatomic elements (eg. O_2) = 0.
2. Hydrogen = +1 (except when bonded to a metal, then −1).
3. Oxygen = -2 (except peroxides, eg. H_2O_2, = −1). (When bonded to fluorine, = +2).
4. Metals = group number, i.e. group 1=+1; group 2 =+2; group 3=+3
5. The oxidation number of monoatomic ions is the same as its charge. eg. Zn^{2+}: Zn = +2
6. Group 17 elements = −1.
7. The oxidation number of transition metals is indicated by stock notation. eg. iron (III): Fe = +3
8. In a neutral compound, the sum of the oxidation numbers is 0.
9. In a polyatomic ion the sum of the oxidation numbers is equal to the charge of the ion.

REPRESENTING REDOX REACTIONS

Redox reactions can be shown in two half-reactions showing the transfer of electrons. Oxidation half-reaction: $X \rightarrow X^{2+} + 2e^-$ (electrons are shown as products)

Reduction half-reaction: $Y^{2+} + 2e^- \rightarrow Y$ (electrons are shown as reactants)

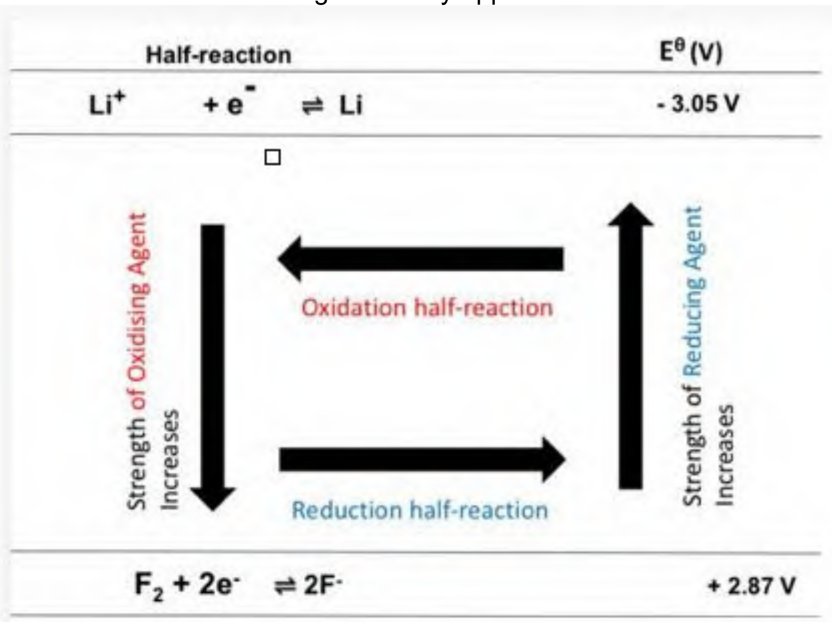
Nett ionic reaction: $X + Y^{2+} \rightarrow X^{2+} + Y$ (no electrons are shown in the nett reaction)

NOTE: The number of electrons in the two half reactions must balance

Redox reactions may be balanced by using half reactions from the table of Standard reduction potentials.

The half- reaction are given on the table of Standard Reduction Potentials, and they are balanced. What you need to do is to identify which substance is reduced or oxidised.

Half – reactions (using table)
Oxidation half-reaction are written from right to left (from products to Reactants)
Reduction half-reaction are written from left to right. As they appear on the table.



The double arrows in the half-reactions indicate that the left hand side can be reduced and the right hand side can be oxidised. Oxidation or reduction takes place depending on what is reacting. From the given information, the half-reactions must be constructed. When writing a half-reaction, use one arrow.

Example1: Oxidation half-reaction: $Li \longrightarrow Li^+ + e^-$

Reduction half-reaction: $Cu^{2+} + 2\,e^- \longrightarrow Cu$

Example2: $MnO_4^- + 8\,H^+ + 5\,e^- \longrightarrow Mn^{2+} + 4\,H_2O$

From the equation give above the oxidation number of Mn in MnO_4^- is +7, from the reaction the oxidation number of Mn decrease from +7 to 2+. Mn^{7+} gained 5 electrons to reduce the oxidation number to 2+. The 5 electrons appears on the equation is the difference of the oxidation numbers of Mn on the reactants and on the products.

Worked Example 3

1.1 Give the oxidation number of both elements in ammonia (NH_3) (3)

2.1 Determine the oxidation number of : (2)

2.1.1 Sulphur in sulphate (SO_4^{2-}) ion. (2)

2.1.2 Chromium in $Cr_2O_7^{2-}$. (2)

2.1.3 Oxygen in H_2O_2 (2)

2.1.4 Oxygen in O_2 (1)

[12]

Consider the following UNBALANCED equation below:

3.1 $Fe^{2+}\,(aq) + Cl_2\,(g) \longrightarrow Fe^{3+}\,(aq) + Cl^-\,(aq)$

Define the term *reducing agent* with reference to electron transfer. (2)

3.2 From the above reaction, write down the:

3.2.1 FORMULA of the reducing agent. (1)

3.2.2 FORMULA of the oxidizing agent. (1)

3.2.3 Reduction half-reaction. (2)

3.2.4 Oxidation half-reaction. (2)

3.2.5 Balanced net redox reaction. (2)

[14]

Solutions (Worked examples)

1.1 $x+3(1)=0$✓
$x+3=0$
$x=-3$✓
∴ The oxidation number of Nitrogen is -3 and the oxidation number for hydrogen is +1✓ from the rules. (3)

2.1.1 $x+(-8)=-2$✓
$x=-2+8$ (2)
$x=+6$✓
∴ The oxidation number of Sulphur in sulphate (SO_4^{2-}) ion is +6

2.1.2 $2(x)+7(-2)=-2$✓ (2)
$x=+6$
Oxidation number of Cr in $Cr_2O_7^{2-}$ = + 6 ✓

2.1.3 $2(1)+2(x)=0$✓ (2)
$2x=-2$
$x=-1$
∴ The oxidation number of oxygen in H_2O_2 is −1) ✓

2.1.4 O_2 is a pure element. Therefore, the oxidation number of oxygen in O_2 is 0✓ (1)

3.1 A reducing agent loses electrons. ✓✓ (2)

3.2
3.2.1 Fe^{2+} (aq) ✓ (1)
3.2.2 Cl_2 (g) ✓ (1)
3.2.3 Cl_2 (g) + 2e⁻ ⟶ 2Cl⁻ (aq) ✓✓ (2)
3.2.4 Fe^{2+} (aq) ⟶ Fe^{3+} (aq) + e⁻ ✓✓ (2)
3.2.5 $2Fe^{2+}$ (aq) + Cl_2 (g) ⟶ $2Fe^{3+}$ (aq) + $2Cl^-$ (aq) ✓✓ (2)

[14]

REDOX REACTIONS ACTIVITIES

Multiple choice questions

QUESTION 1 [10 marks]

1.1 Oxidation takes place when the …
A Reducing agent loses electrons.
B Oxidising agent loses electrons.
C Reducing agent gains electrons.
D Oxidising agent gains electrons. (2)

1.2 Consider the reaction below.

$$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$$

Which substance is the oxidising agent?
A Zn
B Cu^{2+}
C Zn^{2+}
D Cu (2)

1.3 The oxidation number of phosphorus in H_3PO_4 is …
A +3
B -2
C 2
D 5 (2)

1.4 The oxidation number of sulphur in HSO_4^- is ….
A +2
B +6
C +1
D +4 (2)

1.5 Consider the following redox reaction:
$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$
Electrons are transferred from …
A Zn (s) to Zn^{2+} (aq).
B Cu^{2+} (aq) to Cu (s).
C Zn(s) to Cu^{2+} (aq).
D Zn^{2+} (aq) to Cu (s). (2)

Redox Reactions Long Questions
QUESTION 2 [13 marks]
A silver Christmas tree can be made by placing copper wire, shaped in the form of a tree, into a silver nitrate solution. The unbalanced equation for the reaction is:

$Cu(s) + AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + Ag(s)$

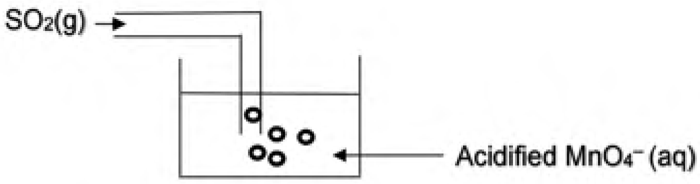
2.1 Define the term *oxidation* in terms of oxidation numbers. (2)
2.2 Write down the following for the reaction above:
2.2.1 Formula of the reducing agent (2)
2.2.2 Name of the oxidising agent (2)
2.2.3 Oxidation half-reaction (2)
2.2.4 Balanced net ionic equation using the ion-electron method (3)
2.3 Use oxidation numbers to explain your choice of oxidising agent in QUESTION 2.2.2. (2)

QUESTION 3 [17 marks]
3.1 A clean piece of copper (Cu) is placed in a solution of silver nitrate ($AgNO_3$).
The balanced net ionic equation is:

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

3.1.1 Define reduction in terms of electrons transfer. (2)
3.1.2 What type of reaction does copper undergo in the above reaction? Choose from OXIDATION or REDUCTION. Explain your answer. (3)
Write down the:
3.1.3 Formula or Name of the spectator ions in the reaction. (1)
3.1.4 Reduction half reaction. (2)

3.2 Sulphur dioxide gas (SO_2) is bubbled in an acidified solution of potassium permanganate as shown in the diagram below.



It is observed that the solution turns from purple to colourless due to the reduction of MnO_4^- ions to Mn^{2+} ions. During the reaction, SO_2 is oxidized to sulphate ions (SO_4^{2-})
3.2.1 Determine the oxidation number of sulphur, S in SO_4^{2-}. (2)
Write down the:
3.2.2 Oxidation half reaction (2)
3.2.3 Balanced net ionic equation using the half reaction method (5)

QUESTION 4 [13 marks]
The reaction between dichromate ions ($Cr_2O_7^{-2}$) and iron (II) ions (Fe^{2+}) in an acidic medium is given below.

$Cr_2O_7^{-2}(aq) + Fe^{2+}(aq) + H^+(aq) \rightarrow Cr^{3+}(aq) + Fe^{3+}(aq) + H_2O(\ell)$

4.1 Determine the oxidation number of CHROMIUM in $Cr_2O_7^{-2}$(aq). (2)
4.2 Define *reduction* in terms of electron transfer. (2)
4.3 Write down the FORMULA of the substance that undergoes oxidation. Explain the answer in terms of oxidation numbers. (2)
4.4 Write down the FORMULA of the oxidising agent. (2)
4.5 Write down the reduction half-reaction. (2)
4.6 Write down the net balanced ionic equation for the reaction, using the ion-electron method. (3)

QUESTION 5 [14 marks]

The unbalanced equations for two redox reactions, in which SO_2 is involved, are shown below.

Reaction 1: $SO_2(g) + H_2S(g) \rightarrow S(s) + H_2O(\ell)$

Reaction 2: $SO_2(g) + KMnO_4(s) + H_2O(\ell) \rightarrow MnSO_4(aq) + K_2SO_4(aq) + H_2SO_4(aq)$

5.1 Explain what is meant by the term *redox reaction*. (2)

5.2 Write down the oxidation number of Mn in:

5.2.1 $KMnO_4$ (1)

5.2.2 $MnSO_4$ (1)

5.3 Is MnO_4^- in **Reaction 2** OXIDISED or REDUCED? Give a reason for the answer. (2)

5.4 In which reaction, **Reaction 1** or **Reaction 2**, does SO_2 act as an oxidising agent? Give a reason for the answer. (2)

5.5 Write down the oxidation half-reaction in **Reaction 1** (2)

5.6 Use the Table of Standard Reduction Potentials and write down the balanced net ionic equation for **Reaction 1**. Show the half-reactions and how you arrived at the final equation. (4)