KWAZULU-NATAL PROVINCE

EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS)

LEARNER SUPPORT DOCUMENT

GRADE 11

PHYSICAL SCIENCES

2026

PREFACE

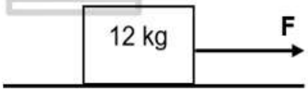
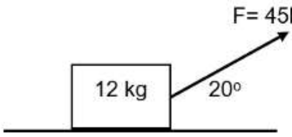
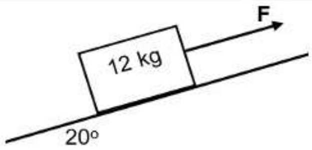
This support document serves to assist Physical Sciences learners on how to deal with curriculum gaps and learning losses. It addresses all the topics in the Grade 11 curriculum.

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:

DIFFERENT KIND OF FORCES AND NEWTON'S LAWS-GRADE 11

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).

		
$N = F_g = mg$ $= 12 \times 9,8$ $= 117,6$ N	$N = F_g - F_y = mg - F\sin\alpha$ $= 12 \times 9,8 - 45 \times \sin 20^\circ$ $= 102,21$ N	$N = F_{g\perp} = mg\cos\theta$ $= 12 \times 9,8 \times \cos 20^\circ$ $= 110,51$N

- **Frictional force** –
  Friction is the parallel component of the contact force on an object by the surface on which it rests or moves.

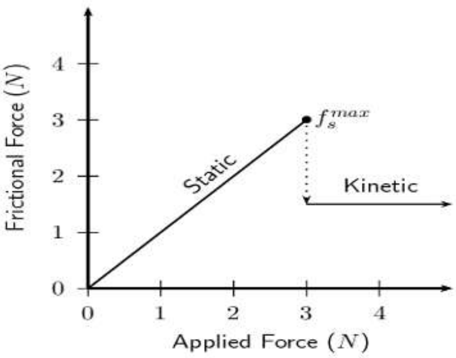
There are two types of friction: Static friction (μs). and kinetic friction (μk).

Static 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:
$f_s^{max} = \mu_s.N$

Kinetic friction

Kinetic friction is the force that opposes the motion of a moving
object relative to a surface.
Kinetic friction is calculated as:
$f_k = \mu_k.N$



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.

1. **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.

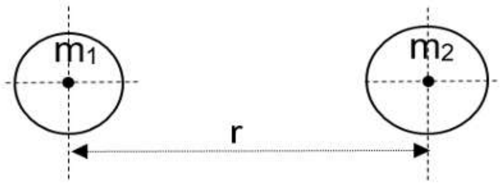
Fnet ≠ 0 N → Velocity ≠ 0 m.s^{-1} ($v_i \neq v_f$) a ≠ 0 m.s^{-2} → Object accelerates ($a = \frac{F_{net}}{m}$)

- **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.

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

Forces $F_{A\text{ on }B}$ and $F_{B\text{ on }A}$ 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.

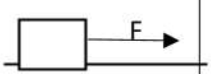
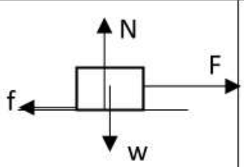
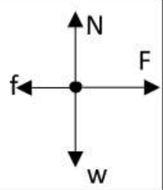
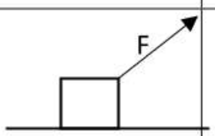
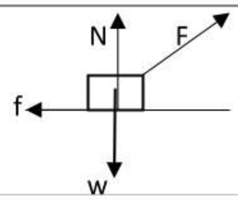
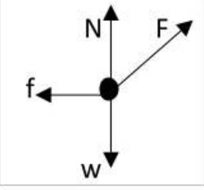


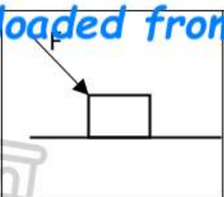
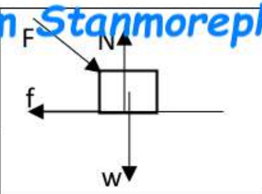
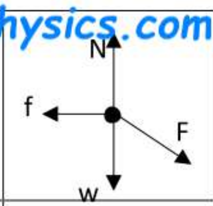
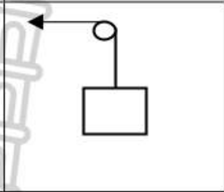
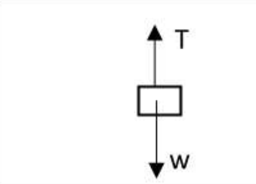
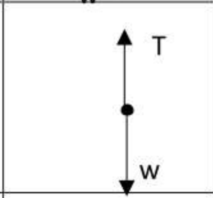
$$F = \frac{G.m_1.m_2}{r^2}$$

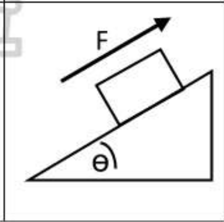
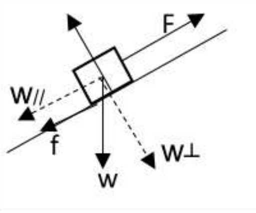
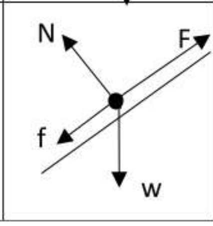
F: Gravitational force (N)
m₁, m₂: Masses (kg)
r: Distance from centres (m)
G: Gravitational constant

- **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

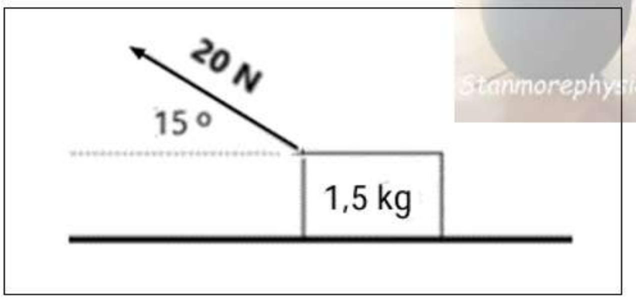
MCQ Questions

1.1 A passenger in a car continues moving forward when the brakes are suddenly applied because of:

A. Zero resultant force
B. Inertia
C. Equal and opposite
D. Forward resultant force (2)

B√√

1.2 A box of 1,5 kg is being pulled with a force of 20 N at an angle of 15° to the horizontal, as shown in the diagram. The normal force is ....

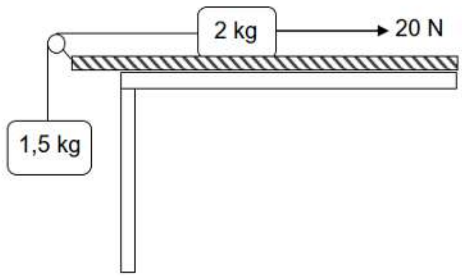


A. 14,70 N
B. 9,52 N
C. 19,88 N
D. 5,18 N (2)

B√√

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)

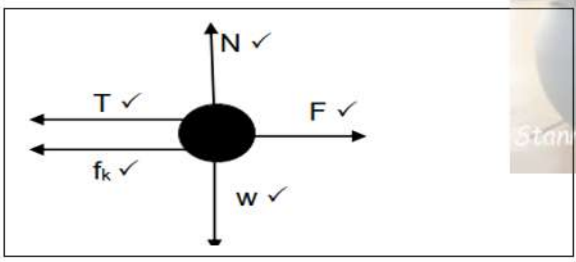
1.4 Calculate the magnitude of tension in the string. (2)

[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

$16{,}9 - 2a = 1{,}5a + 14{,}7$ ✓ (6)

$2{,}2 = 3{,}5a$ a= $0.63\,m.s^{-2}$ ✓

1.4 $T = 16{,}9 - 2a$

$T = 16{,}9 - 2\,(0{,}63)$ ✓

$T = 15.64$ N ✓

OR

$T = 1{,}5a + 14{,}7$

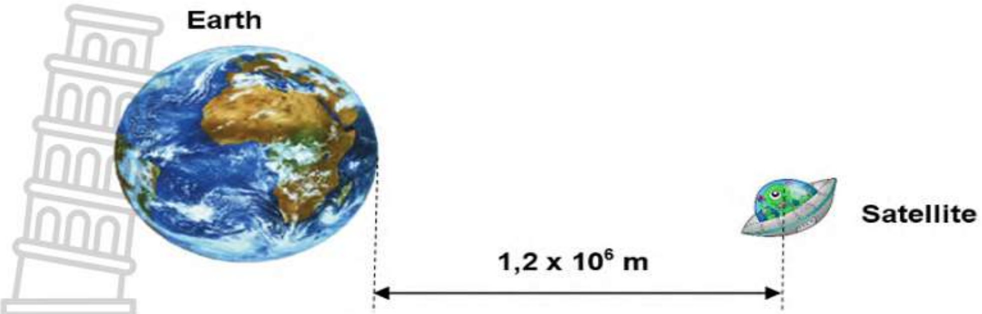
$T = 1{,}5\,(0{,}63) + 14{,}7$

$T = 15{,}64$ N (2)

[15]

QUESTION 2

A satellite of mass 1000 kg is orbiting the earth at a distance of 1 200 km from the earth's surface.



2.1 How does the force which the earth exerts on the satellite compare with the force that the satellite exerts on the earth? Answer only GREATER THAN, LESS THAN or EQUAL TO. And State the relevant physics law that you applied to answer the question. (3)

2.2 State Newton's law of universal gravitation in words. (2)

2.3 Calculate the force that the earth exerts on the satellite to keep it in orbit. (3)

2.1 The mass and radius of the planet A are 7,35 x 1022 kg and 1 737 km respectively. Calculate the acceleration due to gravity on planet A. (4)

[12]

SOLUTIONS

2.1 Equal to. ✓ When object A exerts a force on object B, object B simultaneously exerts an oppositely directed force of equal magnitude on object A. ✓ ✓ (3)

2.2 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. ✓ ✓ (2)

2.3.1

$$F = \frac{GM_1M_2}{d^2} \checkmark$$

$$F = \frac{6{,}67 \times 10^{-11} \times 5{,}98 \times 10^{6} \times 1\,000}{(6{,}38 \times 10^{6} + 1{,}2 \times 10^{6})^2} \checkmark$$

$$F = 6{,}94 \times 10^{-15} \text{ N} \checkmark$$

(3)

2.3.2 (4)

$$g = \frac{GM}{d^2} \checkmark$$

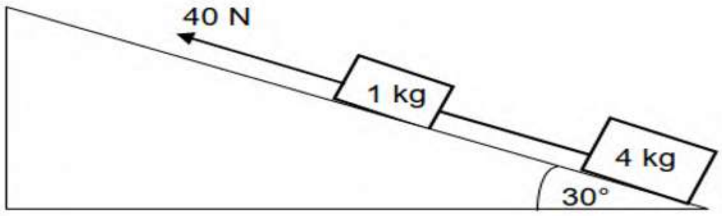
$$g = \frac{6{,}67 \times 10^{-11} \times 7{,}35 \times 10^{22}}{(1{,}737 \times 10^{6})^2 \checkmark} \checkmark$$

$$g = 1{,}62 \text{ m.s}^{-2} \checkmark$$

[12]

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)

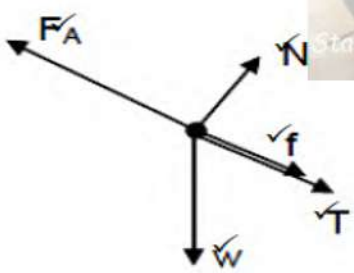
3.3.2 Tension in the string connecting the two blocks. (6)

[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

$T - (mg \sin \theta + f_k)$ ✓ $= 4a$✓

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

$T - 29,6 = 4a$ …………. (2)

From (1) and (2)

. $a = 0,61$ m.s^{-2} ✓

$T = 29,6 + 4(0,61)$ ✓

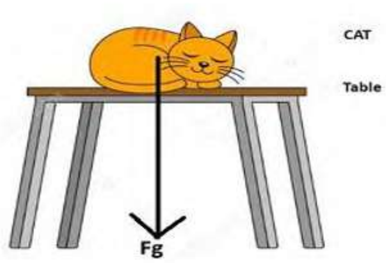
[16]

ACTIVITIES: DIFFERENT KIND OF FORCES AND NEWTON'S LAWS GRADE 11

MCQ Questions

QUESTION 1

1.1 A cat is sleeping on top of a fixed table. The gravitational force experienced by the cat if represented as F_g. The reaction force to the gravitational force on the cat is …



A. The force of the table on the cat.

B. The force of the cat on the table.

C. The force of the cat on the Earth.

D. The force of the Earth on the cat. **(2)**

1.2 Two planets in the Universe, X and Y, have the same mass. The diameter of planet Y is twice that of planet X. The distance between the centers of the two planets is represented as r. The gravitational force between the two planets is F. Which of the following changes will not affect the magnitude of the force F?.

A. Double the mass of both planets and half the distance between the planets.

B. Half the mass of both planets and double the distance between the planets.

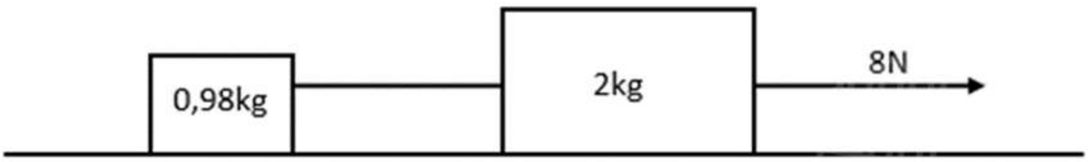
C. Double the mass of both planets and triple the distance between the planets.

D. Half the mass of both planets and half the distance between the planet. **(2)**

STRUCTURED QUESTIONS

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)

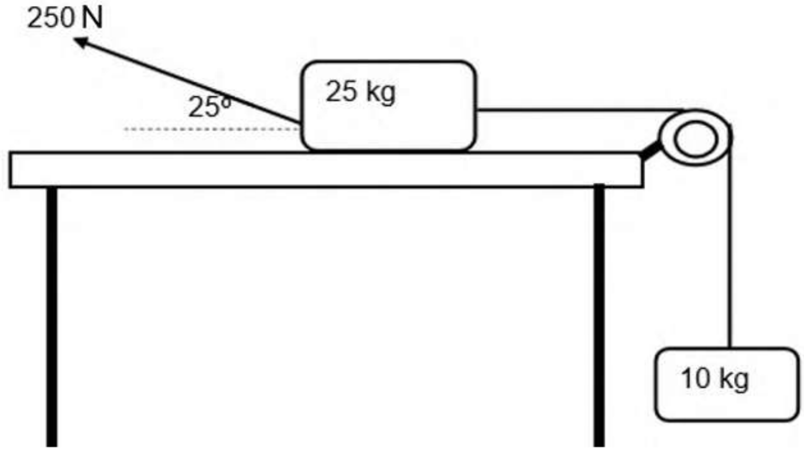
1.3 Determine the tension in the string. (3)

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)

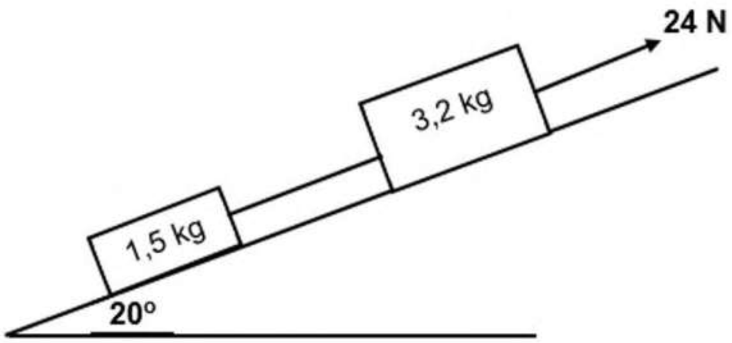
[17]

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.

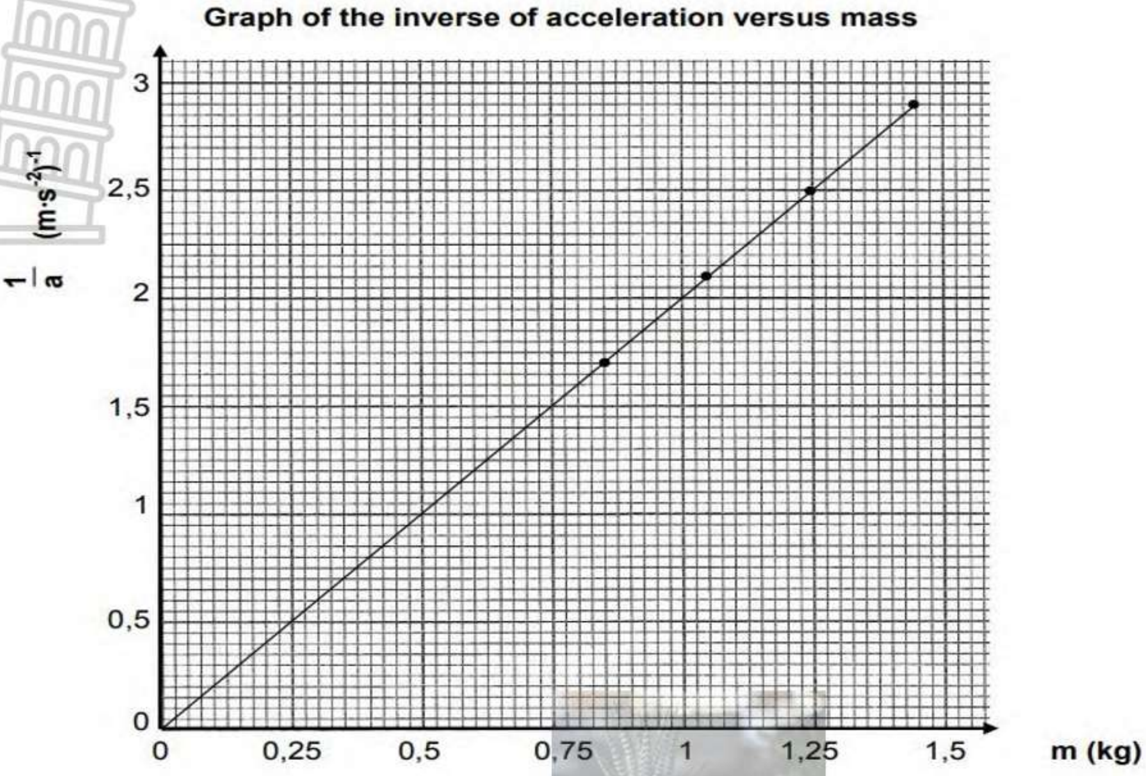


3.1	State Newton's Second Law of Motion in words.	(2)
3.2	Draw a labelled free-body diagram of all forces acting on the 1,5kg block.	(4)
3.3	Calculate the:	
3.3.1	Tension in the string connecting the blocks	(5)
3.3.2	Coefficient of kinetic frictional force between the 3,2kg block and the surface	(6)

[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.



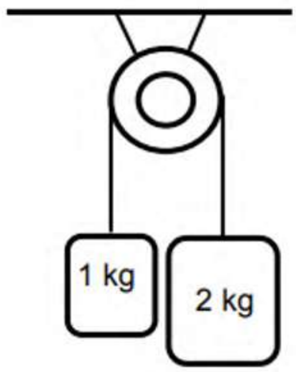
4.1.1 State Newton's Second Law of Motion in words. (2)

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

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.

5.1 State Newton's Universal Gravitational Law in words. (2)

5.2 Explain the term weightlessness (2)

5.3 Calculate the force between the Earth and the satellite A. (4)

5.4 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 6

Gravitational force exist between the sun and the Earth.

6.1 Define the term weight. (2)

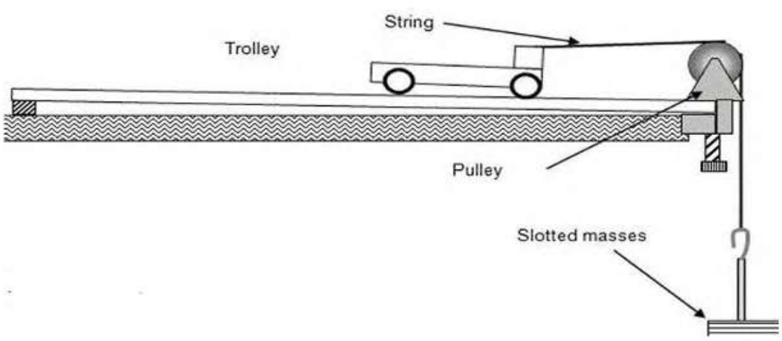
6.2 The mass of the sun is 330 000 times greater than that of the Earth. The distance between the centres of the sun and the Earth is 1,38 x 10^9 m. Calculate the gravitational force that the sun exerts on the Earth. (4)

6.3 How will the gravitational force that the Earth exerts on the Sun compare to the answer to QUESTION 6.2? Write only GREATER THAN, LESS THAN or EQUAL TO. Give a reason for the answer. (2)

[8]

QUESTION 7

Gr 11 Learners investigate the relationship between net force and acceleration by pulling a trolley across a surface which is slightly inclined to compensate for friction. The trolley is connected to different masses by a string of negligible mass. The string passes over a frictionless pulley. Refer to the diagram below



The ticker tape attached to the trolley passes through the ticker timer. The acceleration of the trolley is determined by analysing the ticker- tape. The results of the net force produced by the different masses and the acceleration of the trolley were recorded in the table below.

NET FORCE (N)	a ($m \cdot s^{-2}$)
0,3	0,36
0,6	0,73
0,9	1,09
1,2	1,45

7.1 Write down an investigative question for this experiment. (2)

7.2 The learners record the results in a table

7.2.1 Identify the independent variable (1)

7.2.2 Identify the dependent variable. (1)

7.3 Use the graph paper to draw a graph of the acceleration versus net force. (4)

7.4 Calculate the gradient of the graph. (3)

7.5 Use the gradient of the graph calculated in QUESTION 7.4 to determine the mass of the trolley. (2)

[13]

ELECTROSTATICS

- The SI unit for electric charge is a 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

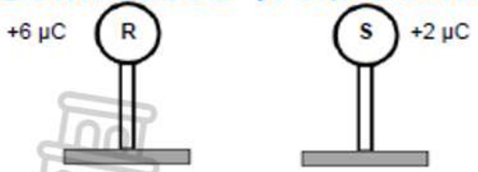
$$Q_{new} = \frac{Q_1 + Q_2 + Q_3}{3}$$

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. 1.6×10^{-19} C.
  $n = \frac{Q}{q_e}$
  where $q_e = 1.6 \times 10^{-19}$ C and n is an integer (whole number)

WORKED EXAMPLE 1

The diagram below shows two small identical metal spheres, **R** and **S**, each placed on a wooden stand, in a vacuum. Spheres **R** and **S** carry charges of +6 μC and +2 μC respectively.



Spheres **R** and **S** are brought into contact for a while and then separated by a distance of 8 mm between their centres.

1.1 Which sphere loses electrons? Write down **R** or **S**. (1)

1.2 Calculate the number of electrons transferred during contact. (4)

[5]

SOLUTION 1

1.1 **S** ✓ (1)

1.2

OPTION 1	**OPTION 2**
$Q_{new} = \frac{Q_1+Q_2}{2}$ $= \frac{6\times10^{-6}+2\times10^{-6}}{2}$ ✓ $= 4\times10^{-6}\text{C}$ $n = \frac{Q}{e}$ ✓ $n = \frac{4\times10^{-6}-2\times10^{-6}}{1{,}6\times10^{-19}}$ ✓ $n = 1{,}25\times10^{13}$ electrons ✓	$Q_{new} = \frac{Q_1+Q_2}{2}$ $= \frac{6\times10^{-6}+2\times10^{-6}}{2}$ ✓ $= 4\times10^{-6}\text{C}$ $n = \frac{Q}{e}$ ✓ $n = \frac{4\times10^{-6}-6\times10^{-6}}{-1{,}6\times10^{-19}}$ ✓ $n = 1{,}25\times10^{13}$ electrons ✓

(4)

[5]

COULOMB'S LAW

The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance (r) between them.

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

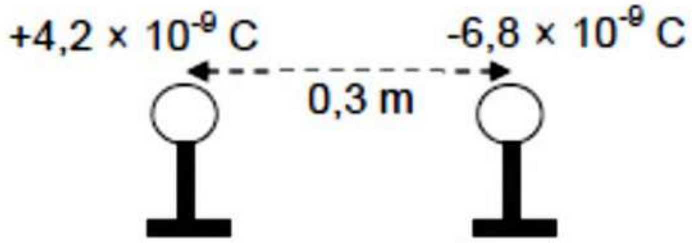
F – electrostatic force (N) – vector quantity

k – Coulomb's constant ($9.0 \times 10^9\ N.m^{-2}.C^{-2}$)

Q_1 and Q_2 – charges (C)

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)

[5]

SOLUTION 2

2.1 The magnitude of the electrostatic force exerted by one-point charges (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them. ✓✓ (2)

2.2 $F = \frac{KQ_1Q_1}{r^2}$✓

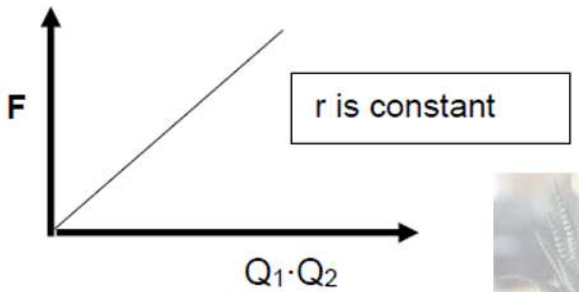
$= \frac{(9\times10^9)(4{,}2\times10^{-9})(6{,}8\times10^{-9})}{(0{,}3)^2}$ ✓

$= 2{,}856 \times 10^{-4}$ N (attraction)✓ (3)

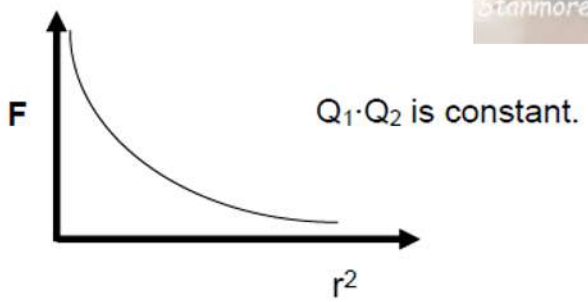
[5]

Graphical representation of Coulombs law:

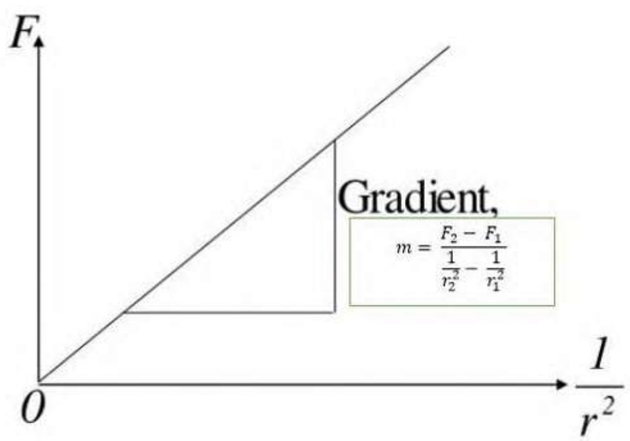
- The electrostatic force is directly proportional to the product of the charges ($F \alpha\ Q_1 \cdot Q_2$)



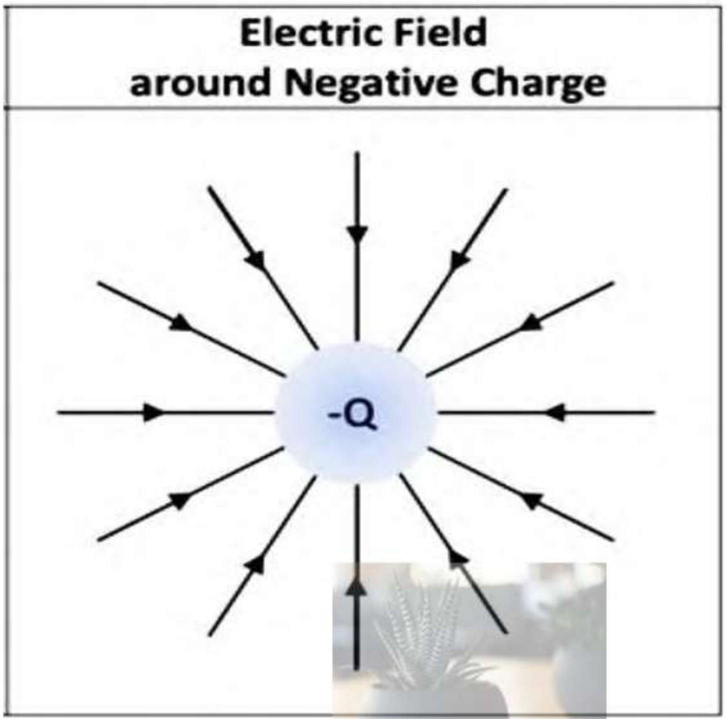
- The electrostatic force is inversely proportional to the square of the distance between the two charges. $F\alpha\ \frac{1}{r^2}$

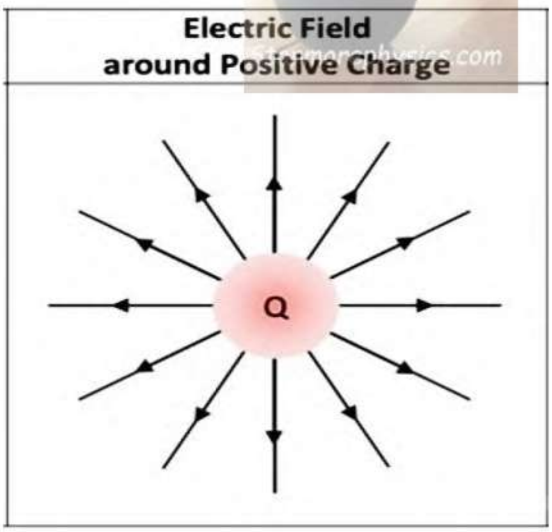


- Electrostatic force is directly proportional to the inverse of a square of a distance.

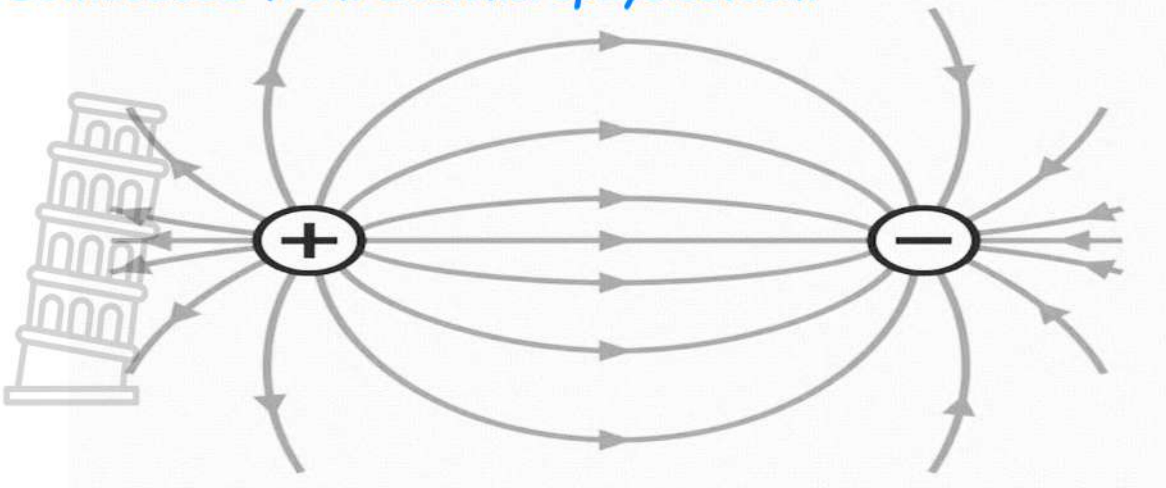


- **An electric field** is described as a region of space in which an electric charge experiences a force.
- The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point
    - **Field lines around the single point charge**



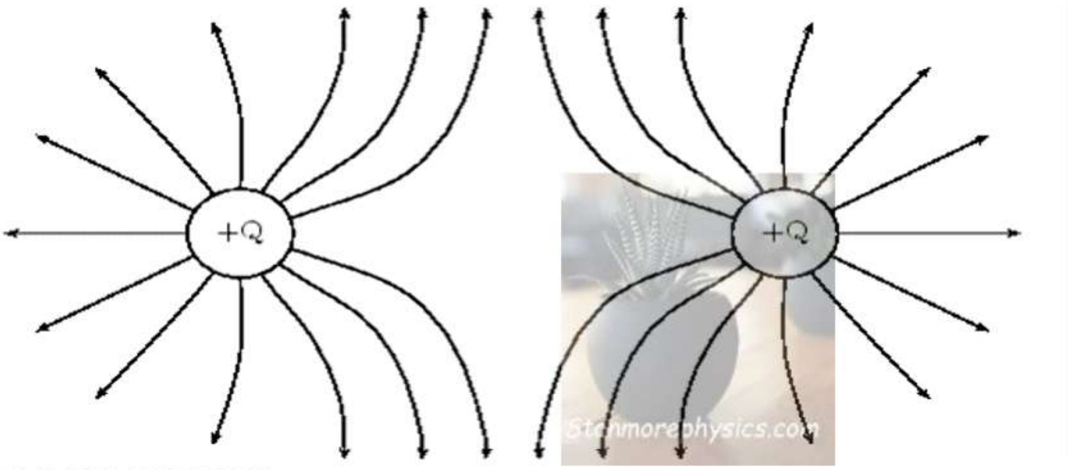


- **Field lines between two unlike charges**

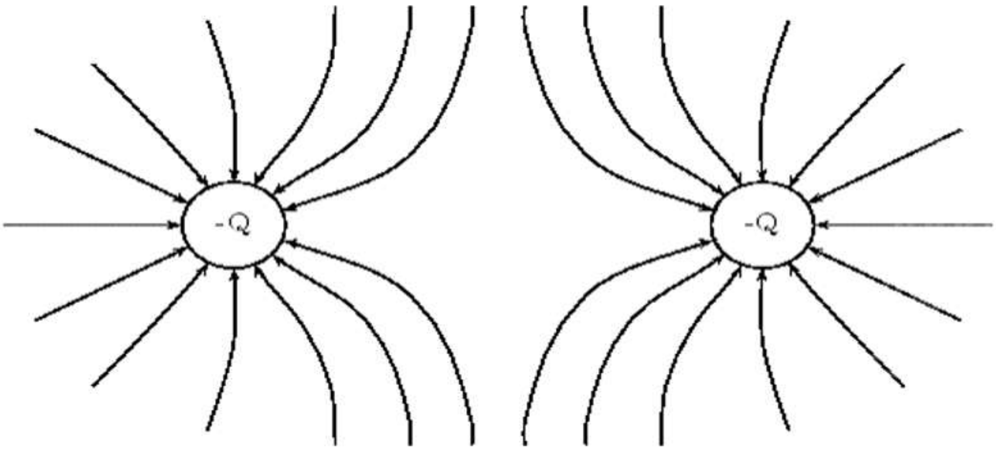


- Electric Field Lines between the two like charges

POSITIVE CHARGES



NEGATIVE CHARGES



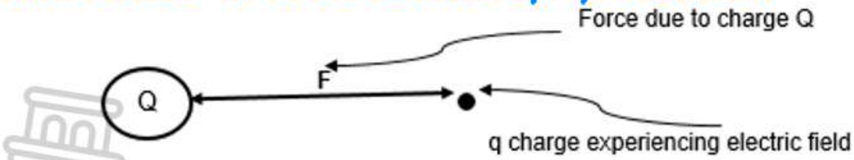
- **The electric field at a point** is the electrostatic force experienced per unit positive charge placed at that point.

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

  q is the charge that experiences the force (C).

  E – electric field (N.C^{-1}) – vector quantity

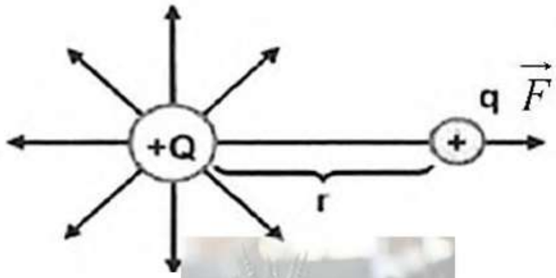
  F – Electrostatic force (N) – vector quantity



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 exert on each other is: $F = \frac{kQq}{r^2}$
- The test charge placed at a point in electric field will experience a force; the magnitude of the force experienced by the test charge will depend on the distance (r) of the test charge (q) from the charge (Q) setting the field: $F = Eq$

$$Eq = \frac{kQq}{r^2}$$
$$\therefore E = \frac{kQ}{r^2}$$



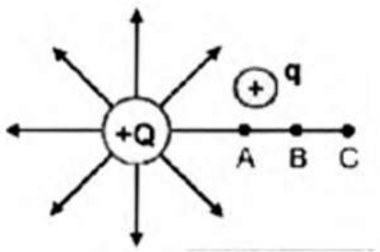
$\mathbf{E} = \frac{\mathrm{kQ}}{\mathrm{r}^2}$

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

Q is the charge setting the field (C)

r is the distance (m)

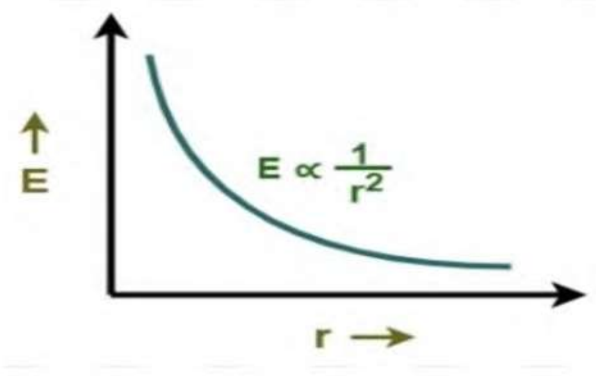
The magnitude of the electric field at different points is dependent on the position of a test charge in the field. The greater the distance between the two charges in the field, the smaller the force experienced by a test charge.



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

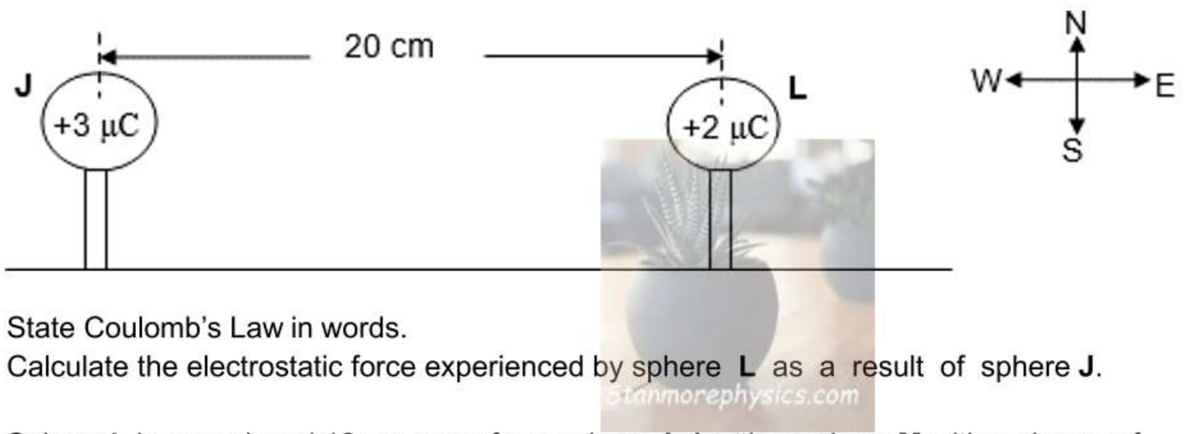
Graphical representation of Electric Field

- The electric field is inversely proportional to the square of the distance. $E \propto \frac{1}{r^2}$



WORKED EXAMPLE 1

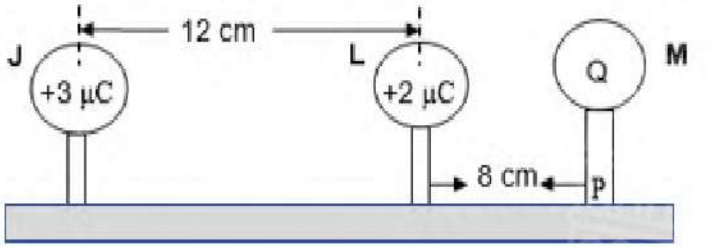
Two metal spheres, **J** and **L** placed on wooden stands, carry charges +3 μC and +2 μC respectively. The diagram is not drawn to scale.



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

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

1.3 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.



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

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

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

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

[19]

SOLUTION 1

1.1 The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them ✓✓ (2)

1.2 $F_J = \frac{kQ_1Q_2}{r^2}$ ✓

$F_{XY} = \frac{9\times10^{9}\times3\times10^{-6}\times2\times10^{-6}}{(0.2)^2\ ✓}$ ✓

$F_{XY} = 1.35\ N\ right$ ✓

(4)

1.3.1 $Q_L = -3 \times 10^{-6}$ ✓ (1)

1.3.2

OPTION 1	OPTION 2
$n_e = \frac{Q_f - Q_i}{q_e}$ ✓ $n_e = \frac{-3\times10^{-6}-2\times10^{-6}}{1.6\times10^{-19}}$ ✓ $n_e = 3.125\times10^{13}$ ✓	$n_e = \frac{Q_f - Q_i}{q_e}$ ✓ $n_e = \frac{-3\times10^{-6}+8\times10^{-6}}{1.6\times10^{-19}}$ ✓ $n_e = 3.125\times10^{13}$ ✓

(3)

1.4 $E_{net} = E_J + E_M$✓

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

$$E_{net} = \frac{(9\times10^9)(3\times10^{-6})✓}{(0.12)^2} + ✓\frac{(9\times10^9)(3\times10^{-6})✓}{(0.08)^2}$$

E_{net} = (+1 875 000) + (+4 218 750) ✓(both substitutions)

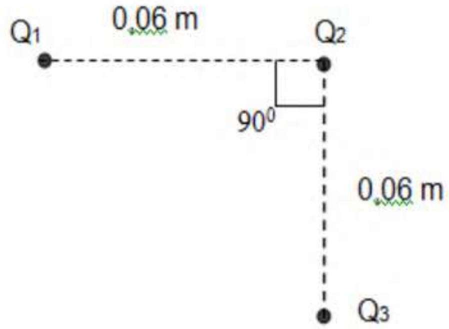
E_{net} = 6 093 750 N•C^{-1} West/Left ✓

(5)

[19]

WORKED EXAMPLE 2

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 x 10^{-6} C, Q_2 has a charge of +3 x 10^{-6} C, and Q_3 has a charge of +6 x 10^{-6} C.



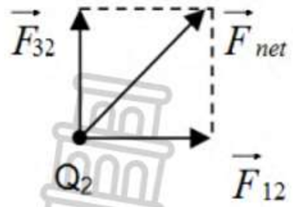
2.1 Draw a free body diagram to show the forces acting on the point charge Q_2 and find the resultant force that acts on Q_2 graphically. Ignore gravitational force (3)

2.2 Calculate the magnitude of the resultant force that acts on point charge Q_2. (6)

[9]

SOLUTION 2

2.1



F_{12}	✓
F_{32}	✓
F_{net}	✓

(3)

2.2 $F_{net} = \sqrt{(F_{12})^2 + (F_{32})^2}$ ✓

$$F_{net} = \sqrt{\left[\frac{kQ_1Q_2}{r_{12}^2}\right]^2 + \left[\frac{kQ_1Q_2}{r_{32}^2}\right]^2} \checkmark$$

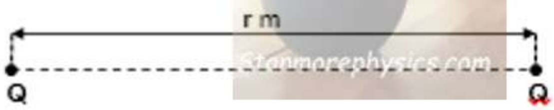
$$= \sqrt{\left[\frac{9 \times 10^9 \times 6 \times 10^{-6} \times 3 \times 10^{-6}}{(0.06)^2}\right]^2_{\checkmark} + \left[\frac{9 \times 10^9 \times 6 \times 10^{-6} \times 3 \times 10^{-6}}{(0.06)^2}\right]^2_{\checkmark}}$$

$F_{net} = 63.64\ N$ ✓ (5)

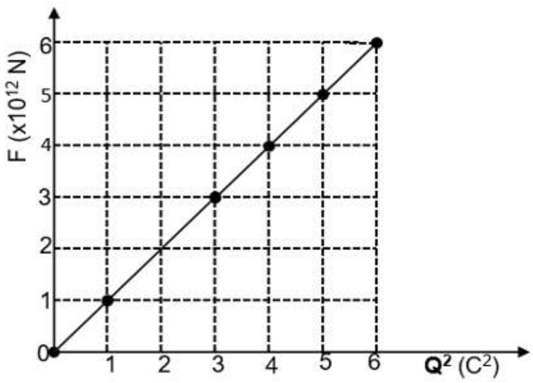
[8]

WORKED EXAMPLE 3

3.1 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, **Q²**.



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

3.1.2 Write down the relationship between the electrostatic force **F** and the product of the two-point charges, **Q^2**. (1)

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

3.1.4 Using the mathematical expression of Coulomb's law and the answer to **QUESTION 3.1.3**, calculate the distance **r** between the charges. (4)

[9]

SOLUTION 3

3.1.1 Distance (between the point charges)/medium/air ✓ (1)

3.1.2 The electrostatic force is directly proportional to the product of charges. ✓ (1)

3.1.3
$$\text{gradient} = \frac{\Delta F}{\Delta Q^2}$$
$$= \frac{(4-3)\times 10^{12}}{(4-3)^2} \checkmark$$ **NOTE:** accept any value from the graph
$$= \frac{1\times 10^{12}}{1} \checkmark$$
$$= 1\times 10^{12}\,\mathrm{N\cdot C^{-2}} \checkmark$$
(3)

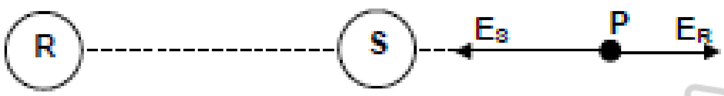
3.1.4
$$F = \frac{KQ_1Q_2}{r^2} \checkmark$$
$$\frac{F}{Q^2} = \frac{K}{r^2}$$
$$1\times 10^{12} \checkmark = \frac{9\times 10^9}{r^2} \checkmark$$
$$r^2 = 9\times 10^{-3}$$
$r = 0{,}09487$ m ($0{,}095$ m) ✓ (4)

[9]

MULTIPLE CHOICE

QUESTION 1

1.1 **R** and **S** are two small, charged spheres placed a distance apart.
P is a point to the right of sphere **S**. ER and ES are the electric fields at point **P** due to the charges on spheres **R** and **S** respectively. See the diagram below.

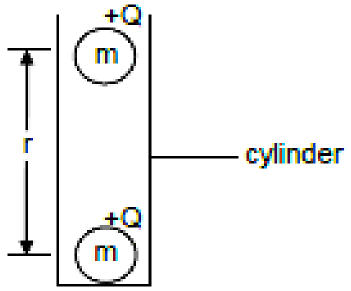


Which ONE of the following combinations is CORRECT for the net charge on spheres **R** and **S**?

	SPHERE R	SPHERE S
A	Positive	Negative
B	Negative	Positive
C	Negative	Negative
D	Positive	Positive

(2)

1.2 Two small identical spheres, each with mass m and charge +Q, are placed in a vertical cylinder. The spheres remain stationary when their centres are r metres apart, as shown in the diagram below. Ignore ALL frictional effects.



Which ONE of the following expressions can be used to CORRECTLY calculate the distance r?

A $\sqrt{\frac{kQ^2}{mg}}$

B $\sqrt{\frac{kmg}{Q^2}}$

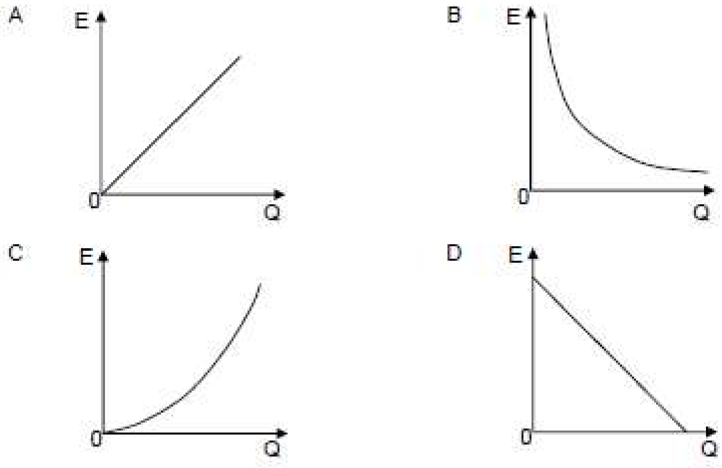
C $\sqrt{\frac{Q^2}{kmg}}$

D $\sqrt{\frac{mg}{kQ^2}}$

(2)

1.3 The magnitudes of electric fields generated by different point charges are measured at a fixed point. For each measurement, the distance between this fixed point and the charges are the same.

Which ONE of the following sketch graphs CORRECTLY shows the relationship between the magnitude of the electric field (E) and the magnitude of the charge (Q)?



(2)

1.4 Two point charges, **X** and **Y**, produce a net electric field (E_{net}) at point **P** which is directed to the RIGHT, as shown in the diagram below.

Which ONE of the following combination of charges **X** and **Y** CANNOT have?

	X	**Y**
A	+	+
B	-	+
C	+	-
D	-	-

(2)

1.5 Two identical insulated conducting spheres **A** and **B** carry equal charges. They are separated by a distance **d** and exert a force with magnitude **F** on each other, as shown in the diagram below.

A third identical UNCHARGED sphere **C** touches **A**, and is then removed. If the distance between spheres **A** and **B** remains the same, then the magnitude of the electrostatic force exerted on sphere **B** is now:

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

B $\frac{1}{4}F$

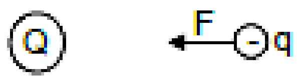
C $2F$

D $4F$ (2)

[10]

QUESTION 2

2.1 A small negative charge q placed at a fixed distance from charged sphere Q, experiences a force F, as shown in the diagram below.

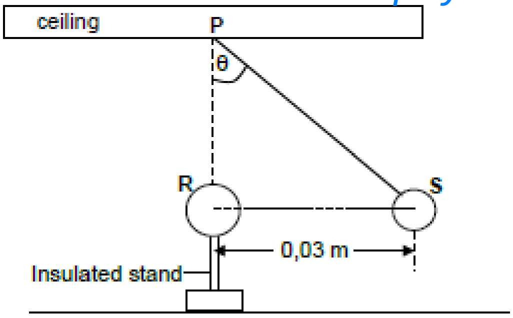


The charge q is now removed.

Draw the electric field pattern for the charged sphere Q. (3)

2.2 Sphere **S** is attached to the ceiling at point **P** by a light inextensible string. When sphere **R**, on an insulated stand, is brought close to sphere **S** they repel and sphere **S** comes to rest with the horizontal distance between the centres of the spheres equal to 0,03 m.

Sphere **R** is directly below point **P**. The string makes an angle θ with the vertical, as shown in the diagram below.



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

2.2.2 Draw a labelled free-body diagram showing ALL the forces acting on sphere **S** when it is at rest. (3)

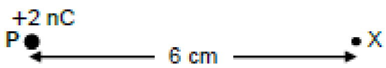
Sphere **R** has a charge of +6 nC. Sphere **S** has a charge +3 nC and a mass of 0,15 g.

2.2.3 Calculate angle θ. (5)

[13]

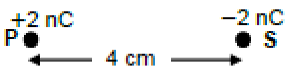
QUESTION 3

P is a +2 nC point charge. X is a point 6 cm away from charge **P**, as shown in the diagram below.



3.1 Calculate the magnitude of the electric field at X. (3)

Point charge **S**, with a charge of −2 nC, is placed 4 cm to the right of charge **P**, as shown in the diagram below.



3.2 Draw the resultant electric field pattern due to charges **P** and **S**. (3)

3.3 A third point charge **T** is placed 2 cm to the right of **S**, as shown in the diagram below. Point charge **T** experiences a net electrostatic force of $2,5 \times 10^{-4}$ N to the left.

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

3.3.2 What is the polarity of charge **T**? Choose from POSITIVE or NEGATIVE. (1)

3.3.3 Calculate the magnitude of charge **T**. (5)

[14]

QUESTION 4

In FIGURE 1 below two identical point charges, placed a distance X apart, exert a force of 1 920 N on each other.

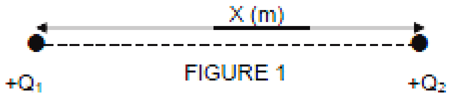


FIGURE 1

In FIGURE 2, the charges are separated a further 6 m. The force exerted by one charge on the other is 120 N.

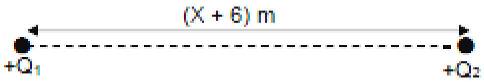


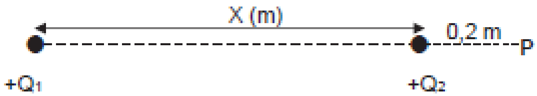
FIGURE 2

4.1 Calculate the:

4.1.1 Distance X in metres (5)

4.1.2 Magnitude of the charges (4)

4.2 The charges are returned to their original positions as in FIGURE 1. An electron is located at point P, a distance of 0,2 m to the right of charge Q_2.



Calculate the net:

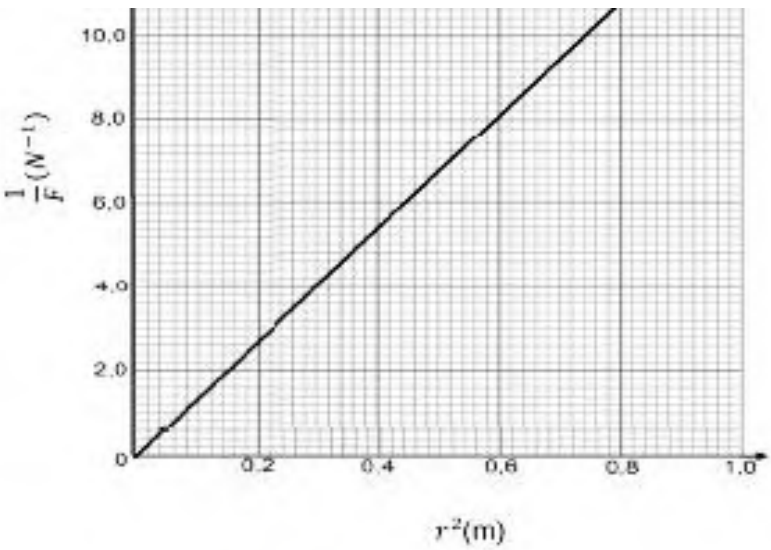
4.2.1 Electric field at point P due to the two charges (5)

4.2.2 Force experienced by the electron at point P due to the two charges (3)

[17]

QUESTION 5

5.1 A class of grade 11 learners wanted to investigate the relationship between the inverse of an electrostatic force and the distance between two identical charges. They carried their experiment and recorded the results. The graph below shows the results obtained by the learners.

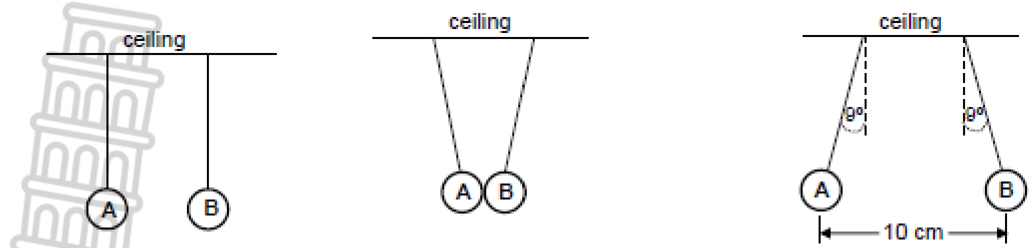


5.1.1 Using the graph, write down the relationship between the distance between the inverse of force and the distance between the charges. (1)

5.1.2 Determine the magnitude of each charge (6)

5.2 Two identical neutral polystyrene balls **A** and **B** are suspended from a ceiling by insulated, light inextensible strings of equal length, as shown in the diagram below.

Ball **B** is then given an initial negative charge, Q_B, of unknown magnitude. The balls attract each other, touch and then repel each other. The balls come to rest with their centres 10 cm apart so that each string makes an angle of 9º with the vertical. See the diagrams below.

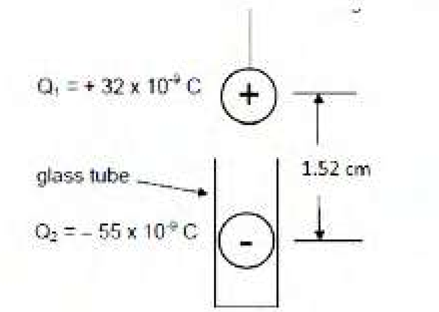


Calculate the magnitude of the initial charge Q_B given to ball **B** if the mass of each ball was 0,012 kg. (6)

[13]

QUESTION 6

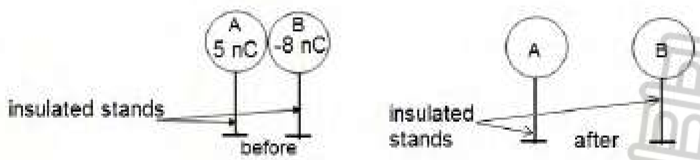
A small sphere, Q_1, with a charge of $+32 \times 10^{-9}$ C, is suspended from a light string secured to a support. A second, identical sphere, Q_2, with a charge of -55×10^{-9} C, is placed in a narrow, cylindrical glass tube vertically below Q_1. Each sphere has a mass of 7 g. The spheres come to equilibrium when Q_2 is 1,52 cm from Q_2, as shown in the diagram. Ignore the effects of air friction.



6.1 Draw a labelled free-body diagram showing all the forces acting on sphere Q_1. (3)

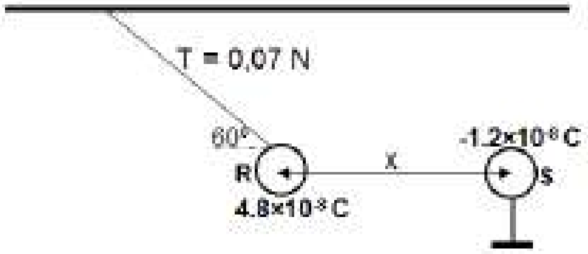
6.2 Calculate the magnitude of the tension in the string. (5)

Sphere **A**, which has a charge of +5 nC, is brought into contact with sphere **B**, which has a charge of -8 nC. The spheres are separated after contact as shown in the diagram below.



6.3 Calculate the charge (in Coulombs) on sphere A after separation. (3)

6.4 Sphere **R**, which has a charge of 4.8×10^{-8} C, is suspended by a light inextensible thread. Sphere **S**, which has a charge of -1.2×10^{-8} C, is positioned on an insulated stand near sphere **R** and in line with it. Sphere **R** is attracted to sphere **S** and comes to rest at distance **x** from sphere **S** as shown in the diagram below. When sphere **R** is in this equilibrium position, the angle between the thread and the horizontal is 60º and the tension (T) in the thread is 0,07 N.

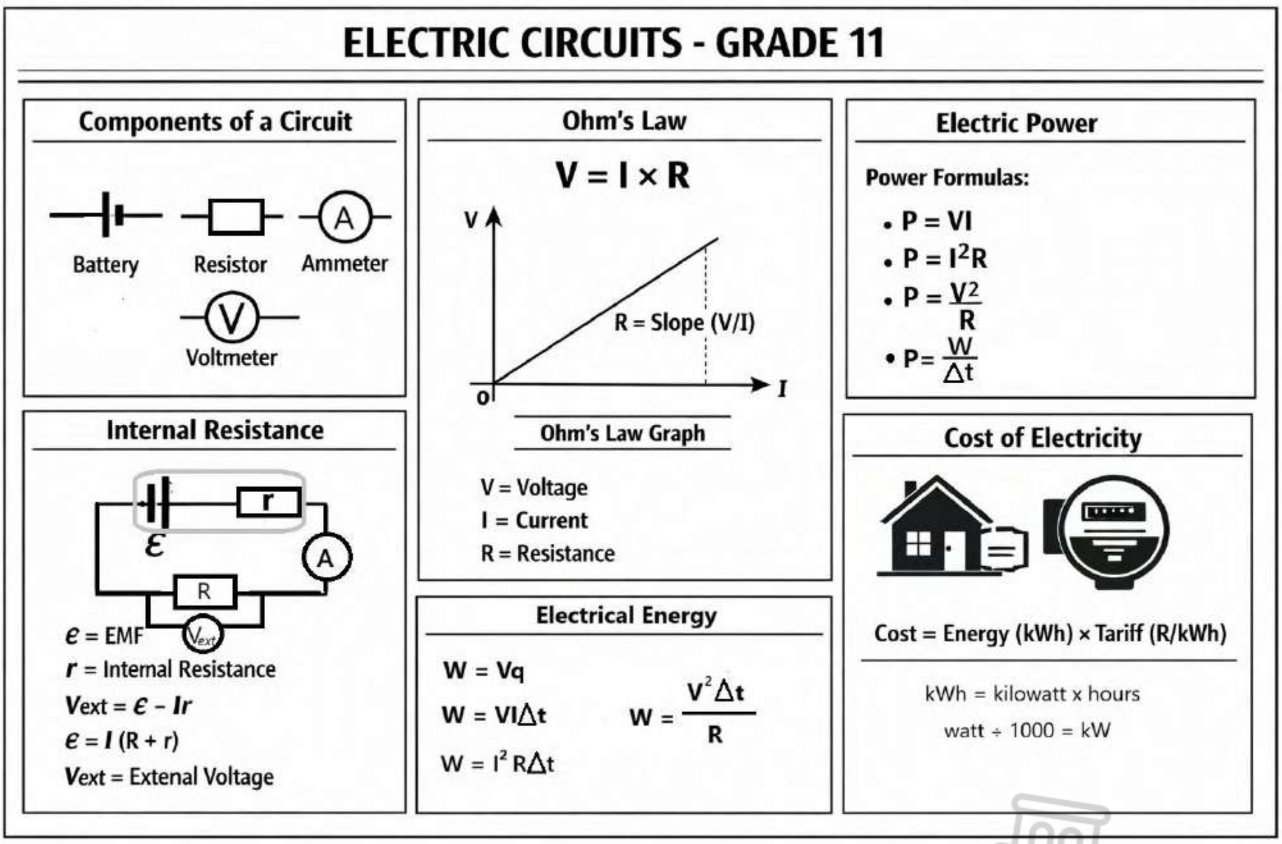


6.4.1 Calculate the magnitude of the horizontal component of the tension in the thread. (2)

6.4.2 Calculate the distance x between the centres of spheres R and S. (4)

[17]

ELECTRIC CIRCUITS

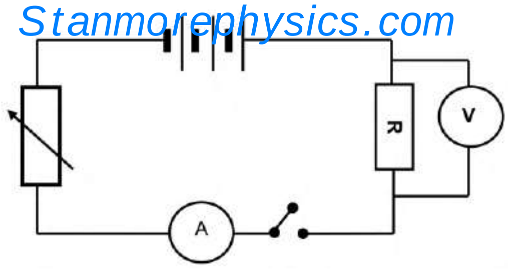


Internal resistance

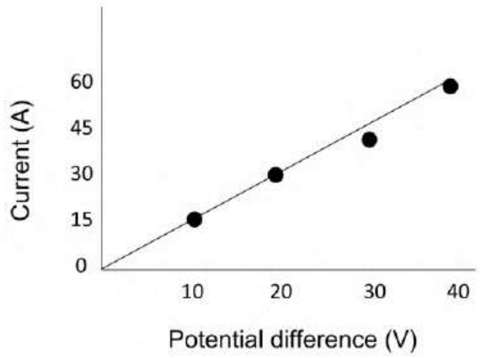
Real batteries are made from materials which have resistance. This means that real batteries are not just sources of potential difference (voltage), but they also possess internal resistance. If the total potential difference source is referred to as the emf, ε, then a real battery can be represented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

WORKED EXAMPLE 1 (OHM'S LAW)

Learners investigate the relationship between the potential difference across a rheostat (variable resistor) and the current flowing through the rheostat.



The following graph is drawn from the result obtained from the investigation:



1.1 For this investigation write down the:
1.1.1 the investigative question. (2)
1.1.2 control variable (1)
1.2 Name and state the law that was investigated by the learners? (3)
1.3 Calculate the gradient of the graph (3)
1.4 Hence write down the value of the unknown resistor. (1)
[10]

SOLUTIONS

1.1.1 What is the <u>relationship between the potential difference</u> across the resistor <u>and</u> the <u>current</u> through the resistor?✓✓

1.1.2 Temperature✓

1.2 Ohm's Law✓
The <u>potential difference</u> across a conductor is <u>directly proportional to</u> the <u>current</u> in the conductor.✓✓

1.3 $\text{gradient} = \frac{30-15✓}{20-10✓} = 0{,}50✓$ $\quad\quad \text{gradient} = \frac{30-0}{20-0} = 0{,}50$ $\quad\quad \text{gradient} = \frac{15-0}{10-0} = 0{,}50$

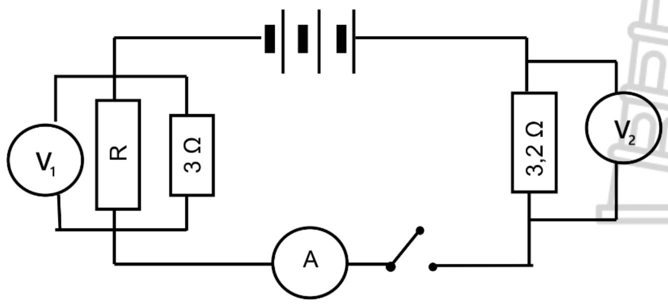
1.4 $(0{,}5)^{-1} = 2{,}00\Omega$✓

It is important to note the expression that the gradient of the graph is represented by $\text{gradient} = \frac{\Delta I}{\Delta V}$ and the Ohm's Law expression is $R = \frac{V}{I}$, **NOTICE THESE TWO EXPRESSIONS ARE INVERSES OF EACH OTHER**, therefore $\text{gradient}^{-1} = R$

[10]

WORKED EXAMPLE 2 (CIRCUITS WITHOUT INTERNAL RESISTANCE)

A battery in the diagram below has negligible internal resistance and an **emf** of 20V.



The reading on the ammeter is 4A when the switch is closed.
Calculate the:

2.1 total resistance of the circuit. (3)
2.2 Reading on $\mathbf{V_1}$ when the switch is closed. (4)
2.3 resistance of **R**. (4)
2.4 current flowing through the 3Ω resistor when the switch is closed (2)
2.5 power dissipated by the 3,2Ω resistor. (3)
2.6 Resistor **R** is removed.
Will the reading on the ammeter INCREASE, DECREASE or REMAIN THE SAME? (1)
[17]

SOLUTIONS

2.1 $R = \frac{V}{I}$✓

$= \frac{20}{4}$✓

$= 5{,}00\Omega$✓

<u>NOTE:</u> when using Ohm's Law, the quantities must represent the same 'R', i.e. the **TOTAL** potential difference (this is called **ε**) over the **TOTAL** current (this is any ammeter reading in series with the power supply) will produce the **TOTAL** resistance.

2.2 **<u>NOTE:</u>** The question is asking for the value for a voltmeter where the resistance is not known, so Ohm's Law has two unknowns. The only other way to solve for potential difference, without Ohm's Law is to use the relationship that potential difference has in a **SERIES** circuit. To do that, first the reading on the second voltmeter must be solved.

$V_2 = IR$

$= (4)(3{,}2)$✓

$= 12{,}80V$✓

$V_1 = V_T - V_2$

$= 20 - 12{,}8$✓

$= 7{,}20V$✓

2.3 **<u>NOTE:</u>** The question is asking for the value for a resistor where the current is not known, so Ohm's Law has two unknowns. The only other way to solve for resistance, without Ohm's Law is to use the relationship that resistance has in a **PARALLEL** circuit. To do that, first the reading for the total parallel must be solved.

$R_P = R_T - R_S$

$= 5 - 3{,}2$✓

$= 1{,}80\Omega$✓

$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$

$1{,}8 = \frac{1}{3} + \frac{1}{R}$✓

$\left(\frac{1}{R}\right)^{-1} = \left(1{,}8 - \frac{1}{3}\right)^{-1}$

$R = 4{,}50\Omega$✓

<u>NOTE:</u> The most correct formula that **MUST** be utilised must come from the **DATASHEET**.

2.4 $R = \frac{V}{I}$

$3 = \frac{7{,}2}{I}$✓

$I = 2{,}40A$✓

All the requirements to use Ohm's Law have been met. The resistance is known, the potential difference is known

2.5 Known quantities

- V = 12,8V
- I = 4A
- R = 51,2Ω

Possible formulae

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

$P = VI$✓

$= (12{,}8)(4)$✓

$= 51{,}20W$✓

$P = I^2R$

$= (4)^2(3{,}2)$

$= 51{,}20W$

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

$= \frac{12{,}8^2}{3{,}2}$

$= 51{,}20W$

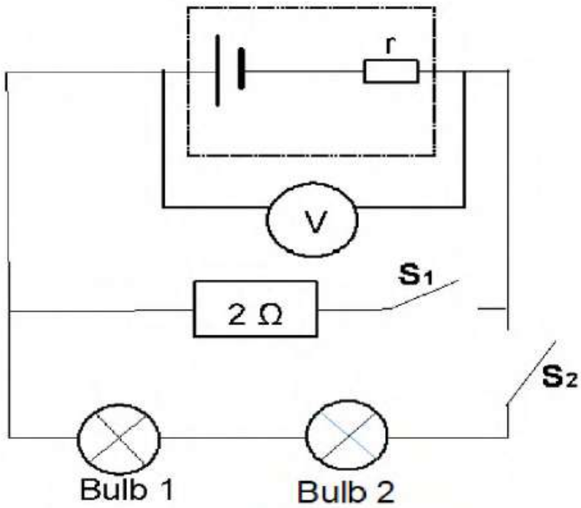
2.6 DECREASE✓

<u>NOTE:</u> Removing the resistor, which is in parallel, will make the circuit series. This causes the total resistance to increase. Provided the power source remains constant, according to Ohm's Law resistance is inversely proportional to the current flowing through it. I.E. resistance decreases causing current to decrease.

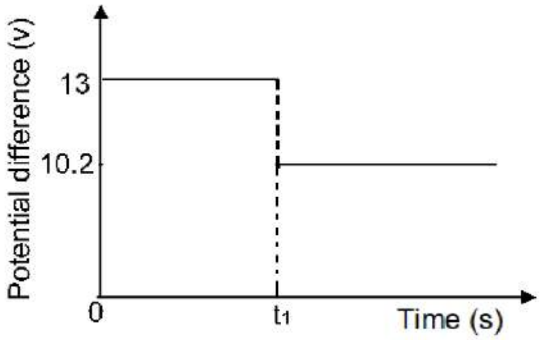
[17]

WORKED EXAMPLE 3 (Circuits WITH internal resistance)

A resistor and two identical bulbs are connected in parallel to a cell with an unknown internal resistance as shown in the circuit diagram below. The resistor has a resistance of 2Ω and is controlled by switch $\mathbf{S_1}$. The light bulbs are controlled by switch $\mathbf{S_2}$. Th resistance of the connecting wires may be ignored.



The graph below shows the potential difference across the terminals of the battery before and after $\mathbf{S_1}$ is closed, whilst $\mathbf{S_2}$ is open. Switch $\mathbf{S_1}$ is closed at $\mathbf{t_1}$.



3.1 Define the term **emf**. (2)
3.2 Use the graph to write down **ε** of the battery. (1)
3.3 With ONLY $\mathbf{S_1}$ closed, calculate the:
3.3.1 Current through the resistor. (3)
3.3.2 Internal resistance, **r**, of the battery. (3)
3.4 BOTH switches $\mathbf{S_1}$ and $\mathbf{S_2}$ are now closed. The battery delivers a current of 5,5A during this period.
3.4.1 Calculate the resistance of each bulb. (4)
3.4.2 How will the reading on the voltmeter be affected if the 2Ω resistor is removed? Write down only INCREASES, DECREASES or REMAINS THE SAME. Give a reason for your answer. (3)
[16]

SOLUTIONS

3.1 The maximum energy provided by a battery per unit charge passing through it.✓✓
3.2 13V✓

NOTE: As a **MAXIMUM** value it should be the largest possible based on the given information.

3.3.1
$$R = \frac{V}{I} \checkmark$$
$$2 = \frac{10{,}2}{I} \checkmark$$
$$I = 5{,}10A \checkmark$$

NOTE: Choosing a formula is easier when variable that are known are identified.

3.3.2
$$\varepsilon = I(R + r) \checkmark$$
$$13 = 5{,}10(2 + r) \checkmark$$
$$r = 0{,}55\Omega \checkmark$$

3.4.1
$$R = \frac{V}{I}$$

$R = \frac{13}{5,5}$ ✓
$R = 2{,}37\Omega$ determining the total resistance of the circuit

$R_T = R_{ext} + r$ determine the resistance of the external circuit
$2{,}37 = R_{ext} + 0{,}55$ ✓
$R_{ext} = 1{,}82\Omega$

To determine the resistance of each bulb, consider that the initial statement indicated that the bulbs are IDENTICAL. Therefore x for each bulb.

$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$
$\frac{1}{1{,}82} = \frac{1}{2} + \frac{1}{2x}$ ✓
$\left(\frac{1}{2x}\right)^{-1} = \left(\frac{1}{1{,}82} - \frac{1}{2}\right)^{-1}$
$x = 10{,}11\Omega$ ✓

<u>NOTE:</u> Rounding off should be done only on the final answer. In this case the value would be 9,73Ω.

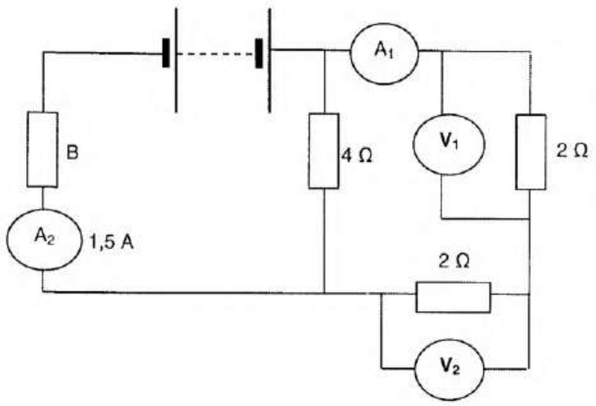
3.4.2 INCREASES✓
- Total resistance increases, current decreases✓
- V_{int} decreases✓

$\varepsilon = V_{ext} + V_{int}$, the emf does not change, therefore if the internal potential difference decreases the external potential difference MUST increase.

[16]

WORKED EXAMPLE 4 (POWER, ENERGY & COST)

In the circuit below, the battery has an ε of 12V. The battery and the connecting wires have negligible resistance.



4.1 Define power (2)
4.2 How much power is dissipated in the circuit above? (3)
4.3 Calculate:
4.3.1 The reading on **A_1**. (1)
4.3.2 The reading on **V_2**. (3)
4.3.3 How much energy is dissipated in 2 minutes. (3)
4.4 For resistor **B** determine show that the potential difference across it is 9V. (2)
4.5 Hence calculate the cost of running resistor **B** for 1 year if the rate is R0,45 per kilowatt-hour. (5)

[19]

SOLUTIONS

4.1 <u>Rate</u> of at which <u>work is done</u> or energy transferred.✓✓
4.2 $P = VI$ ✓
$= (12)(1{,}5)$ ✓
$= 18{,}00W$ ✓
4.3.1 0,75A✓

Since each branch has the same resistance, they will have the same current, and in a parallel circuit, current id divided, in this case they will be divided equally: $1{,}5 \div 2 = 0{,}75A$.

4.3.2 $V = IR$ ✓
$V = (0{,}75)(2)$ ✓
$V = 1{,}50V$ ✓

NOTE: Questions are scaffolding, the previous answer is meant to HELP with the current question.

4.3.3 Known quantities
- V = 1,5V
- I = 0,75A
- R = 2Ω
- Δt = 120s

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

$W = VI\Delta t$ ✓
$= (1{,}5)(0{,}75)(120)$ ✓
$= 135{,}00J$ ✓

$W = I^2R\Delta t$
$= (0{,}75)^2(2)(120)$
$= 135{,}00J$

$W = \frac{V^2\Delta t}{R}$
$= \frac{(1{,}5)^2(120)}{(2)}$
$= 135{,}00J$

4.4 $V = V_1 + V_2$
$V = 1{,}5 + 1{,}5$
$V = 3{,}00V$

$\varepsilon = V_B + V_{parallel}$
12 ✓ $= V_B + 3$ ✓
$V_B = 9V$

4.5 $P = VI$
$P = (9)(1{,}5)$ ✓
$P = 13{,}5W$

$\underline{Cost = 0{,}0135 ✓ \times 8760 ✓ \times 0{,}45 ✓}$
$Cost = R53{,}22$ ✓

NOTE: Do not forget to convert watt to kilowatt (divide by 1000), and years into hours (remember 365 days in 1 year and 24 hours per day.

[19]

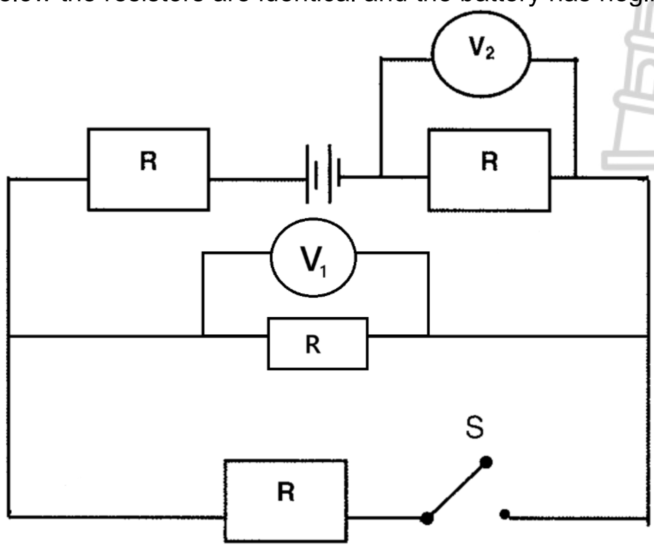
ELECTRIC CIRCUITS MCQ QUESTIONS

QUESTION 1

1.1 When two resistors, each of resistance **R**, are connected in parallel the effective resistance is Y. When these 2 resistors are connected in series, the total resistance will be: (2)

A 2 Y
B 2 RY
C 4 Y
D ½ Y

1.2 In the circuit diagram below the resistors are identical and the battery has negligible internal reistance.

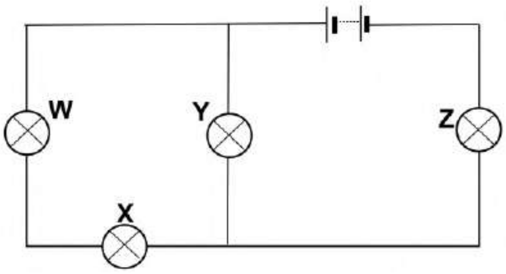


(2)

When te switch S is closed, the readings on voltmeters V_1 and V_2 will CHANGE as follows.

A **V_1** decreases, **V_2** increases
B **V_1** increases, **V_2** increases
C **V_1** stays the same, **V_2** decreases
D **V_1** increases, **V_2** decreases

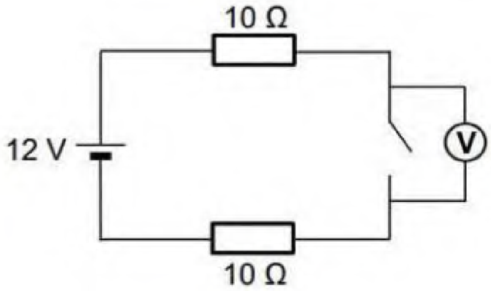
1.3 In the circuit below the four bulbs W, X, Y and Z are identical.



Which of the following pairs of bulbs has equal brightness? (2)

A W and X
B W and Y
C Y and Z
D X and Y

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



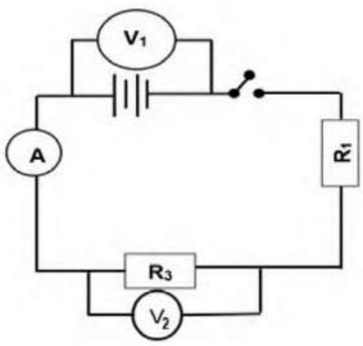
(2)

A 0 V
B 6 V
C 0,6 V
D 16 V

1.5 The unit for electric power is (2)

A N C^{-1}
B $J.s^{-1}$
C $Kg.m.s^{-1}$
D N.s

1.6 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)

A V_1 = 0V ; V_2 = 10V
B V_1 = 10V ; V_2 = 0V
C V_1 = 0V ; V_2 = 0V
D V_1 = 10V ; V_2 = 10V

1.7 Current is the same in (2)

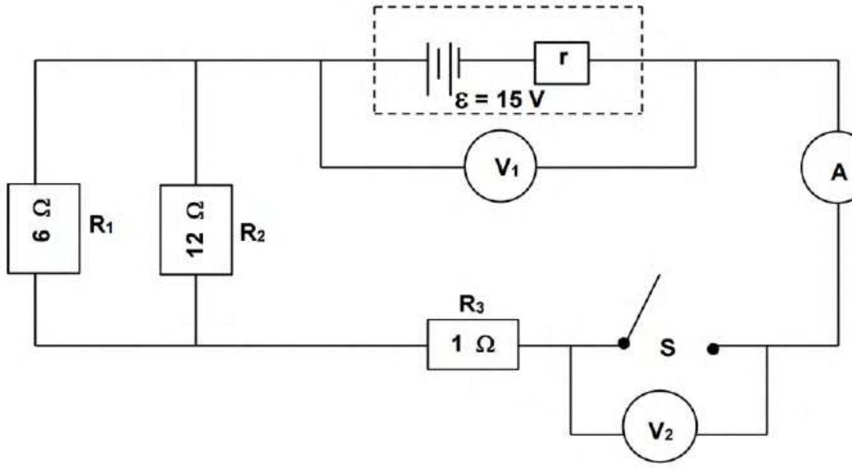
A Series connection
B Parallel connection
C Combination of parallel and series connection
D Two resistor in parallel

[14]

ELECTRIC CIRCUITS STRUCTURED QUESTIONS

QUESTION 2

2.1 In the circuit represented in the diagram below, the battery has an emf **ε** of **15V** and an unknown internal resistance r. Voltmeter $\mathbf{V_1}$ is connected acrosss the battery and voltmeter $\mathbf{V_2}$ is connected across an OPEN SWITCH **S**.



2.1.1 Define the term *emf of a battery*. (2)

2.1.2 Write down the reading on voltmeter $\mathbf{V_2}$. (1)

The switch S is now CLOSED. The reading on voltmeter $\mathbf{V_1}$ drops to **10,5V**.

2.1.3 Using an appropriate equation, EXPLAIN why the reading on $\mathbf{V_1}$ drops. (3)

2.1.4 Calculate the internal resistance of the battery. (4)

2.2 An eletric alarm clock uses a **5,0-W** motor and runs all day, every day. If electricity cost **R1,25 per kWh**, calculate the yearly cost of running the clock. (3)

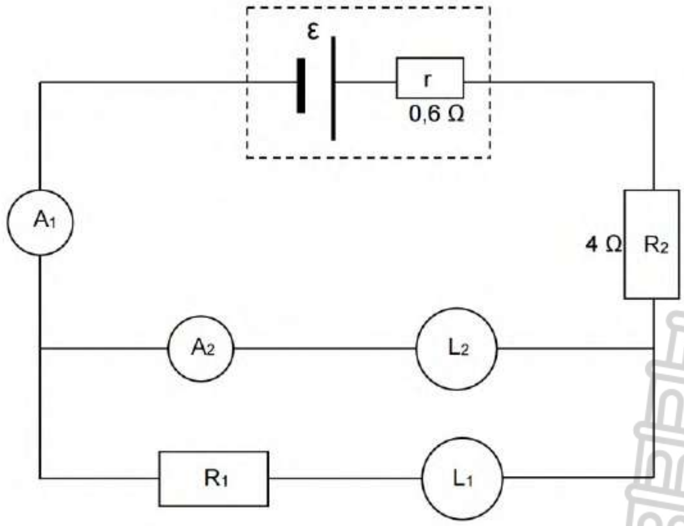
[13]

QUESTION 3

L_1 and L_2 are two light bulbs that have the following ratings:

L_1: 36W ; 20V and L_2: 48W ; 32V

The two bulbs are connected as shown in the circuit diagram below. The batter has an internal resistnce of 0,6Ω while the conducting wires and the ammeters have negligible resistance. R_1 and R_2 are resistors.



3.1 Define the term *power*. (2)

3.2 If both light bulbs operate as RATED, calulate the:

3.2.1 Reading on ammete A_2. (3)

3.2.2 Reading ammeter A_1 (3)

3.2.3 Resistance of resistor R_1. (4)

3.2.4 Emf of the battery. (4)

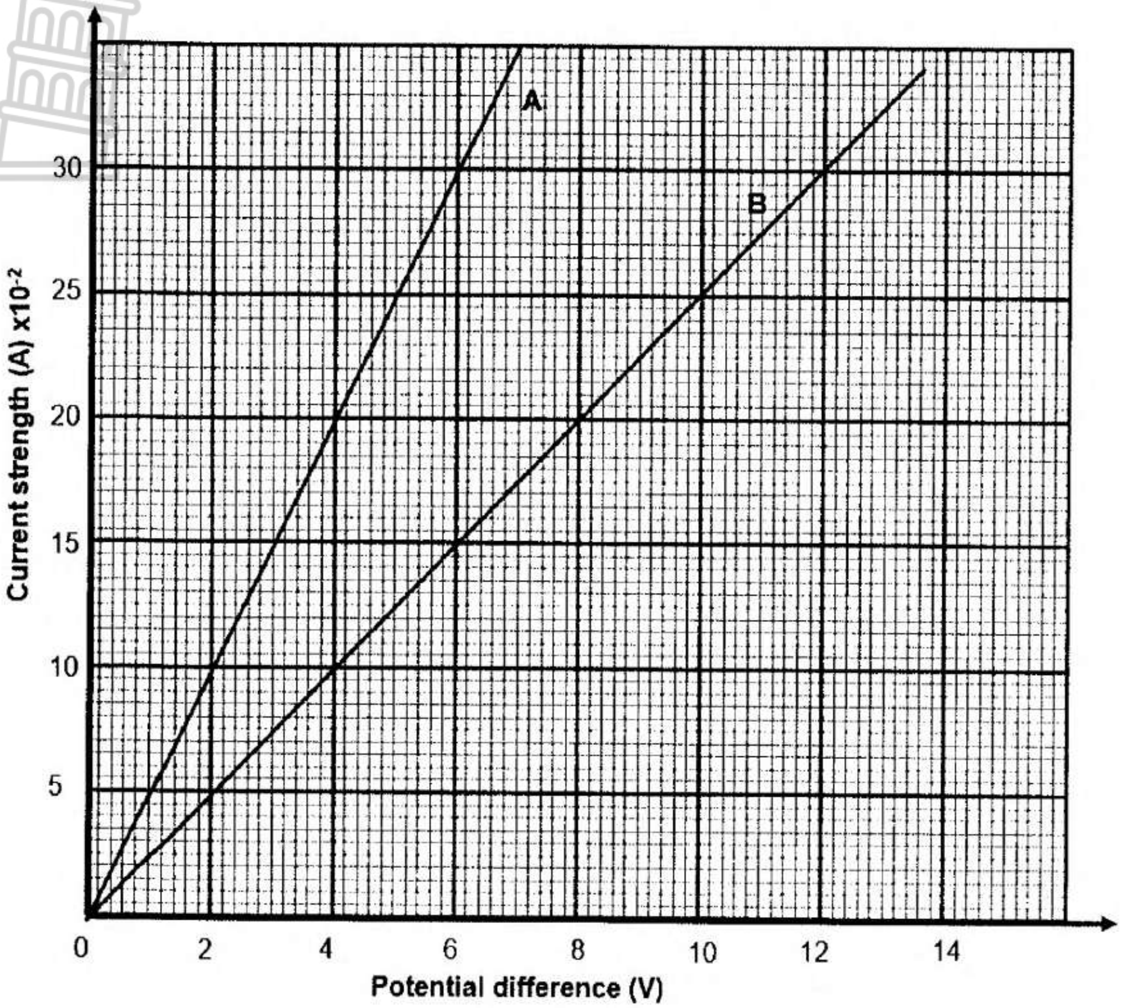
3.3 Bulb L_1 burns out after a while.Assume that the resistance of bulb L_2 remain constant. Will bulb L_2 continue to glow after bulb L_1 burns out? Choose from YES or NO. Support your answer with a suitable calculation. (5)

[21]

QUESTION 4

Two grade 11 learners conduct two separate experiemenst (**experiment A** and **experiment B**) to verify the relationship between the potential difference across a resistor and the current through the resistor. They each used the following components to set up their circuits: a bttery, an ammeter, a resistor of unknown resistance, a voylmeter, a switch, conducting wire and a rheostat.

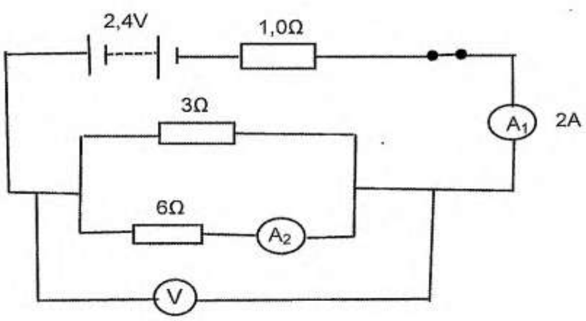
The Current vs Potential Difference graphs obtained by each learner is shown below. Both graphs pass through the origin,



4.1	Write down the name of the law that is being investigated in these experiments.	(1)
4.2	What is the function of the rheostat?	(2)
4.3	State ONE precaution that the learners would have to take to ensure that the temperature of their resistors remain constant.	(1)
4.4	Draw a 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 potential difference across the resistor?	(1)
4.5.2	What does the gradient of the graph?	(1)
4.5.3	What is the current through the resistor when the potential difference across the resistor is 6V?	(1)
4.5.4	Using the graph, calculate the resistance of the resistor in experiment B.	(4)
4.6	Consider graphs A and B	
4.6.1	Which experiment used a resistor when higher resistance? Choose from **A** or **B**.	(1)
4.6.2	Give a reason for the answer.	(2)
		[18]

QUESTION 5

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



5.1	State the Ohms law in words.	(2)
5.2	Calculate the effective resistance of the circuit.	(3)
5.3	Calculate the reading on	
5.3.1	The voltmeter	(3)
5.3.2	The ammeter A_2	(3)
5.4	Calculate the amount of energy (kWh) that is transferred to the circuit in 48 hours.	(5)
5.5	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).	
5.5.1	The reading on A_1 . Explain the answer	(3)
5.5.2	The reading on A_2	(1)

[20]

QUESTION 6

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:

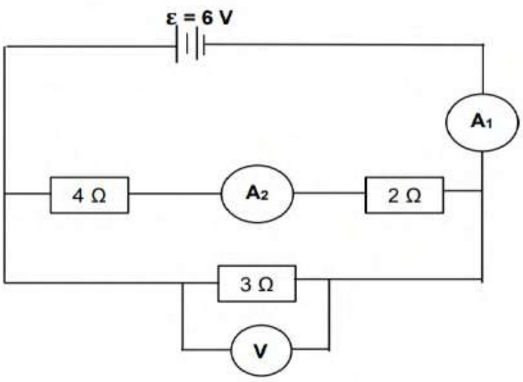
Potential Difference (V)	Current strength (A)
21.4	0.80
35.8	1.20
56.0	1.90
72.04	2.30
98.04	3.20
124.04	4.12

6.1	State Ohm's Law	(2)
6.2	The dependant variable in this was the current	
6.2.1	Name one quantity that was controlled in this investigation.	(1)
6.2.2	State how the quantity in Question 2.2.1 was kept constant	(1)
6.3	Using the information in the table and the graph sheet provided, draw a graph of current versus potential difference.	(5)
6.4	Calculate the gradient of the graph.	(4)
6.5	What quantity does the gradient of the graph represent?	(1)
6.6	Hence determine the resistance of the resistor.	(2)

[16]

QUESTION 7

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



7.1 Calculate the:

7.1.1 Effective resistance in the circuit (3)

7.1.2 Reading on ammeter A1 (1)

7.1.3 Reading on ammeter A2 (3)

7.1.4 Power dissipated by the 4 Ω resistor (3)

7.2 What is the reading on voltmeter V? No calculation is required. (1)

7.3 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]

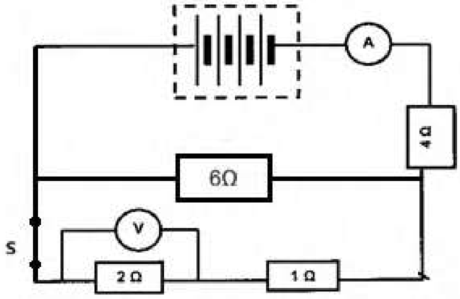
QUESTION 8

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

8.1 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)

8.2 Use the relevant calculations to show that the total resistance in your circuit in 8.1 is equal to R. (3)

8.3 The circuit diagram below shows a battery of known Emf with neglible internal resistance, connected as shown below.



The reading on the voltmeter is 4V.

Calculate :

8.3.1 The effective resistance in the circuit. (3)

8.3.2 The current flowing through the 1Ω resistor. (3)

8.3.3 The reading on the ammeter. (4)

8.3.4 The Emf of the battery (3)

8.4 The switch S is now opened

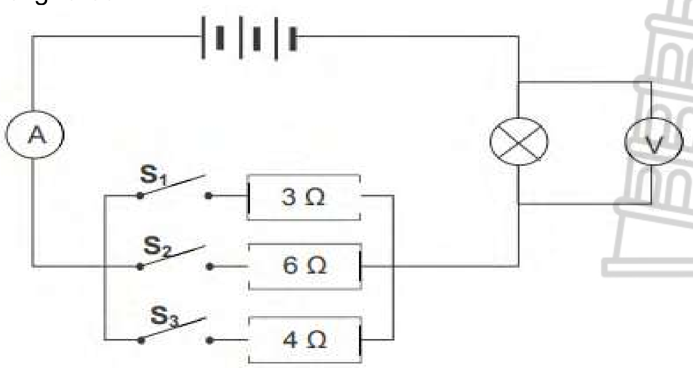
8.4.1 How will the energy dissipated by the 4Ω resistor change if the time is in operation remains constant ? State whether it will increase , decrease or remain the same. (1)

8.4.2 Briefly explain your answers using relevant formulae. (2)

[20]

QUESTION 9

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 wires may be ignored.



9.1 State the Ohms' law in words. (2)

9.2 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

SWITCHS 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

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

9.3 Calculate the :

9.3.1 Resistance of the bulb. (3)

9.3.2 Potential difference of the battery (4)

9.4 Define the term power. (2)

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

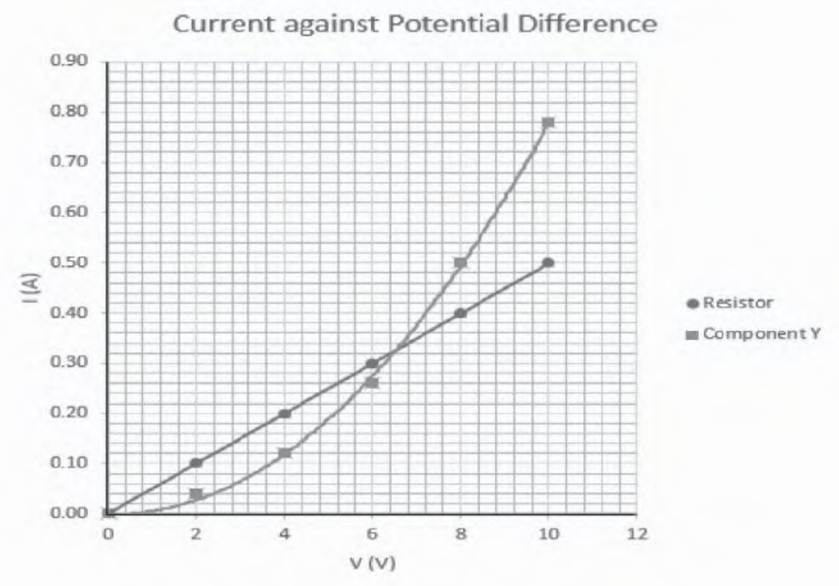
9.6 How will the BRIGHTNESS of the bulb be affected as more switches in the circuit are closed? Write only INCREASES, DECREASES or REMAINS THE SAME. (1)

9.7 Explain the answer to question 9.6. (2)

[21]

QUESTION 10

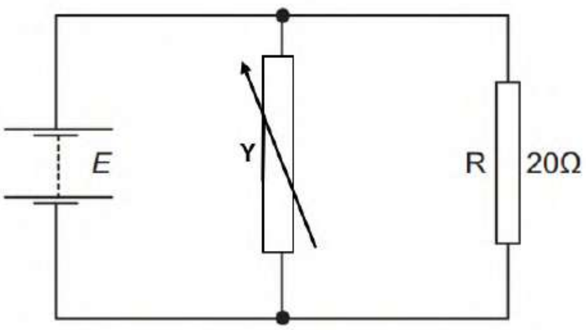
The variation with potential difference V of the current I in a component Y and in a resistor R are shown in the graph. The current is plotted on the y axis and the potential difference is plotted on the x axis.



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

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

10.2 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:

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

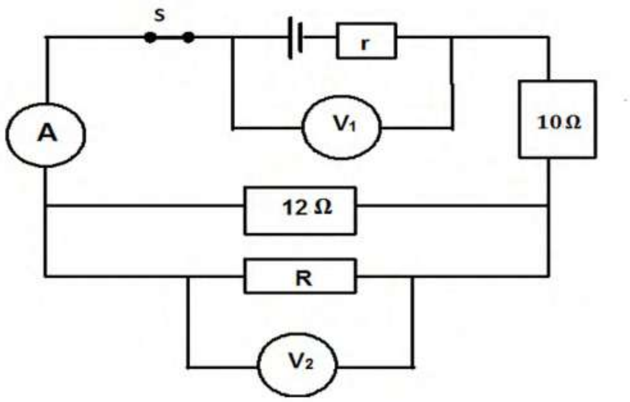
10.2.2 The total resistance of the circuit for a voltage of 8,0 V (3)

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

[15]

QUESTION 11

The battery in the circuit diagram below, has an internal resistance r. When switch S is closed, the reading on voltmeter V_2 is 18 V and resistor R dissipates 13,5 W.



11.1	State Ohm's Law in words.	(2)
11.2	Calculate the resistance of resistor R.	(3)
11.3	Calculate the reading on the ammeter A.	(5)
11.4	Explain, in words, what is meant by the term internal resistance of a battery.	(2)
11.5	Calculate the potential difference across the 10 Ω resistor.	(3)
11.6	When switch S was opened, the reading on voltmeter V_1 was 45,9 V. Calculate the internal resistance of the battery.	(5)
11.7	Does the internal resistance in the circuit INCREASE, DECREASE, or REMAIN THE SAME when resistor R is removed?	(1)

[21]

QUANTITATIVE ASPECT OF CHEMICAL CHANGE – GRADE 11
Grade 10 → Grade 11:

- Empirical formula extended to molecular formula
- Calculations involving limiting and excess reagents
- Percentage purity

- The mole is the SI unit for the amount of substance (describe as mole)
- 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 $g{\cdot}mol^{-1}$

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
$n = \frac{m}{M}$
$5 = \frac{295{,}5}{M}$
$M = \frac{295}{5} = 58{,}5\ g{\cdot}mol^{-1}$

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

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

The Mole and the Gases
Avogadro's Law: One mole of any gas occupies the same volume at the same temperature and pressure.
1 mole of ANY gas at STP is occupies a volume of 22,4 dm^3

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. $V_m = 22{,}4\ dm^3mol^{-1}$)

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 $dm^{-3}\cdot mol^{-1}$)
- 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 with a molar volume of 24 dm^3.

Solutions

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

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

V_m = 0,448 dm^3

4.2) Note: Since molar volume is not 22,4 dm^3, this example is NOT at STP.

$V = \frac{60}{1000} = 0{,}06\ dm^3$

$n = \frac{V}{Vm} = \frac{0{,}06}{24} = 0{,}0025$ mol

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

$0{,}0025 = \frac{m}{17}$

m = 0,0425 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) $c = \frac{m}{MV} = \frac{5{,}55}{(111)(0{,}75)} = 0{,}067\ mol\cdot dm^{-3}$

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

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

m = 12,76 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
A compound is made up of potassium (K), chromium (Cr) and oxygen (O) only. A 1 kg sample of this compound has the following composition by mass:

Element	**Mass(g)**
Potassium (K)	265,31 g
Chromium (Cr)	353,74 g
Oxygen (O)	Remainder

6.1 Calculate the mass of oxygen(O) in the 1 kg sample of the compound.

6.2 Determine the empirical formula of this compound.

Solution
6.1 m(O) = 1000 – (265,31 + 353,74)
= 380,95 g

6.2

Element	mass (g)	$n = \frac{m}{M}$	Simplest Ratio	Simplest Ratio (Modified)
K	265,31	$\frac{265,31}{39} = 6,8$	$\frac{6,8}{6,8} = 1$	1 x 2 = 2
Cr	353,74	$\frac{353,74}{52} = 6,8$	$\frac{6,8}{6,8} = 1$	1 x 2 = 2
O	380,95	$\frac{380,95}{16} = 23,81$	$\frac{23,81}{6,8} = 3,5$	3,5 x 2 = 7
Empirical Formula: $K_2Cr_2O_7$				

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

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

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

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

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

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 Reagent

- 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 reagent will determine:
  - ✓ The amount of product formed.
  - ✓ The amount of other (excess) reagent used.

Determining Limiting Reagent

- 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 reagent

9.2.2 The mass of ammonia that can be produced

9.2.3 The mass of the reagent in excess

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

OPTION 1 (Assume N_2 is the limiting reagent)

Check: If this assumption is correct, H_2 will be in excess.

N_2 : $3H_2$

1 : 3

0,3 : x

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

But only 0,75 moles of H_2 was added. Therefore H_2 is NOT in excess and the assumption was incorrect.

H_2 is the limiting reagent.

OPTION 2 (Assume H_2 is the limiting reagent)

Check: If this assumption is correct, N_2 will be in excess.

$3H_2$: N_2

3 : 1

0,75 : x

$\therefore n(N_2) = 0,25$ mol required

But 0,3 moles of N_2 was added. Therefore N_2 is in excess and the assumption was incorrect.

H_2 is the limiting reagent.

[NOTE: Since H_2 is the limiting reagent, the 0,75 moles of H_2 will be used in all ratios to follow.]

9.2.2) Ratio NH_3 to the limiting reagent (H_2)

$3H_2$: $2NH_3$

3 : 2

0,75 : x

X = 0,5 mol of NH_3 formed

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

m = (0,5)(17)

= 8,5 g

9.2.3) First determine the number of moles of the excess reagent that reacted.

$3H_2$: N_2

3 : 1

0,75 : x

X = 0,25 mol of N_2 reacted

$n(N_2) = \frac{m}{M}$

$m = (0,25)(28)$

$= 7$ g of N_2 reacted

But 8,4 g of N_2 was initially added.

$m(N_2)_{excess} = 8,4 - 7 = 1,4$ 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)

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

Step 3**:** (use stoichiometric ratio)

From the balance equation:

(n)KI : (n)PbI_2

2 : 1

4.52×10^{-3} : ?

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

<u>Step 4</u>**:** (convert the number of moles to mass)

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

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

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

<u>Step 5</u>**:** (percentage yield)

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

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

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

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

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

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

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

$$= 0{,}05 \text{ mol}$$

$n(NaNO_3) : n(O_2)$

2 : 1

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

$$= 0{,}025 \text{ mol}$$

Volume of oxygen produced:

$V(O_2) = nV_m$

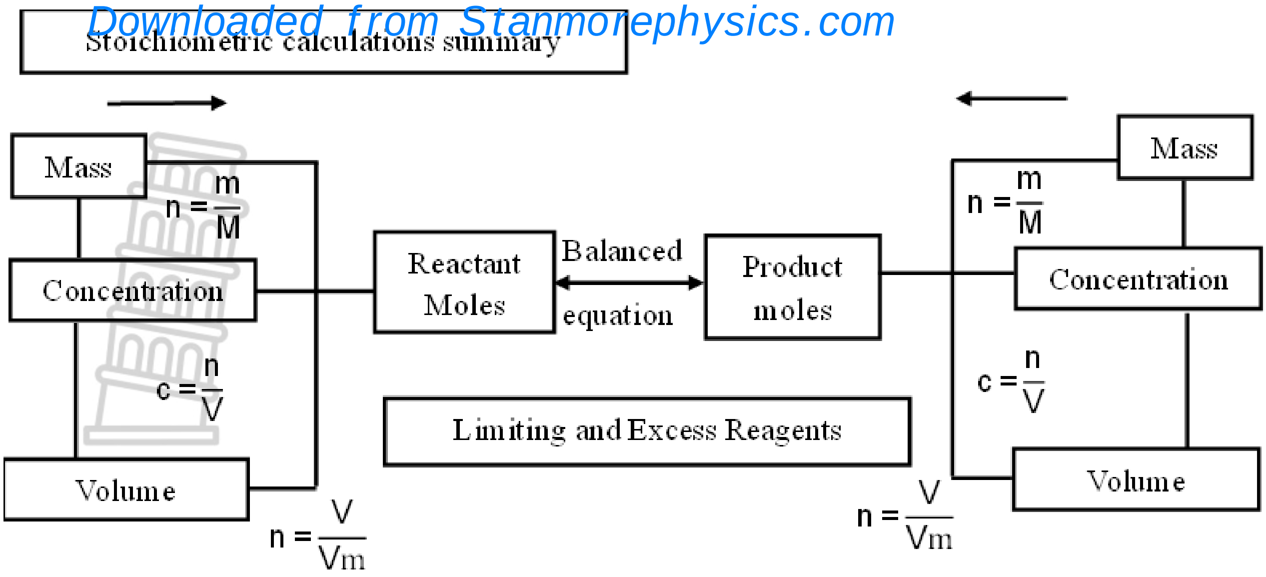
$V(O_2) = 0{,}025 \times 22{,}4$

$= 0{,}56 \text{ dm}^3$

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

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

$$= 89{,}29\%$$



ACTIVITIES

QUESTION 1: MULTIPLE-CHOICE QUESTIONS

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

1.1 The number of ions present in 5 moles of aluminium oxide, $A\ell_2O_3$, is given by…

A $10 \times 6{,}02 \times 10^{23}$
B $5 \times 6{,}02 \times 10^{23}$
C $6 \times 6{,}02 \times 10^{23}$
D $25 \times 6{,}02 \times 10^{23}$ (2)

1.2 Which one of the following contains $6{,}02 \times 10^{23}$ ATOMS?

A 4,48 dm^3 of CH_4 gas at STP
B 22,4 dm^3 of NH_3 gas at STP
C 10 g of Ne
D 28 g of N_2 gas (2)

1.3 A certain chloride is formed when 0,5 moles of element X combines with 1,5 moles of chlorine. Which ONE of the following is the correct empirical formula for this chloride?

A XCl
B XCl_2
C XCl_3
D X_2Cl_3 (2)

1.4 Consider the balanced chemical equation for the reaction below:

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

The number of Oxygen atoms in the SO_3 formed when 22,4 dm^3 SO_2 reacts with excess oxygen (O_2) at STP is …

A $6{,}02 \times 10^{23}$
B $3 \times 6{,}02 \times 10^{23}$
C $2 \times 6{,}02 \times 10^{23}$
D $6 \times 6{,}02 \times 10^{23}$ (2)

1.5 Consider the balanced chemical equation below:

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

Which provides the number of Oxygen atoms required to form 4 moles of aluminium oxide (Al_2O_3)?

A $6 \times 6{,}02 \times 10^{23}$
B $12 \times 6{,}02 \times 10^{23}$
C $3 \times 6{,}02 \times 10^{23}$
D $36 \times 6{,}02 \times 10^{23}$ (2)

[10]

QUESTION 2 – BASIC STOICHIOMETRY

Aluminium powder (Al) reacts with Sulphuric acid (H_2SO_4) according to the balanced equation below.

$$2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

In one such reaction exactly 5 g Aluminium (Al) reacts with Sulphuric acid (H_2SO_4) of concentration 0,1 $mol.dm^{-3}$ at STP.

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

2.2 Calculate the :

2.2.1 Number of moles of Al that reacted (3)

2.2.2 Volume of H_2SO_4 (in dm^3) that reacted (4)

2.2.3 Volume of H_2 gas (in dm^3) that formed at STP (4)

[13]

EMPIRICAL AND MOLECULAR FORMULA

QUESTION 3

A laboratory analysis of an organic compound gave the following mass percent composition:

Carbon: 60,00 %
Hydrogen: 4,48 %
Oxygen: 35,52 %

3.1 Determine the empirical formula of this compound. (6)

The molar mass of the compound is 540 $g{\cdot}mol^{-1}$.

3.2 Determine the molecular formula of this compound. (2)

[8]

QUESTION 4

A 1,50 g sample of a compound containing carbon, hydrogen and oxygen was completely burned in air. The products formed were 1,74 g of carbon dioxide and 0,70 g of water.

4.1 Determine, by calculation, the empirical formula of the compound. (7)

4.2 If the ratio of empirical formula to molecular formula is 1:3, determine the molecular formula of the compound. (2)

[9]

QUESTION 5 – PERCENTAGE COMPOSITION

5.1 Calculate the percentage of carbon in cane sugar $C_{12}H_{22}O_{11}$. (2)

5.2 A metal M forms two chlorides, $MC\ell_2$ and $MC\ell_x$, that contain 55,9% and 65,5% chlorine by mass respectively.

Determine the:

5.2.1 Relative atomic mass of M (4)

5.2.2 Value of x. Show all working. (4)

[10]

QUESTION 6 – CONCENTRATION AND HYDRATED SALTS

6.1 A bottle in a laboratory contains an unknown metal hydroxide (XOH). A lab technician dissolves 1,826 g of the metal hydroxide to make a 100 cm^3 solution.
Upon analysis it was found that the concentration of the metal hydroxide is 0,326 $mol{\cdot}dm^{-3}$.

Determine by calculation, the name of the metal hydroxide. (5)

6.2 A laboratory assistant prepares a solution of calcium nitrate of volume 250cm^3 using $Ca(NO_3)_2{\cdot}4H_2O(s)$ as the solute:

$$Ca(NO_3)_2 \rightarrow Ca^{2+}(aq) + 2NO_3^-(aq)$$

If the concentration of the nitrate ions in the solution is 0,15 $mol{\cdot}dm^{-3}$, calculate the mass of solute that the laboratory assistant used. (5)

[10]

COMPLEX STOICHIOMETRIC CALCULATIONS

QUESTION 7

Methane gas, CH_4, of mass 34,5 g is reacted with oxygen gas in a sealed container according to the following balanced chemical equation.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + H_2O(l)$$

The initial volume of oxygen gas was 69,3 dm^3 when measured at STP.

7.1 Determine the limiting reagent in this reaction. (4)

7.2 Determine the total moles of gas in the container after the reaction is completed. (4)

7.3 Calculate the percentage yield of CO_2 if 58,08 g CO_2 was formed during the reaction. (3)

[11]

QUESTION 8

In an experiment to determine the purity of a sample of calcium carbonate ($CaCO_3$), 3,5 g of an impure sample of $CaCO_3$ was treated with excess hydrochloric acid (HCl).

The balanced equation for the reaction is:

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

If 0,65 dm^3 of carbon dioxide (CO_2) is collected at STP, calculate the percentage purity of the calcium carbonate sample. (6)

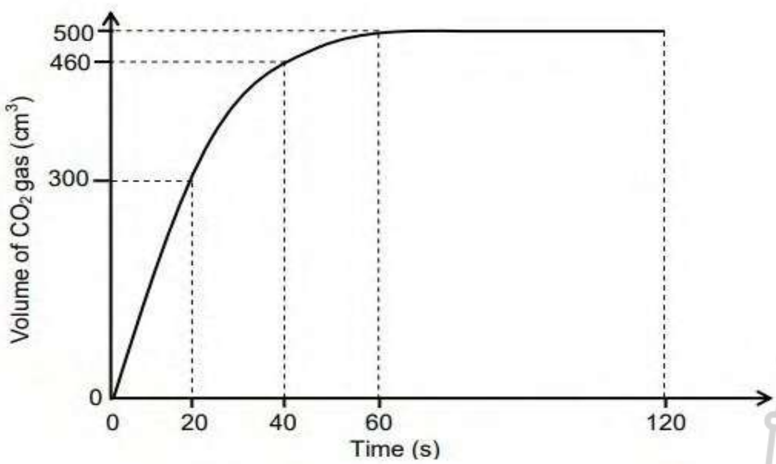
QUESTION 9

In an experiment, a 300 cm^3 solution of hydrochloric acid (HCℓ) of concentration 0,5 $mol.dm^{-3}$ reacts with calcium carbonate powder. The HCℓ is in excess.

The following balanced reaction takes place at 25^0C.

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

The volume of carbon dioxide gas produced is measured at regular time intervals and the following graph is drawn:



9.1 Give a reason why the graph is horizontal after 6 minutes. (1)

9.2 Determine the maximum number of moles of carbon dioxide gas (CO_2) produced. Take the molar gas volume at 25°C to be 24 000 cm^3. (3)

9.3 Calculate the concentration of the HCℓ solution after 6 minutes. Assume that the volume of the solution remains at 300 cm^3. (7)

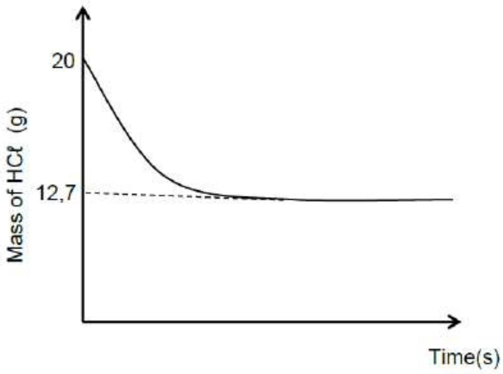
[11]

QUESTION 10

A sample of IMPURE solid calcium carbonate, $CaCO_3$, of mass 12,5 g reacted with dilute hydrochloric acid, HCℓ(aq), according to the following balanced equation:

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

The graph below shows how the mass of the HCℓ(aq) changes with time.



10.1 Write down the name or formula of the limiting reagent in the above reaction. (2)

10.2 Calculate the:

10.2.1 Percentage purity of the calcium carbonate. (7)

10.2.2 Maximum volume of $CO_2(g)$ produced at STP (4)

In another reaction, **X** g of the SAME IMPURE $CaCO_3$ is now reacted with excess HCℓ.

10.3 Calculate the mass of the impure $CaCO_3$ that must be used to produce 12,6 g of H_2O. (5)

[18]

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

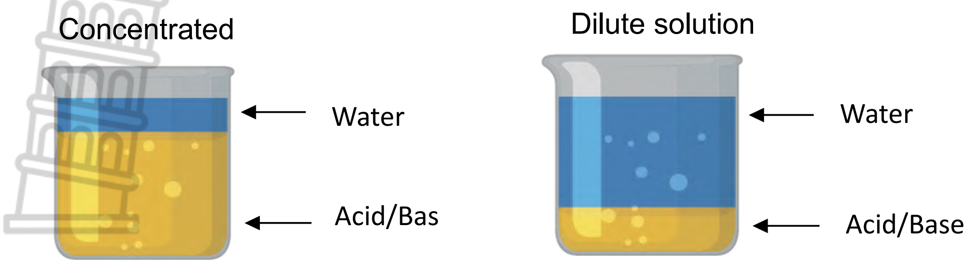
STRONG ACIDS	STRONG BASES
HCℓ – Hydrochloric acid monoprotic)	NaOH – Sodium hydroxide
HNO_3 – Nitric acid (monoprotic	KOH – Potassium hydroxide
H_2SO_4 – Sulphuric acid (diprotic	LiOH – Lithium hydroxide
H_3PO_4 – Phosphoric acid (triprotic)	$Ba(OH)_2$ – Barium hydroxide
WEAK ACIDS	**WEAK BASES**
CH_3COOH – Acetic acid	NH_3 – Ammonia
$(COOH)_2$ – Oxalic acid	$Zn(OH)_2$ – 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.

  - **Concentrated and dilute acids/bases.**

- 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

$V_{H_2O} = 0.17dm^3$

- **Reaction equations of aqueous solutions of acids and bases.**

Examples:

Ionisation equations.

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.)

Dissociation equations

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

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

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

- **Identifying conjugate acid-base pairs.**

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(ℓ) → 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. $H_2SO_4(aq) + Mg(OH)_2(aq) \rightarrow MgSO_4(aq) + 2H_2O(\ell)$

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

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

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 HCℓ

Acid + metal carbonate → salt + water + carbon dioxide

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

- **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^+].

<u>Steps to calculate pH of acids</u>

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)

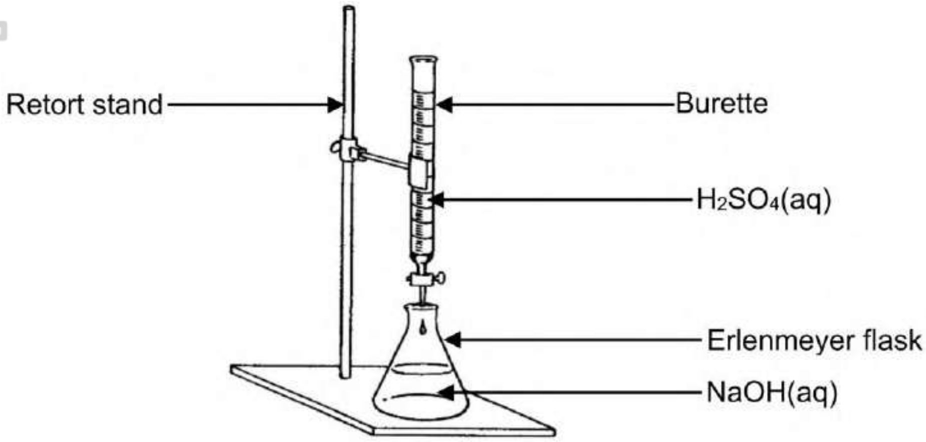
Marking criteria	**tick**
Ratio **1**(H_2SO_4): **2**(H_3O^+)	✓
Formula pH = -log [H_3O^+]	✓
Correct Substitution	✓
Correct Answer	✓

$[H_3O^+]$ = 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	
$c_a = \frac{n}{V}$ $\therefore 0.1 = \frac{1.25 \times 10^{-3}}{V}$ $\therefore V = 0.0125 dm^3$ ✓	

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 $pH = -\log[H_3O^+]$ ✓ (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.

$$HSO_4^- + H_2O \rightarrow H_2SO_4 + OH^-$$

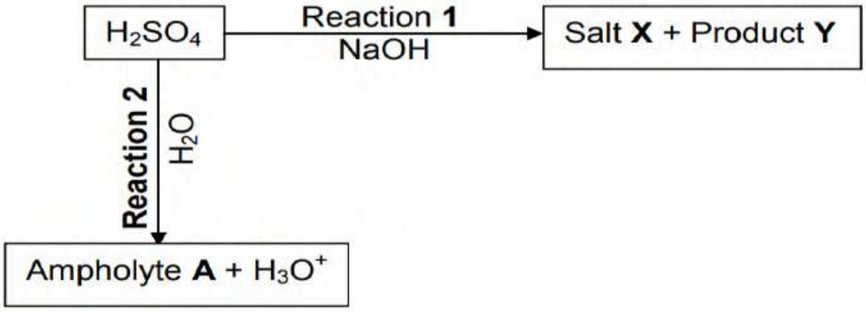
2.4.1 Write down ONE word for the underlined sentence (1)

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.

$NaOH(aq) + NH_4C\ell(s) \rightarrow NaC\ell(aq) + H_2O(\ell) + NH_3(aq)$

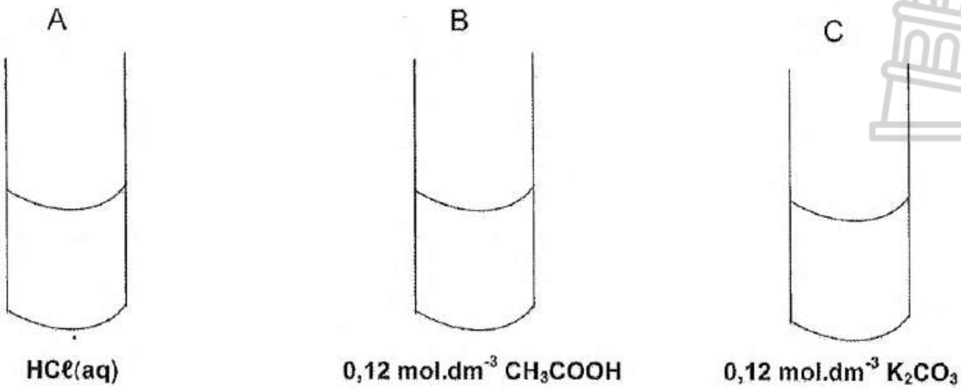
3.2.1 Calculate the concentration of the NaOH solution. (4)

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



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)

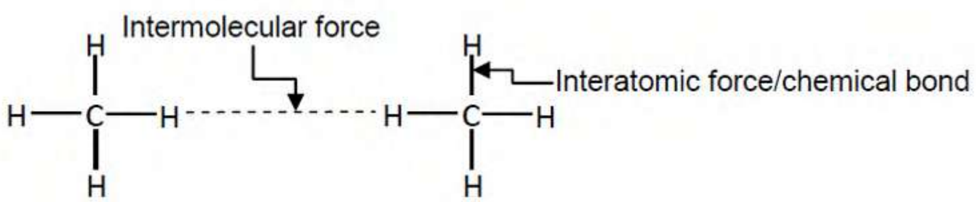
6.1.3 Determine the pH of solution (**I**) at 25 °C. (3)

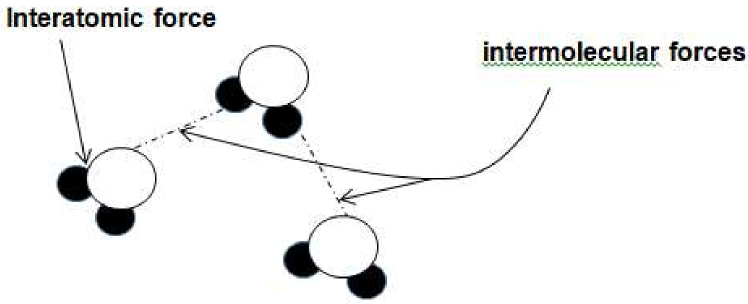
[7]

INTERMOLECULAR FORCES

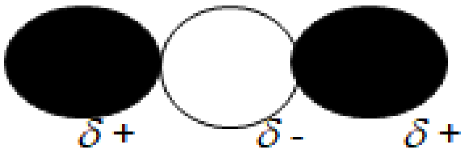
- Intermolecular forces are forces of attraction between molecules in a substance.
- Intermolecular forces are weak forces of attraction between molecules or between atoms of noble gases
- Intermolecular forces are not the same as intramolecular bonds.
- Intramolecular (interatomic) bonds exist between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

Examples of intermolecular forces and intramolecular (interatomic)forces



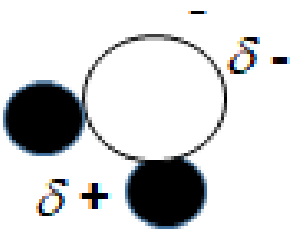


- Molecules can be **polar** or **non-polar**.
- The polarity of a molecule is determined by two factors:
  - The difference in electronegativity between the bonding atoms.
  - The geometry (shape) of a molecule
- **Non-polar molecules** have no dipoles (positive and negative ends) e.g., CO_2



Polar molecule

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

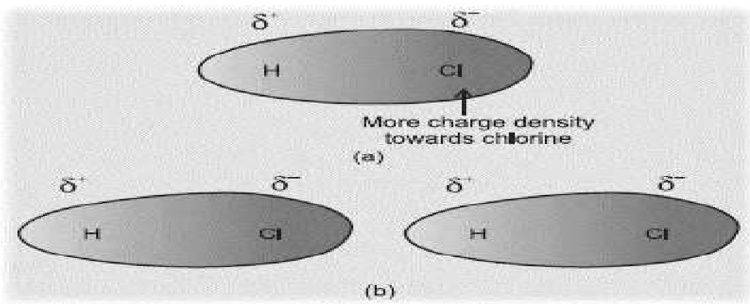


- H_2O molecule has H-end being ∂+ and O-end being ∂-, it has **dipoles.** The molecule is polar

- **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

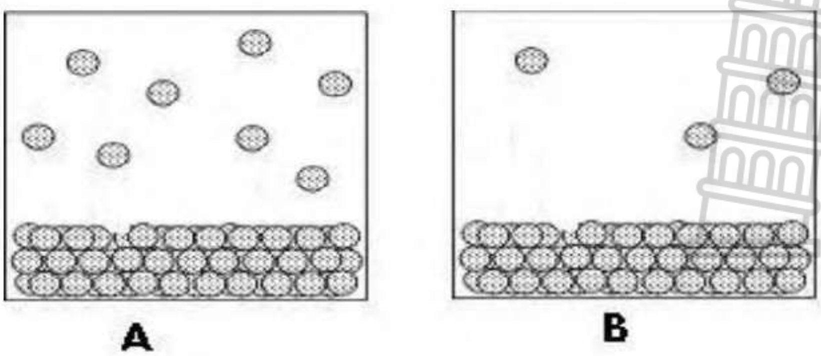
- Intermolecular forces dictate several properties, such as melting points, boiling points, solubility of substances, vapour pressure, viscosity etc.
- Boiling point is the temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the 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.

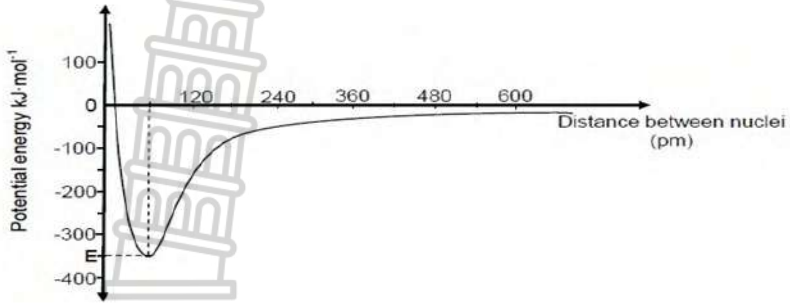


- In the picture above, A has more gas, meaning gas molecules are breaking away from the liquid state easier than molecules in B.
- The intermolecular forces must be weaker in A than in B.
- Molecules in A are less attracted to each other than molecules in B.
- Intermolecular forces in A are weaker than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

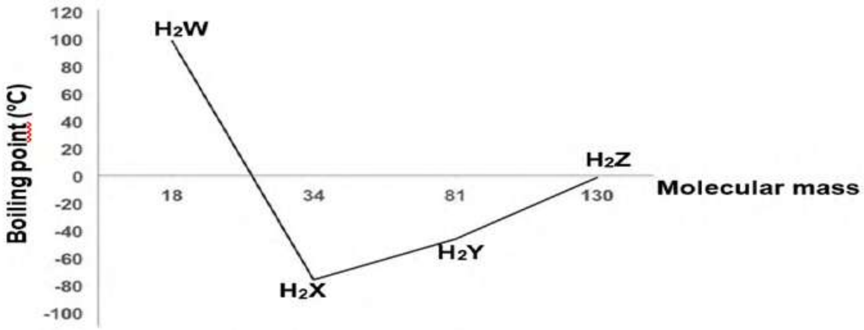
1.2.3 Bond energy✓ (1)

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]

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

$$\Delta H = \text{Energy}_{absorbed} - \text{Energy}_{released}$$

If $\Delta H < 0$ (negative): Exothermic reaction If $\Delta H > 0$ (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.

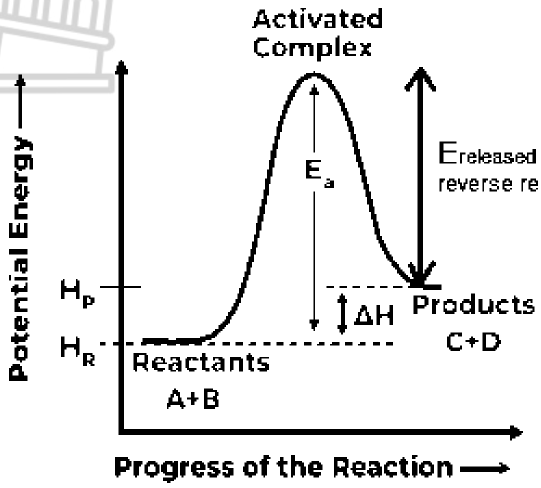
Activation energy: The minimum energy required for a reaction to take place.

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.

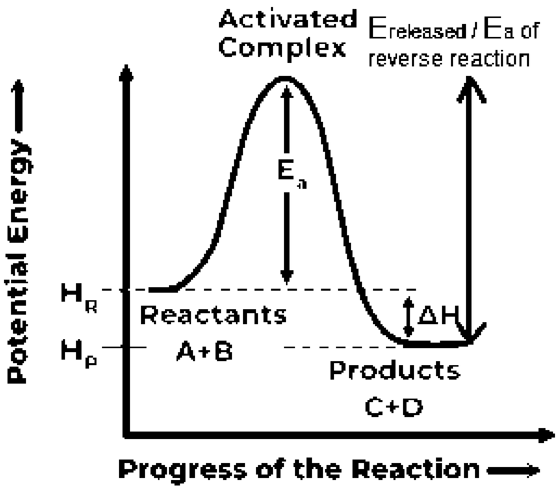
Energy Graphs/ Profiles

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

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

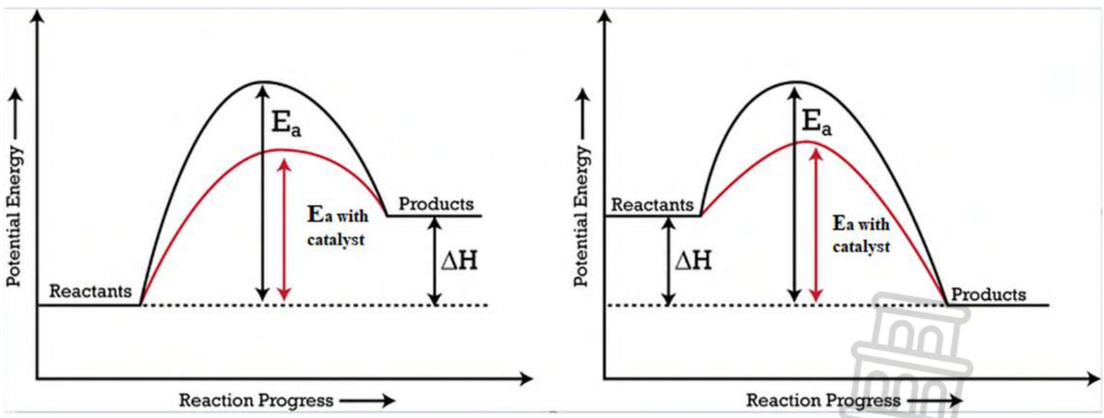


Endothermic Reaction



Exothermic Reaction

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

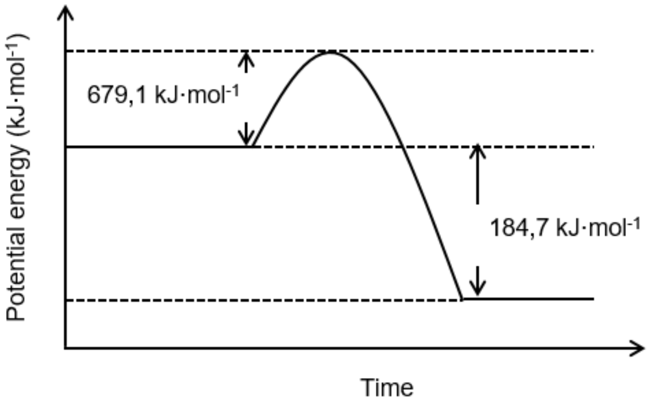
1.1. Calculate the enthalpy change by making use of bond energy values. (4)
Energy absorbed = 3(H – H) + (N ≡ N)
Energy absorbed = 3(436) + 946 ✓ = 2254 kJ.mol^{-1}
Energy released = 6(N – H)
Energy released = 6 (389) ✓ = 2334 kJ.mol^{-1}
Δ H = 2254 – 2334 ✓ = - 80 kJ.mol^{-1} ✓

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
$Energy_{released} = n\Delta H$ ✓
$Energy_{released} = (0,357142857)(80)$ ✓ $= 28,57$ 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 $C\ell_2$) 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 $HC\ell$ 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

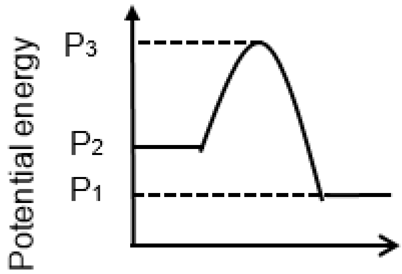
ΔH per mol HI $= -\frac{21}{2}$ ✓ $= 10{,}5$ kJ.mol^{-1}

$Energy_{required} = n\Delta H$

$Energy_{required} = (0{,}390625)(10{,}5)$ ✓ $= 4{,}10$ 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. Clearly indicate the following on the graph: (3)

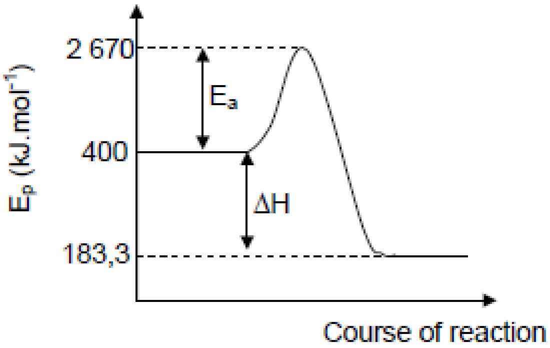
- Activation energy
- Heat of reaction (ΔH)
- Reactants and products

[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)

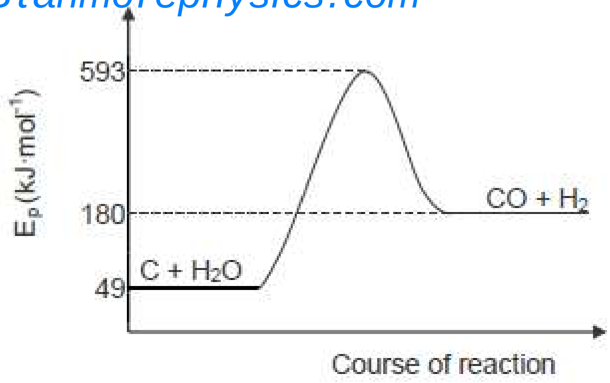
[13]

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. (5)
On the graph indicate values for:

- 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]

IDEAL GASES AND THERMAL PROPERTIES

According to the Kinetic Molecular Theory (KMT), molecules of a gas:

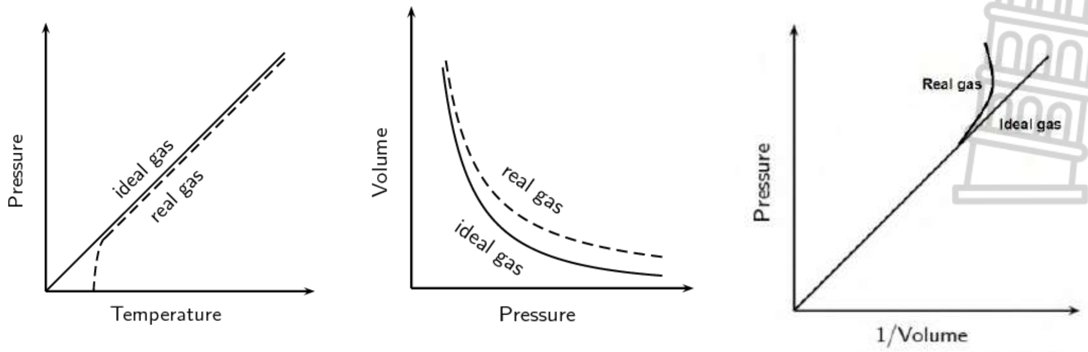
- Have the highest kinetic energy (move the fastest with different speeds)
- Are further apart, forces of attraction are very weak
- Easy to compress
- Exert pressure when they collide with each other and the sides of the container
  - Pressure is the force per unit area. $p=\frac{F}{A}$ (p ∝number of collisions)

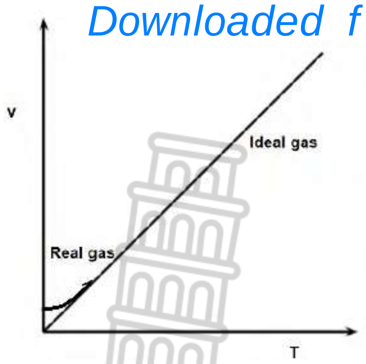
Ideal Gases
Molecules of an ideal gas:

- 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





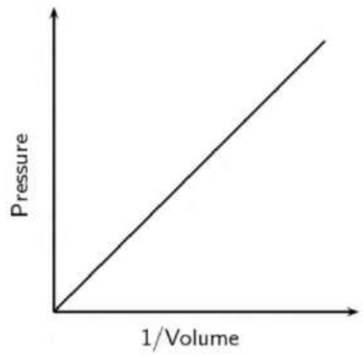
At **High Pressure** real gases occupy a volume. Gas molecules become compressed and are closer to each other. Forces of repulsion between molecules become strong. Volume is higher than predicted.
At **Low Temperature** gases liquefy. Forces of attraction between molecules become strong. Gas molecules occupy a volume, volume is higher than predicted.

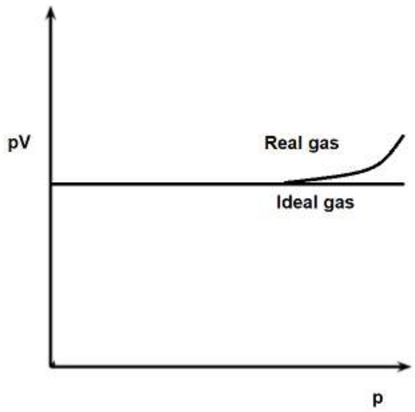
Real gases act like ideal gases at (1) High Temperature and (2) Low Pressure

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.

$$p \propto \frac{1}{V}$$

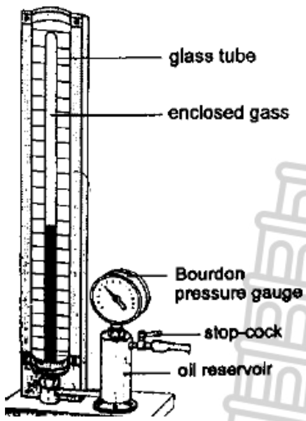




gradient=pV
k=pV
units of k=Pa × m^3
units of k=$N.m^{-2}$ × m^3
units of k =N.m
units of k=J

Boyle's Law Equation: $p_1V_1=p_2V_2$

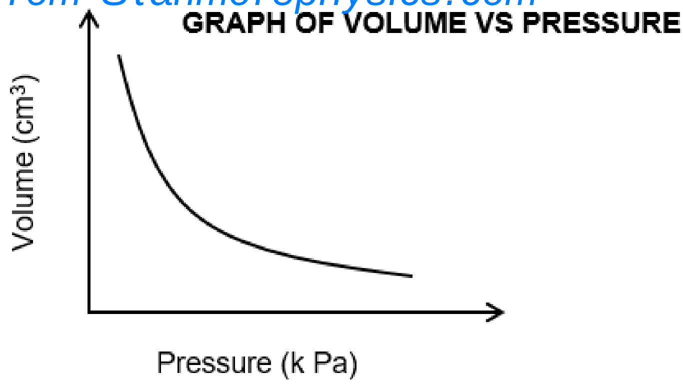
Common conversions:
kPa=1000 Pa $1cm^3=10^{-6}m^3$ $1dm^3=10^{-3}m^3$



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.



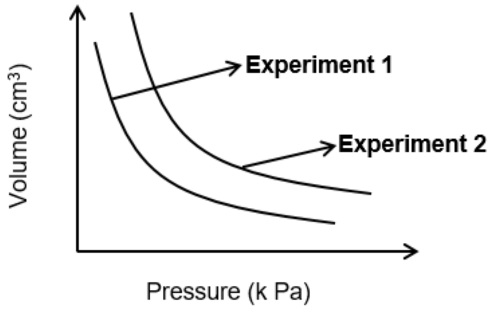
1.1. Write down the name of the law which formulates the pressure-volume relationship shown by the graph. (1)

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 ✓

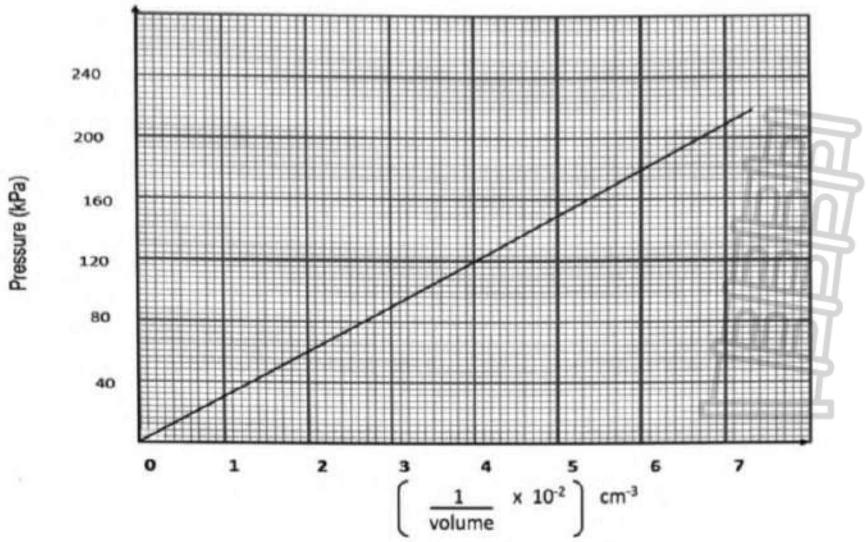
Kinetic energy of the molecules will be higher and they will move more freely ✓ *increasing the volume.* ✓

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 x 10^{-2} ✓

$\therefore v=\frac{1}{6{,}7 \times 10^{-2}}$ ✓

v=14,93 cm^3 ✓

2.4. Determine the pressure exerted by the gas when its volume is 11,11 cm^3. (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)

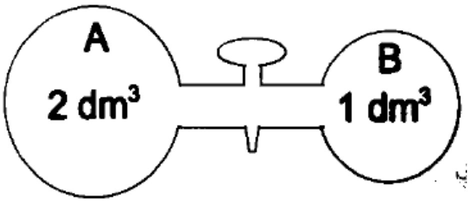
$p_1V_1=p_2V_2$✓

(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)



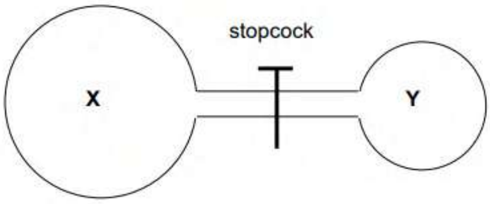
$p_1V_1=p_2V_2$ ✓

(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

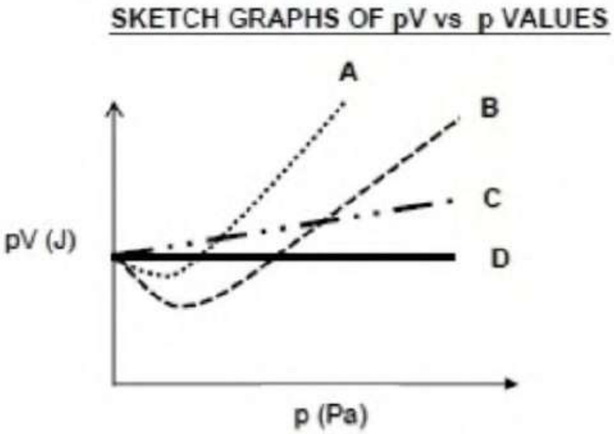
C $\frac{3}{4}$ v

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 ºC 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)

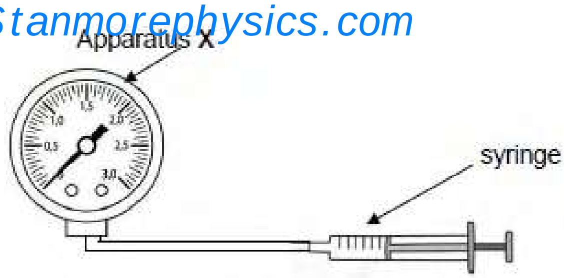
3.3. Write down TWO conditions under which real gases behave more like an ideal gas. (2)

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)

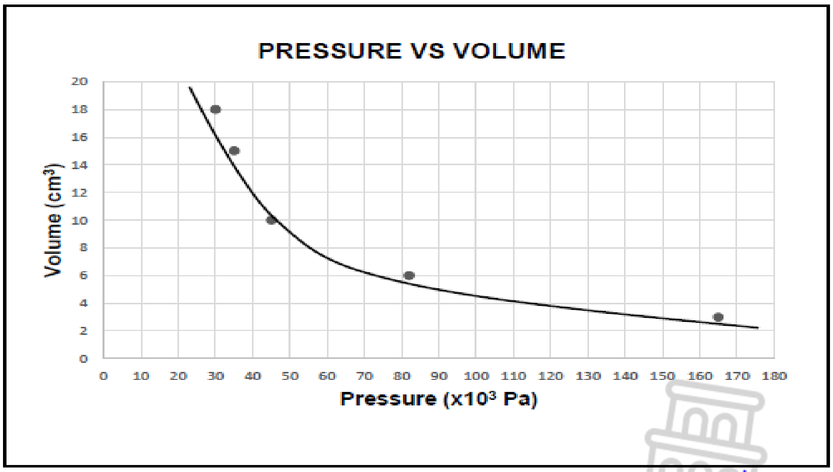
4.5. Using the information from the graph write down the learner`s conclusion. (2)

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)

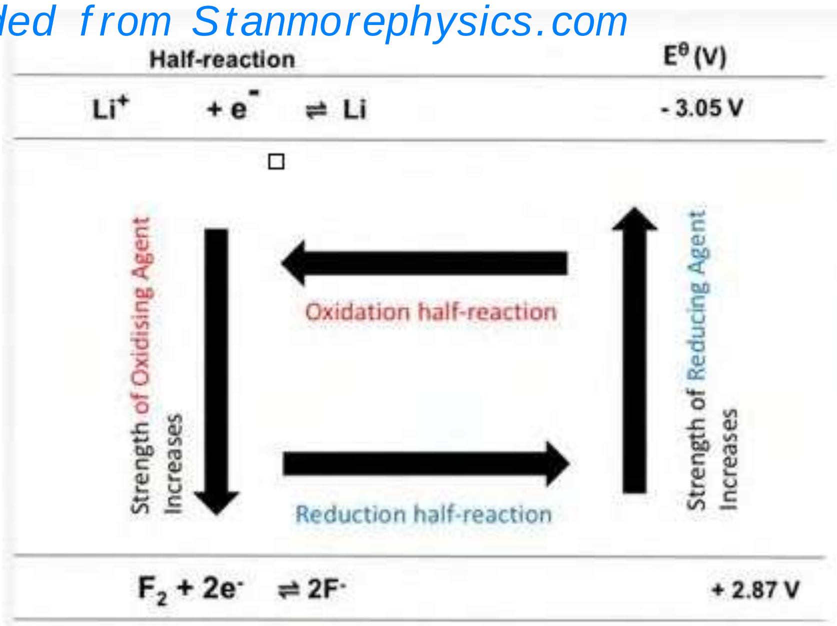
Nett ionic reaction: $X + Y^{2+} \rightarrow X^{2+} + Y$ (no electrons are shown in the nett reaction)

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: $Cu^{2+} + 2e^- \longrightarrow Cu$

Example2: $MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$

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

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 example)

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 $Cl_2 (g) + 2e^- \longrightarrow 2Cl^- (aq)$ ✓✓ (2)

3.2.4 $Fe^{2+} (aq) \longrightarrow Fe^{3+} (aq) + e^-$ ✓✓ (2)

3.2.5 $2Fe^{2+} (aq) + Cl_2 (g) \longrightarrow 2Fe^{3+} (aq) + 2Cl^- (aq)$ ✓✓ (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]

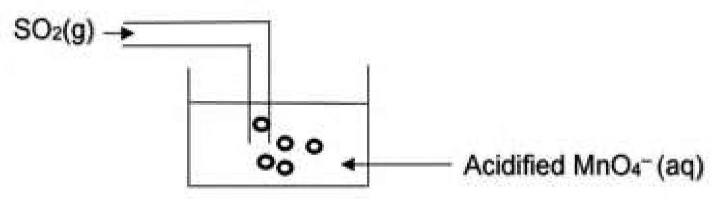
3.1 A clean piece of copper (Cu) is placed in a solution of silver nitrate ($AgNO_3$).
The balanced net ionic equation is:

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

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)