Education

KwaZulu-Natal Department of Education
REPUBLIC OF SOUTH AFRICA

CURRICULUM DIRECTORATE

LEARNER SUPPORT DOCUMENT

GRADE 10-12

PHYSICAL SCIENCES

WINTER AND SPRING REVISION MATERIAL

JUNE 2019

NEWTONS'LAWS OF MOTION

Different kinds of forces:

***Weight, normal force, frictional force, applied force (push, pull), tension (strings or cables*)**.

1.1. DEFINITIONS

- **Define *weight*, W,** as the gravitational force that the earth exerts on any object that has mass.
- **Define *normal force*, N**, as the force or the component of a force which a surface exerts on an object with which it is in contact, and which is perpendicular to the surface.
- **Define *frictional force*, f,** as the force that opposes the motion of an object and which acts parallel to the surface.
- **Define *static frictional force*, f_s**, as the force that opposes the tendency of motion of a stationary object relative to a surface.
- **Define *kinetic frictional force*, f_k**, as the force that opposes the motion of a moving object relative to a surface.

Know that a frictional force:

- Is proportional to the normal force
- Is independent of the area of contact
- Is independent of the velocity of motion

1.2. SOLVE PROBLEMS

1.2.1. Solve problems using $f_s^{max} = \mu_s N$

Where f_s^{max} is the maximum static frictional force and μ_s is the coefficient of static friction.

NOTE:

- If a force, F, applied to a body parallel to the surface does not cause the object to move, F is equal in magnitude to the static frictional force.
- The static frictional force is a maximum (f_s^{max}) just before the object starts to move across the surface.
- If the applied force exceeds f_s^{max}, a resultant (net) force accelerates the object.

1.2.2. Solve problems using $f_k = \mu_k N$,

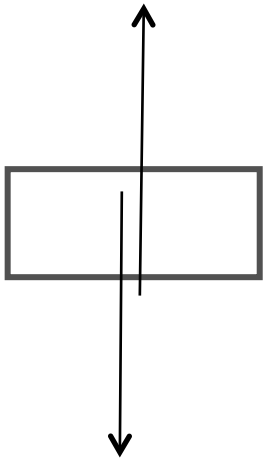
where f_k is the kinetic frictional force and μ_k the coefficient of kinetic friction.

2. Force diagrams, free-body diagrams

- **Draw force diagrams.**
- **Draw free-body diagrams.**
  (This is a diagram that shows the relative magnitudes and directions of forces acting on a body/particle that has been isolated from its surroundings) '
- **Resolve a two-dimensional force**
  (such as the weight of an object on an inclined plane) into its parallel (x) and perpendicular (y) components.
- **Determine the resultant/net force of two or more forces.**

EXAMPLES

Example 1
Object resting on a horizontal surface.
When an object is resting on a horizontal surface the normal force will have the same magnitude, but an opposite direction to the weight of the object or gravitational force.
An object resting on a horizontal surface

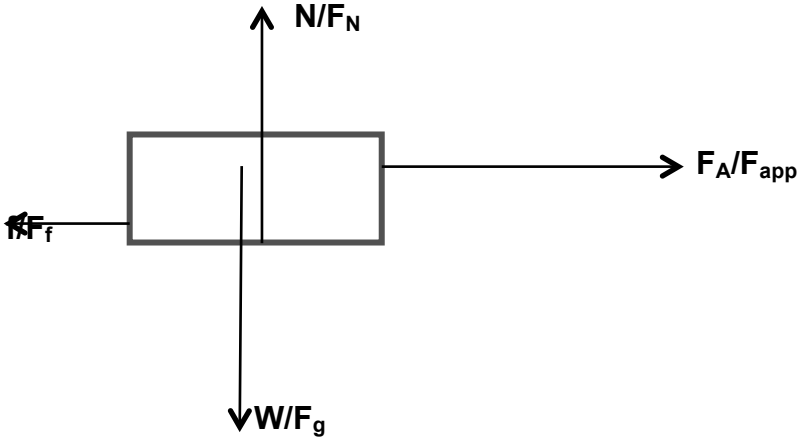
Force diagram	***Free-body diagram***
N / F_N  **W / F_g**	***N/F_N***  ***W / F_g***
So F_N= -F_g or F_N= -mg (the negative sign indicates the direction of the force)	

Example 2

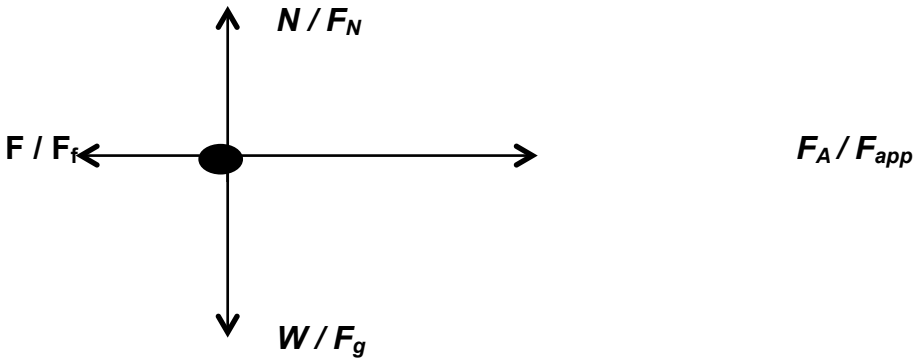
An object moving on a horizontal surface/plane.

A box is being pushed, to the right, along a horizontal rough surface.

FORCE DIAGRAM



FREE-BODY DIAGRAM



So $F_N = -F_g$ or $F_N = -mg$

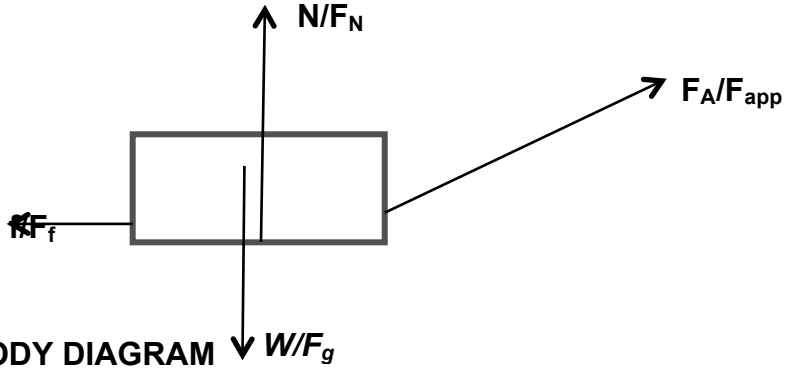
But f /F_f < F_A / F_{app}

Example 3

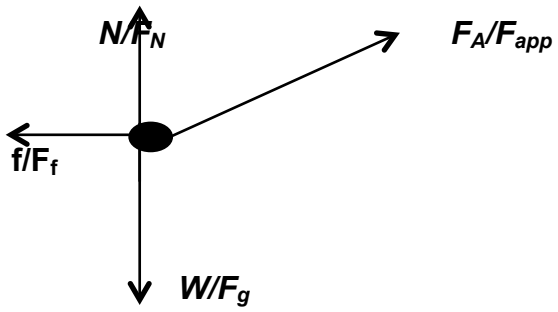
An object moving on a horizontal surface/plane with applied force at an angle to the horizontal.

A box is being pulled, to the right, with a force applied at an angle β along a horizontal rough surface.

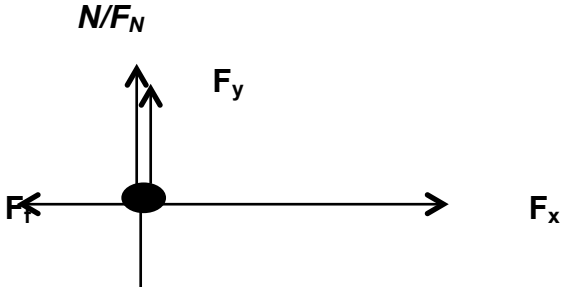
FORCE DIAGRAM



FREE-BODY DIAGRAM



RESOLVING F_A/F_{app} INTO COMPONENTS



NOTE : *The normal force is not always equal to the weight, ($F_N \neq -F_g$ or $F_N \neq -mg$) but the weight is equal to the normal force added to the vertical component of the applied force, ($W = F_N + F_y$).*

Therefore $F_N = W - F_y$

$F_y = F_A \sin\beta$

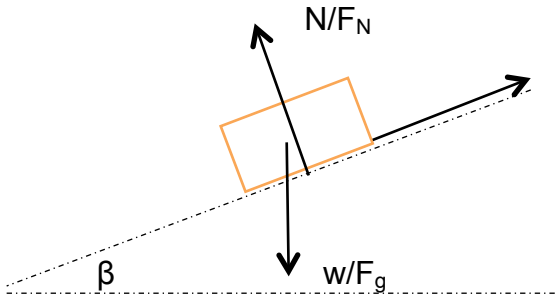
$F_x = F_A \cos\beta$

EXAMPLE 4

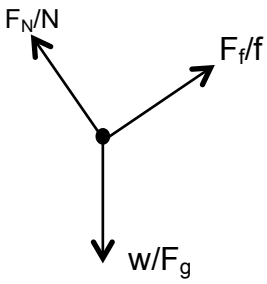
Object resting on an inclined surface:
When an object is resting on a **rough** inclined plane (surface), the normal force will have the same magnitude, but an opposite direction to the perpendicular component of the weight of the object or gravitational force. **($F_{g\perp} = N$)**

An object resting on an inclined plane (surface)

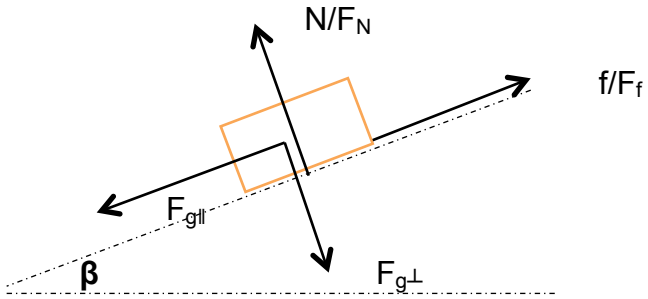
FORCE DIAGRAM



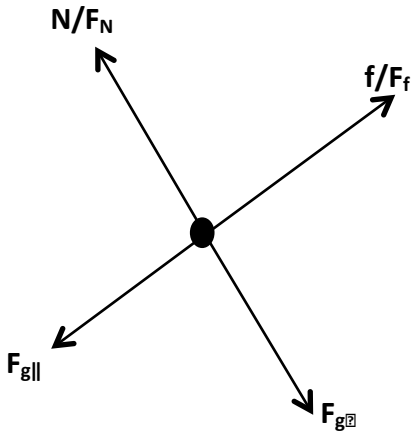
FREE-BODY DIAGRAM



The weight can be resolved into the parallel ($F_{g\parallel}$) and perpendicular components ($F_{g\perp}$).



FREE-BODY DIAGRAM



NOTE :

W or Fg = mg

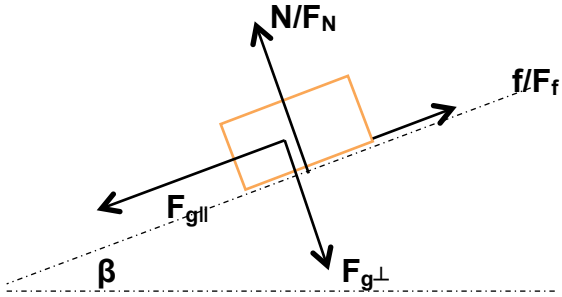
$F_{g\perp}$ = mg Cosβ

$F_{g\parallel}$ = mg Sinβ

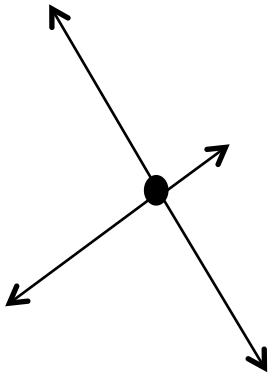
$F_{g\parallel}$ = -F_f

EXAMPLE 5

Object sliding down on an inclined surface:
When an object is sliding down on a **rough** inclined plane (surface).
FORCE DIAGRAM



FREE-BODY DIAGRAM

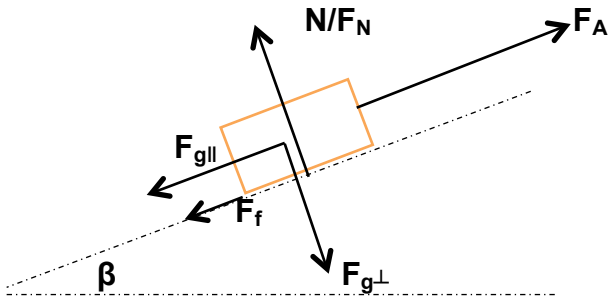


NOTE:

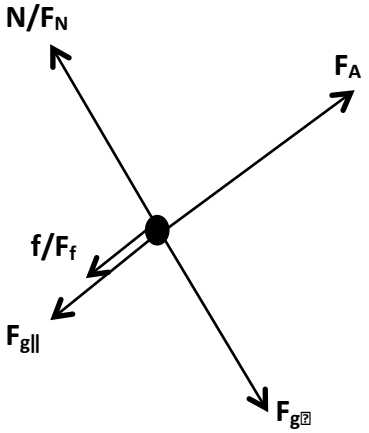
$F_{g\parallel} > F_f$ / $N = F_{g\perp}$

EXAMPLE 6

Object pulled up the inclined surface:
When an object is pulled up on a **rough** inclined plane (surface).
FORCE DIAGRAM



FREE-BODY DIAGRAM



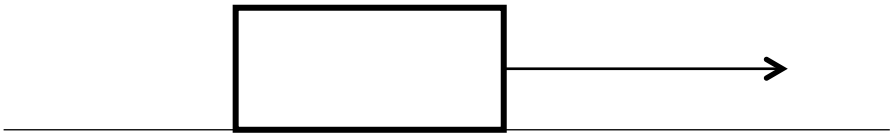
NOTE:
$F_A > F_f + F_{g\parallel}$ (for accelerating object),

$F_A = F_f + F_{g\parallel}$ (for object moving at constant velocity

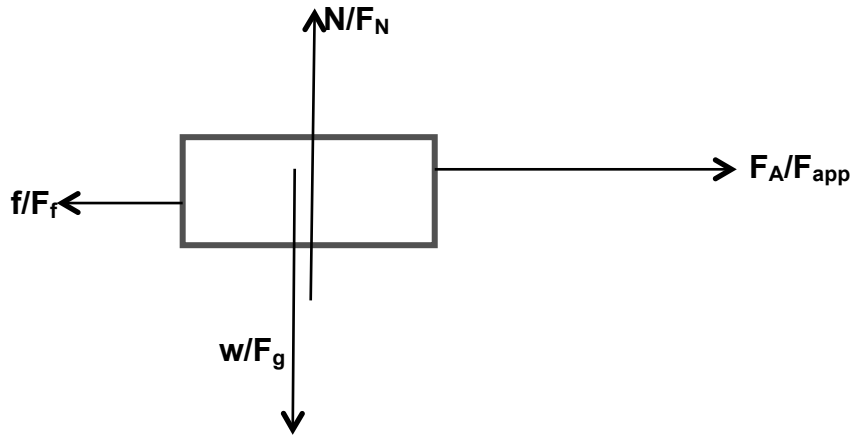
Worked examples

A 6kg box is pulled, to the right on a horizontal surface, by a force of 20N. The box experiences

a constant frictional force of 3N during its motion.



A. Drawing the force diagram



B. Calculating the Normal force

$w = mg$
$w = (6)(9.8)$
$w = 58.8N\ downwards$

Therefore F_N = 58.8N upwards

C. Calculating the coefficient of kinetic friction

$f_k = \mu_k N$
$3 = \mu_k(58.8)$
$\mu_k = 0.05$

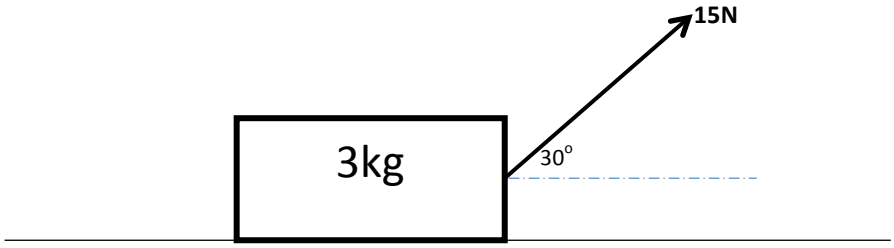
D. Calculating the net/resultant force

Taking right as + and left as –

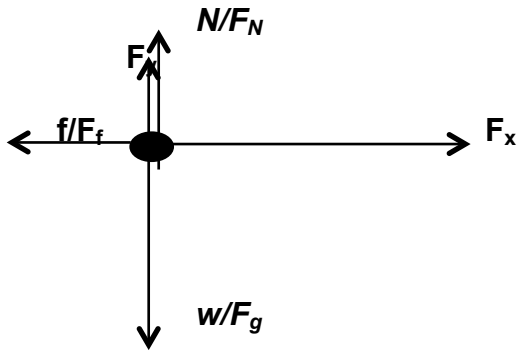
$F_{net} = F_A + f_k$
$= 20 + (-3)$
$= 17N\ right$

PROBLEM 2

A 3kg block is pulled to the right, by a 15N force, applied at an angle of 30° to the horizontal. The surface has a coefficient of kinetic friction of 0.2.



A. Drawing a free-body diagram



B. Calculating a Normal force

$W = F_N + F_y$

$F_N = W - F_y$

$= mg - FSin\theta$

$= (3)(9.8) - (15)Sin30$

$F_N = 21.9N$ upwards

C. Calculating net force

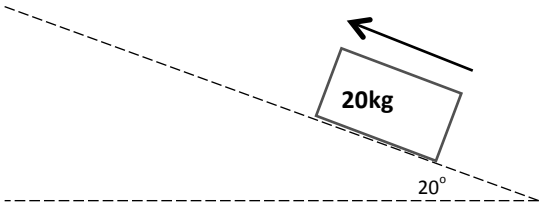
$F_{net} = F_x + f_k$

$= 15\ Cos\ 30^o + [-(0.2 \times 21.9)]$

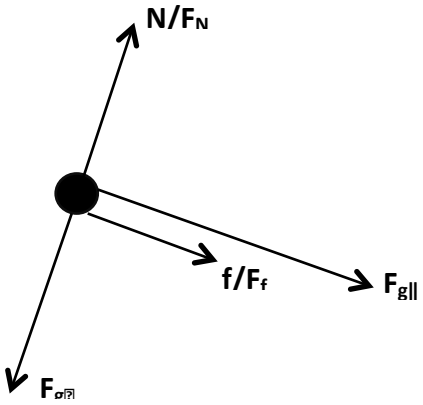
$= 3.12N\ right$

PROBLEM 3

A 20kg wooden box slides up a surface inclined at 20^o to the horizontal. The box experiences a constant frictional force of 2.5N as it slides up the surface.



A. Drawing the free-body diagram



B. Calculating the net force

$F_{net} = F_{g\parallel} + f_k$

$= mgSin20^o + \mu_k N$

$= (20 \times 9.8\ Sin\ 20^0) + (2.5)$

$= 69.54N\ down\ the\ incline$

NEWTON"S FIRST LAW

An object continues in a state of rest or uniform (moving with constant) velocity unless it is acted upon by an unbalanced (net or resultant) force.

NEWTON"S SECOND LAW

When a resultant/ net force (F_{net}) is applied on an object of mass (m), it accelerates in the direction of the net force. The acceleration (a) is directly proportional to the net force and inversely proportional to the mass of the object.

The mathematical expression for the law can be written as:

$F_{net} = ma$

F_{net} is the net force measured in newtons (N)

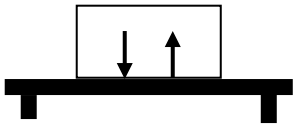
m is the mass of an object measured in kilograms (kg)

a is the acceleration measured in metre per second squared ($m.s^{-2}$)

NEWTON'S THIRD LAW

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

Example



A box on the table exerts a force, (W = mg) on the table downwards, and the table exerts equal but upwards force on the box. It is important to note that ***whilst the two forces are equal in magnitude and opposite in direction, they cannot cancel*** since **they do not act on the same object.**

Further applications of Newton's third law

i) When swimming, the swimmer pushes the water backwards with his/her hands, and the water then pushes the swimmer forward.

ii) When a person walks, his legs and toe muscles exert a force on the floor in a slanted, downward direction. The floor exerts an equal but opposite force, which pushes the person forward.

iii) Space rockets are propelled by recoil. The rapidly expanding gases which escape from the combustion chamber experiences a downward force, this escaping gas will then exert an equal force, which pushes the rocket upwards.

Activity 3.1

You are given a vase resting on a table, as shown below.

(a) Identify one contact force.
(b) Identify one non-contact force
(c) Identify all the action–reaction forces for the vase.
(d) Identify all the action–reaction forces for the table.

NEWTON'S LAW OF UNIVERSAL GRAVITATION

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

The mathematical expression for the law can be written as:

$$F = \frac{Gm_1m_2}{r^2}$$

F is the gravitational force

m_1 is the mass of body one

m_2 is the mass of body two

4.1 The magnitude of the gravitational force exerted by one body on another body is F. When the distance between the centres of the two bodies is doubled, the magnitude of the gravitational force, in terms of F, will now be …

A. $\frac{1}{4}$ F

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

C. 4 F

D. 2 F

suppose m_1 is the mass of a planet, and m_2 the mass of a body on that planet, then

$F = \frac{Gm_1m_2}{r^2}$ is the weight of the body. Hence $w = F$

$$m_2 g = \frac{Gm_1m_2}{r^2}$$

therefore $$g = \frac{Gm_1}{r^2}$$

Comparison of mass and weight

- Mass is the actual amount of material contained in a body and is measured in kilograms whereas weight is the force exerted by the gravity on that object and it is measured in newtons.
- Mass is independent of everything but weight is different on the Earth, moon, etc.
- Mass is a scalar quantity and weight is a vector quantity.

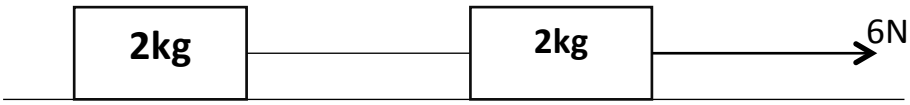
Weightlessness

- Weightlessness is the phenomenon which occurs when there is no force of support on your body. When your body is effectively in free fall accelerating downwards at the acceleration of gravity, then you are not being supported.

ASSESSMENT ACTIVITIES

QUESTION 1 (June 2008)

Two blocks X and Y, each of mass 2kg, are connected by an inelastic rope of negligible mass. When a constant force of 6N is applied horizontally to the right on block Y, the blocks accelerate at 0,5 $m \cdot s^{-2}$. The frictional force between the blocks and the surface is the same.



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

1.2 Draw two separate force diagrams with labels showing the horizontal forces acting on X and Y. (4)

1.3 Explain why block X and Y experience the same frictional force. (2)

1.4 Calculate the frictional force experienced by block X and the tension in the string that connects X and Y. (9)

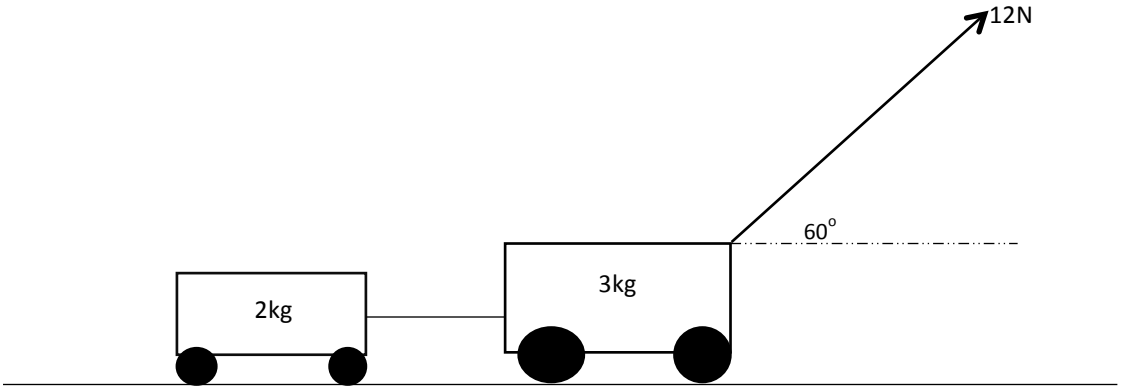
QUESTION 2 (March 2003)

A toy train engine P, of mass 3kg, is connected by a string to a wagon Q of mass 2kg.

Thuli fastens a cable to P and pulls it with a force of 12N at an angle of 60^{o} with the horizontal,

as shown below.

The train moves over a wooden floor which has a coefficient of kinetic friction of 0.05.



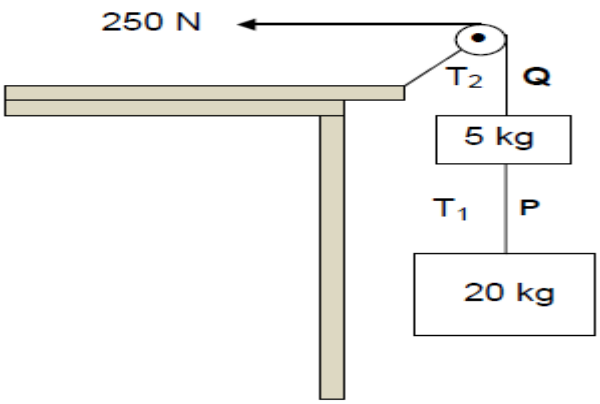
2.1 Calculate the magnitude of the horizontal component of the applied force. (3)

2.2 Draw two separate force diagrams showing all the forces that act on P and Q respectively. (7)

2.3 Calculate the magnitude of the acceleration of the train. (7)

QUESTION 3 (NOVEMBER 2014)

Two blocks of masses 20 kg and 5 kg respectively are connected by a light inextensible string, P. A second light inextensible string, Q, attached to the 5 kg block, runs over a light frictionless pulley. A constant horizontal force of 250 N pulls the second string as shown in the diagram below. The magnitudes of the tensions in P and Q are T_1 and T_2 respectively. Ignore the effects of air friction.



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

3.2 Draw a labelled free-body diagram indicating ALL the forces acting on the 5 kg block. (3)

3.3 Calculate the magnitude of the tension T1 in string P. (6)

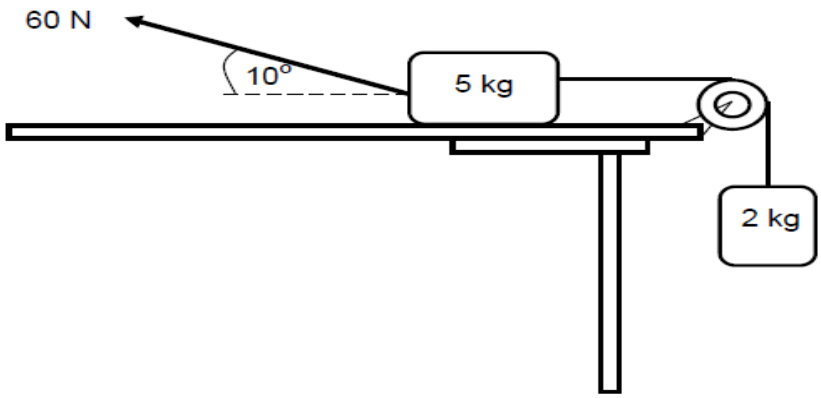
3.4 When the 250 N force is replaced by a sharp pull on the string, one of the two strings break.

Which ONE of the two strings, P or Q, will break? (1)

QUESTION 4 (JUNE 2015)

A 5 kg block, resting on a rough horizontal table, is connected by a light inextensible string passing over a light frictionless pulley to another block of mass 2 kg. The 2 kg block hangs vertically as shown in the diagram below.

A force of 60 N is applied to the 5 kg block at an angle of 10^{o} to the horizontal, causing the block to accelerate to the left.



The coefficient of kinetic friction between the 5 kg block and the surface of the table is 0,5. Ignore the effects of air friction.

4.1 Draw a labelled free-body diagram showing ALL the forces acting on the 5 kg block. (5)

4.2 Calculate the magnitude of the:

4.2.1 Vertical component of the 60 N force (2)

4.2.2 Horizontal component of the 60 N force (2)

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

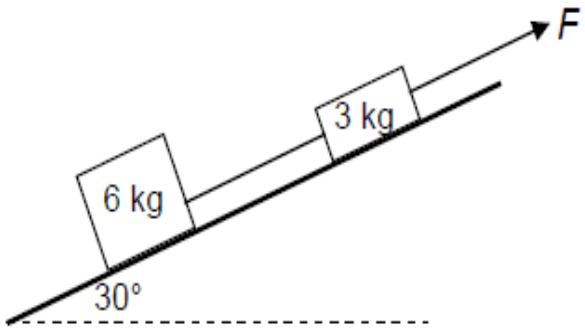
Calculate the magnitude of the:

4.4 Normal force acting on the 5 kg block (2)

4.5 Tension in the string connecting the two blocks (7)

QUESTION 5 (Examplar 2014)

A light inelastic string connects two objects of mass 6 kg and 3 kg respectively. They are pulled up an inclined plane that makes an angle of 30° with the horizontal, with a force of magnitude F. Ignore the mass of the string.



The coefficient of kinetic friction for the 3 kg object and the 6 kg object is 0,1 and 0,2 respectively.

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

5.2 How will the coefficient of kinetic friction be affected if the angle between the incline and the horizontal increases? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

5.3 Draw a labelled free-body diagram indicating all the forces acting on the 6 kg object as it moves up the inclined plane. (4)

5.4 Calculate the:

5.4.1 Tension in the string if the system accelerates up the inclined plane at 4 $m \cdot s^{-2}$ (5)

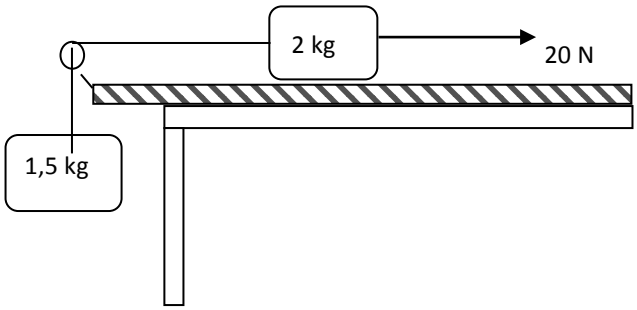
5.4.2 Magnitude of F if the system moves up the inclined plane at CONSTANT VELOCITY (6)

5.5 How would the tension in the string, calculated in QUESTION 2.4.1, be affected if the system accelerates up a FRICTIONLESS inclined plane at 4 $m \cdot s^{-2}$?

Write down only INCREASES, DECREASES OR REMAINS THE SAME. (1)

QUESTION 6

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 effects of air friction.



6.1 Define the term kinetic frictional force. (2)

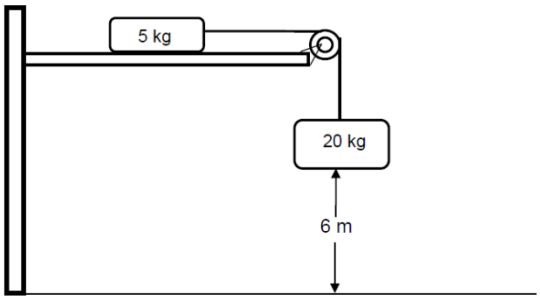
6.2 Draw a labelled free-body diagram indicating ALL the forces acting on the 2 kg block. (5)

6.3 Apply Newtons' Second Law to each of the blocks and calculate the magnitude of the acceleration of the blocks. (6)

QUESTION 7

7.1 A 5 kg mass and a 20 kg mass are connected by a light inextensible string which passes over a light frictionless pulley. Initially, the 5 kg mass is held stationary on a horizontal surface, while the 20 kg mass hangs vertically downwards, 6 m above the ground, as shown in the diagram below.

The diagram is not drawn to scale.



When the stationary 5 kg mass is released, the two masses begin to move. The coefficient of kinetic friction, μk, between the 5 kg mass and the horizontal surface is 0,4. Ignore the effects of air friction.

2.1.1 Calculate the acceleration of the 20 kg mass. (5)

2.1.2 Calculate the speed of the 20 kg mass as it strikes the ground. (4)

2.1.3 At what minimum distance from the pulley should the 5 kg mass be placed initially, so that the 20 kg mass just strikes the ground? (1)

2.2 A person of mass 60 kg climbs to the top of a mountain which is 6 000 m above ground level.

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

7.2.2 Calculate the difference in the weight of the climber at the top of the mountain and at ground level. (6)

MOMENTUM

- ✓ is the product of the object's mass and its velocity.
- ✓ The formula to calculate momentum is:

$$p = mv$$

where:

p = momentum in $kg.m.s^{-1}$

m= mass of an object in kg

v= velocity of an object in $m.s^{-1}$

- ✓ Momentum (p) is a vector quantity - it has magnitude and direction
- ✓ Direction of momentum (p) depends on the direction of the object's velocity.
- ✓ S.I units are: **$kg.m.s^{-1}$**

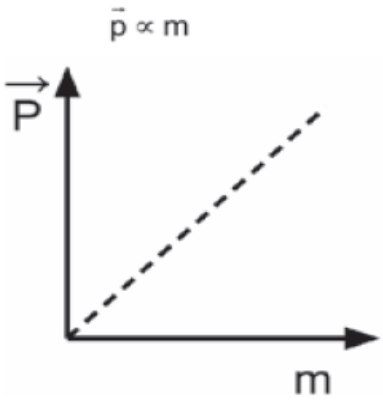


Diagram: A

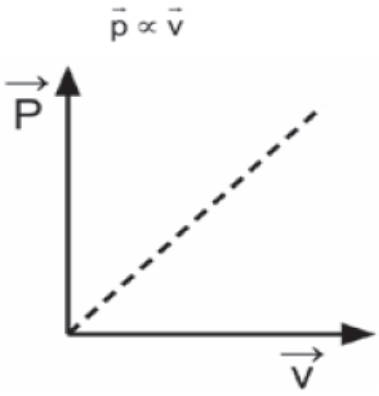


Diagram: B

- ✓ From the graphs above:
  - ➢ Momentum is directly proportional the mass of an object (**Diagram A**)
  - ➢ Momentum is directly proportional to the velocity of an object (**Diagram: B**)

Vector nature of momentum

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

Example: **Science Clinic DBE Essential 2017**

A golf ball of mass 50 g leaves a golf club at a velocity of 90 $m \cdot s^{-1}$ in an westerly direction.Calculate the momentum of the golf ball.

Solution:

Convert grams (g) to kilograms (kg)

m = 50g = 0,05 kg

$v = 90\ m.s^{-1}$

$p = mv$

$= (0,05)(90)$

$= \mathbf{4,5\ kg.\ m.s^{-1}\ westerly}$

Change in momentum

- ✓ When a moving object comes into contact with another object (moving or stationary) it results in a change in velocity for both objects and therefore a change in momentum (p) for each one.
- ✓ Since an object's mass remains constant during a collision(assuming it does not break up or approach the speed of light), it follows that the change in its velocity is what causes a change in its momentum.
- ✓ We only study objects moving in straight line e.g. forwards and backwards, left and right or up and down.

Change in velocity	Change in momentum
$\Delta v = v_f - v_i$	$\Delta p = p_f - p_i$
where:Δv = change in velocity in $m.s^{-1}$	$\Delta p = mv_f - mv_i$
v_f = final velocity in $m.s^{-1}$	$\Delta p = m(v_f - v_i)$
V_i = initial velocity in $m.s^{-1}$	where:
	Δp = change in momentum in $kg.m.s^{-1}$
	p_f = final momentum in $kg.m,s^{-1}$
	p_i = initial momentum in $kg.m.s^{-1}$
	m = mass in kg

The change in momentum can be calculated by using:

$\Delta p = pf - pi$

Tips on solving momentum problems

1. Make a sketch (on your work rough page) of the situation.
2. Always choose and indicate direction and write it down clearly.it is recommended that you choose direction (e.g. let to the right be positive).
3. Write down the given information and the unknown variable. Remember to include the correct signs for the directions of the initial and final velocity.
4. Choose the correct formula from the data sheet.
5. Substitute the values into the formula.
6. Solve the unknown variable

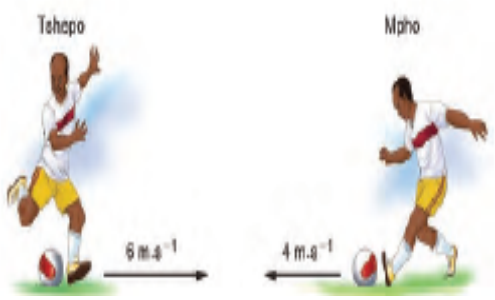
Example: **Solutions for All Grade 12 pages 17-18**

During a soccer training session, Mpho passes a 0,45 kg soccer ball along the ground to Tshepo.The ball rolls at 4 $m.s^{-1}$ toward Tshepo who immediately kicks it straight back to Mpho. The ball leaves Tshepo's boot with a speed of 6 $m.s^{-1}$. Ignore friction.

a) Calculate the initial and final momentum of the soccer ball.

b) Calculate the change in momentum of the soccer ball.

c) Draw a labelled vector diagram of the soccer ball's initial, final and change in momentum vectors



Solution

Let to the left be positive or (Let towards Tshepo be positive)

Given data: m = 0,45 kg , v_i= + 4 $m.s^{-1}$, v_f = - 6 $m.s^{-1}$, $\mathbf{p_i}$ = ? $\mathbf{p_f}$ = ?

Δp = ?

a) $p_i = mv_i$

= (0,45)(+4)

= +1,8 $kg.m.s^{-1}$

= 1,8 $kg.m.s^{-1}$ to the left

$p_f = mv_f$

= (0,45)(-6)

= -2,7 $kg.m.s^{-1}$

= 2,7 $kg.m.s^{-1}$ to the right

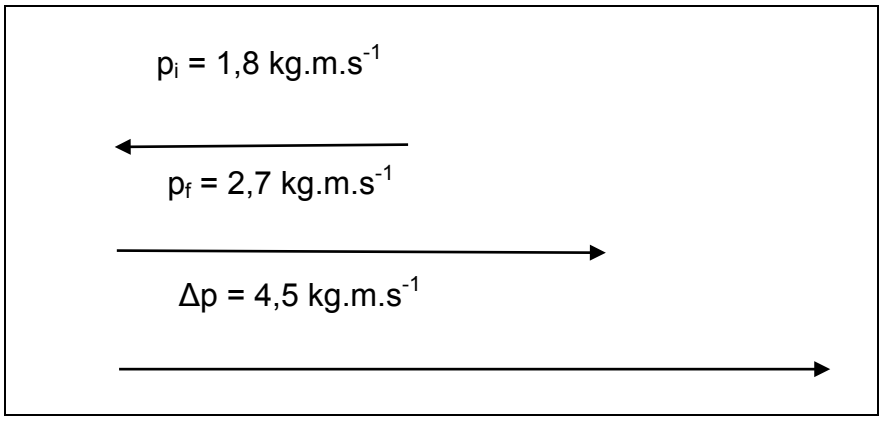
b) $\Delta p = p_f - p_i$

= -2,7 - (+1,8)

= -4,5 $kg.m.s^{-1}$

= 4,5 $kg.m.s^{-1}$ to the right

c)



NB:vector diagram not drawn into scale

Newton's Second Law of Motion in terms of Momentum

- ✓ States that the resultant/net force acting on an object is equal to the rate of change of momentum.
- ✓ Express Newton's second law of motion in symbols:

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

- ✓ $F_{net} = \frac{\Delta p}{\Delta t}$ can be applied to situations where both the mass and velocity of an object are changing

Impulse

- ✓ **Impulse:** is the product of the net force and the contact time.
- ✓ Impulse = $\mathbf{F_{net}\ \Delta t}$
- ✓ Impulse is a vector quantity and the S.I units are N.s
- ✓ Impulse is equal to the change in momentum

In symbols: $\mathbf{F_{net}\ \Delta t = \Delta p}$

- ✓ $\mathbf{F_{net}\ \Delta t = \Delta p}$ is known as impulse-momentum theorem.
- ✓ Impulse-momentum theorem can be used to calculate:
  - ➢ the force exerted
  - ➢ the time for which the force is applied.
  - ➢ the change in momentum for variety of situations involving the motion of an object in one dimension.

Example

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

Solution

Given: m= 0,1 kg F_{net} = 1000 N v_f = 30 m.s^{-1} v_i = 0 m.s^{-1} t = ?

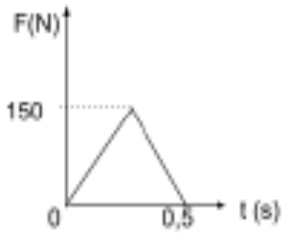
$F_{net}\Delta t = m\,\Delta v$

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

$= 0,003$ s

t = **3×10^{-3} s**

2. The following graph shows the force exerted on a hockey ball over time. The hockey ball is initially stationary and has a mass of 150 g.



Calculate the magnitude of the impulse (change in momentum) of the hockey ball.

Solution

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

Impulse= $\frac{1}{2}$ bh

Impulse = $\frac{1}{2}(0,5)(150)$

= **37,5 N.s**

Conservation of Momentum

- ✓ The principle of conservation of linear momentum states that:The total linear momentum of a closed system remains constant (is conserved)
- ✓ This principle can be represented in either of the three ways:

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

OR

$$m_A v_{iA} + m_B v_{iB} = m_A v_{fA} + m_B v_{fB}$$

- ✓ **Isolated/closed system:** a system on which the resultant/ net external force is zero.

- ✓ **External forces**: Forces outside of the system.
- ✓ **System:** A set number of objects and their interactions with each other.

Elastic Collision and Inelastic Collision

- ✓ **Elastic collision :** a collision in which both momentum and kinetic energy are conserved.
- ✓ **Inelastic collision** : a collision in which momentum is conserved and kinetic energy is not conserved.

NB

- ➢ To prove that a collision is elastic, we only have to prove that kinetic energy is conserved.
- ➢ Kinetic energy can be calculated using the mass and velocity of an object:
- ➢ $E_k = \frac{1}{2}mv^2$

Where:

E_k = kinetic energy in Joules (J)

m = mass (kg)

v = velocity ($m.s^{-1}$)

- ➢ **Elastic collision:** E_k(before) = E_k(after)
- ➢ **Inelastic collision:** E_k(before) ≠ E_k(after)

(some energy is lost as sound or heat)

Example: (GP- SSIP 2014 Physical Sciences session 1-4)

A bullet of mass 10 g, moving at a velocity of 300 $m \cdot s^{-1}$, strikes a wooden block of mass 1,99 kg resting on a flat horizontal surface as shown in the diagram below. The bullet becomes embedded in the block. Ignore the effects of air friction.

1.1 Write down in words the *principle of conservation of linear momentum*. (2)

1.2 Calculate the speed of the block-bullet system immediately after the collision. (4)

1.3 Is this collision elastic or inelastic? Give a reason for the answer. (2)

Solution

1.1 The <u>total (linear) momentum remains constant</u>/is conserved ✓

<u>an isolated</u>/a closed system/the absence of external forces. ✓

(**NB**: choose one direction as positive)

1.2

To the right as positive

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

$m_1v_{i1} + m_2v_{i2} = (m_1 + m_2)v_{f2}$ ✓

$(0,01)(300)$ ✓ $+ (1,99)(0) = (0,01 + 1,99)v_{f2}$ ✓

$\therefore v_{f2} = 1,5\ m \cdot s^{-1}$ ✓

1.3 Inelastic ✓

Kinetic energy is not conserved. ✓

Momentum Activities

Multiple Choice Questions

1. The front of a modern car is designed to crumble in case of a head-on collision. The chance of serious injuries to the passenger is reduced because the … **(EC/September 2015)**

   A. net force acting on the passenger is reduced, since the contact time for the car to stop decreases.
   B. net force acting on the passenger is reduced, since the rate of change in momentum decreases.
   C. net force acting on the passenger is reduced, since the change in momentum is reduced.
   D. net force acting on the passenger is reduced, since the change in momentum is increased. (2)

2. Ball M, moving at speed v to the right, collides with the stationery ball N on a smooth horizontal surface.Immediately after the collision, ball M comes to rest and ball N moves to the right with speed v. **(SC/NSC - DBE/2019)**

   Which ONE of the following statements about the collision of the balls is CORRECT?

   A Total momentum is conserved and the masses of the balls are unequal.
   B Total kinetic energy is conserved and the masses of the balls are unequal.

C Total momentum and total kinetic energy are conserved and the masses of the balls are equal.

D Total momentum is conserved but total kinetic energy is not conserved and the masses of the balls are equal. (2)

3. Airbags in modern cars provide more safety during an incident. **(NSC/March 2016)**

The statements below are made by a learner to explain how airbags can ensure better safety in a collision

(i) the time of impact increases

(ii) the impact force decreases

(iii) the impulse increases

Which of the statements above are CORRECT?

A (i) only

B (ii) only

C (ii) and (iii)

D (i) and (ii) (2)

4. Net force is a measure of the

A change in energy

B rate of change in energy

C change in momentum

D rate of change in momentum (2)

Structured Questions

1. Car A (mass 600 kg) was travelling at 5 $m.s^{-1}$ north when it was struck from behind by car B (mass 800 kg) which was travelling at 12 $m.s^{-1}$ north. Car A travels forward (north) at 10 $m.s^{-1}$ after the collision. Car B continues moving forward (north) at 8,25 $m.s^{-1}$ after the collision.

(Physical Sciences Grade 12 Term 1 Resource Pack)

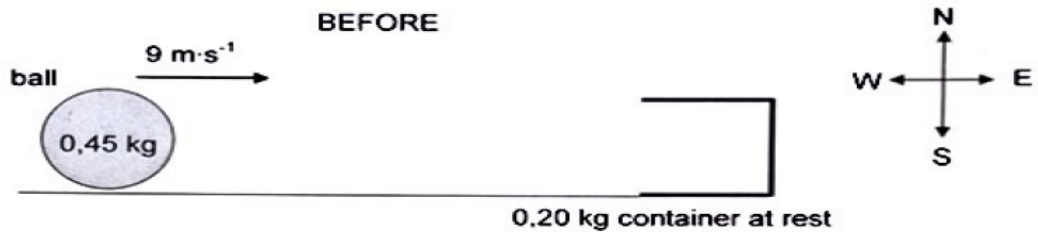
1.1 Calculate the momentum of car B before the collision. (3)

1.2 Calculate the change in momentum of car B during the collision. (4)

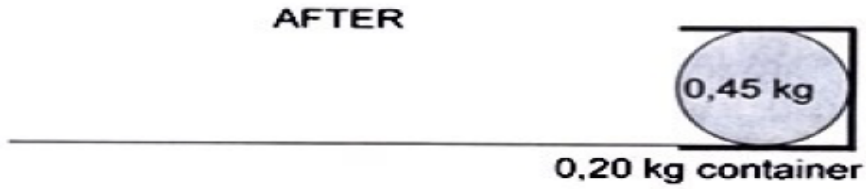
1.3 Calculate the change in momentum of car A during the collision. (4)

1.4 Use Newton's laws to explain why the momentum of car B decreases during the collision. (3)

2. A soccer player kicks a ball of mass 0,45 kg to the east.The ball travels horizontally at a velocity of 9 $m.s^{-1}$ along a straight line,without touching the ground, and enters a container lying at rest on its side, as shown in the diagram below. The mass of the container is 0,20 kg **(Question 4 DBE/2019**)



The ball is stuck in the container after the collision. The ball and the container now move together along a straight line towards the east. Ignore friction and rotational effects.



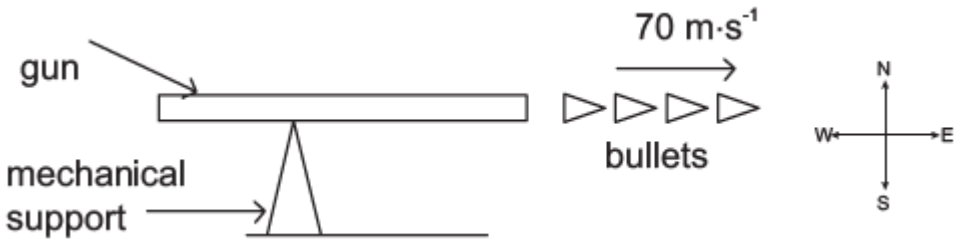
2.1 State the principle of conservation of linear momentum in words (2)

2.2 Calculate the magnitude of the velocity of the ball-container system immediately after the collision (4)

2.3 Determine, by means of a suitable calculation, whether the collision between the ball and container is **elastic** or **inelastic** (5)

3. The diagram below shows a gun mounted on a mechanical support which is fixed to the ground. The gun is capable of firing bullets rapidly in a horizontal direction.**(Physical Sciences Grade 12 Term 1 Resource Pack)**

Each bullet travels at a speed of 700 m.s–1 in an easterly direction when it leaves the gun.(Take the initial velocity of a bullet, before being fired, as zero.)The gun fires 220 bullets per minute. The mass of each bullet is 0,03 kg



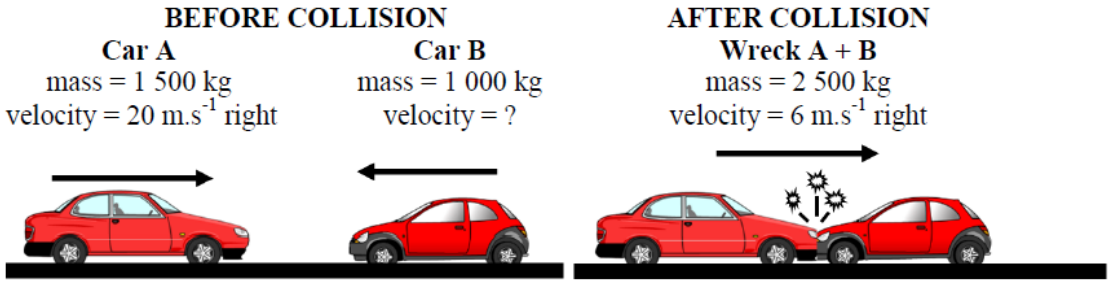
3.1 Define the term impulse in words. (2)

3.2 Calculate the magnitude of the momentum of each bullet when it leaves the gun. (3)

3.3 Calculate the average net force that each bullet exerts on the gun. (5)

3.4 Without any further calculation, write down the average net horizontal force that the mechanical support exerts on the gun.

4. Two cars, A and B, have a head-on collision and lock together on impact, as represented in the sketch below. Ignore frictional effects during the collision but not after the collision. **(IEB/Nov 2013)



4.1 State *the law of conservation of momentum*. (2)

4.2 Calculate the speed of car B immediately before it collided with car A. (6)

4.3 Use suitable calculations to determine whether or not the collision was elastic. (6)

4.4 Calculate the magnitude of the driving force on car A **before** the collision if the power used is 38 kW. (4)

4.5 Define *relative velocity*. (2)

4.6 What is the velocity of car B relative to car A before they collided? (2)

4.7 Define *impulse*. (2)

4.8 4.8.1 Which car, if any, experiences the greater magnitude of impulse during the collision? (1)

4.8.2 Justify your answer to Question 4.8.1 by referring to relevant physical principles and/or supplying supporting calculations. You must refer to or make use of a suitable formula. (3)

4.9 The drivers of both cars have the same mass. Both drivers are wearing seatbelts which stretch slightly to bring the drivers to rest, relative to the car, in the same time period. Neither car has air bags. (3)

4.9.1 Which driver is likely to experience the greater force during the collision, *driver A, driver B* or *both the same*? (4)

Explain your answer with reference to one or more suitable formulae.

4.9.2 Airbags are important safety features in cars. Using principles of physics, explain how airbags protect the driver during a collision. (3)

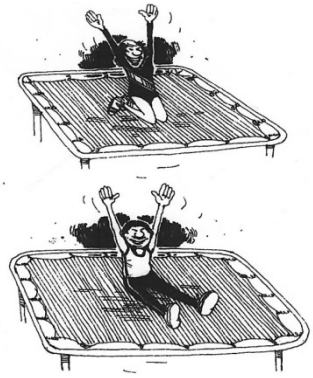
4.10 The wreck (A + B) skids for a distance of 9 m before coming to rest.

4.10.1 Calculate the time taken for the wreck to come to rest. (4)

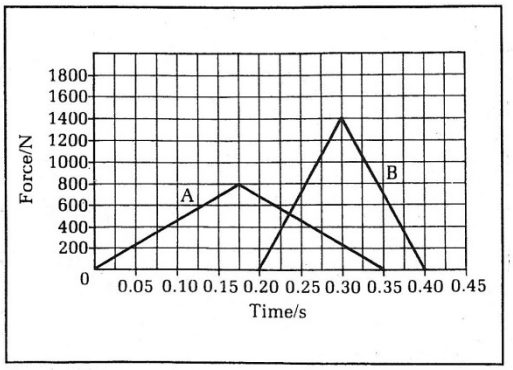
4.10.2 Calculate the frictional force exerted by the road on the wreck. (4)

QUESTION 5 (KZN SEPT 2014)

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



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



5.1 Define IMPULSE. (2)

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

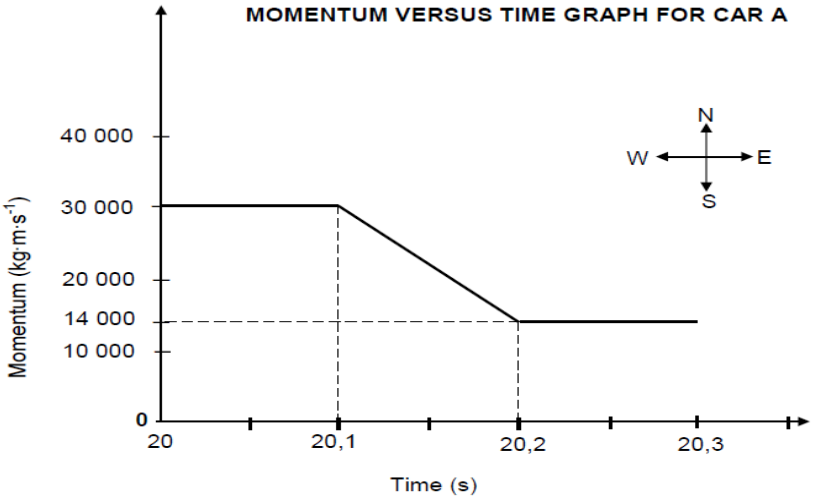
5.3 If the boy and girl jumped onto their trampolines from the same height,

Which ONE of the two will rebound with a greater speed? (1)

QUESTION 6 (DBE NOV 2016)

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

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



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

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

6.2 Calculate the:

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

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

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

VERTICAL PROJECTILE

Projectile is an object upon which the only force acting is the force of gravity.

Projectile motion refers to the free fall motion of an object after it has been projected (launched). It is therefore important for learners to understand clearly what is meant by free fall, During free fall, an object accelerates at the acceleration due to gravity, g= 9,8 $m \cdot s^{-2}$ downwards. This means that the velocity of a projectile changes by 9.8 $m.s^{-1}$ each second, since $a = \Delta v/\Delta t$

EQUATIONS OF MOTION IN A VERTICAL PLANE

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

$$\Delta y = v_i\Delta t + \tfrac{1}{2} g\Delta t^2$$

$$v_f = v_i + a\Delta t$$

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

Solving Projectile Motion Problems

The following procedure summarizes the problem-solving approach.

Carefully read the problem and list known and unknown information in terms of the symbols of the kinematic equations. Identify the unknown quantity which the problem requests you to solve for. Select relevant equation to solve for the unknown quantity you are requested to find. In all calculations except those that need application of simultaneous equations, you just need to have one unknown and three known quantities.

Remember:

- $g=9,8 m.s^{-2}$,
- at the maximum height $v_f = 0\ m.s^{-1}$ for the object thrown vertically upwards.
- If the object is dropped, the initial velocity $v_i = 0\ m.s^{-1}$.

NB: So in all cases you will have $g=9,8m.s^{-2}$ unless otherwise you are required to prove it. Keeping this data in mind and able to interpret the information given in the statement will make calculations easy.

VERTICAL PROJECTILES GRAPHS

Velocity vs time graph

The velocity vs time graph is best describe by the formula $v_f = v_i + a\Delta t$, this equation can be written as $v_f = a\Delta t + v_i$,mathematically this is in the form y= mx+c which is a straight line, so the graph of velocity vs time will always be a straight or combinations of straight line in case of a bouncing object.

Displacement/position vs time graph

The position vs time graph is best describe by the formula $\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

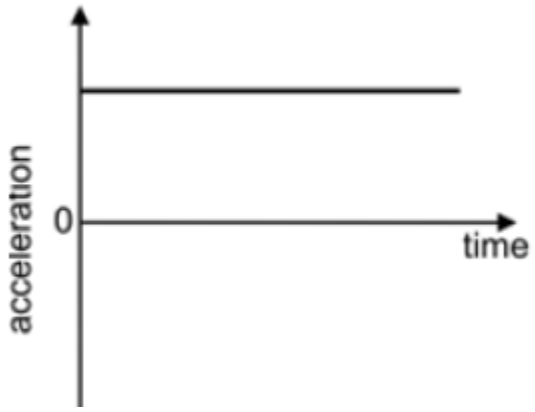
, this equation can be written mathematically this is in the form $y=ax^2+bx+c$

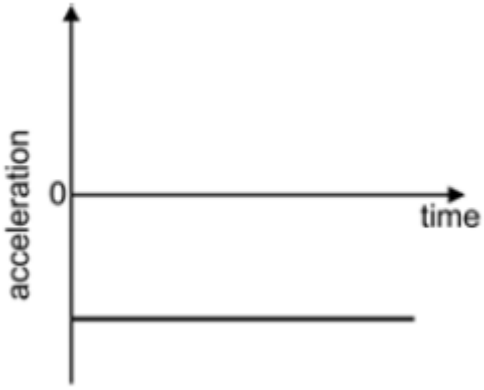
which is a parabola, so the graph of position vs time will always be a parabola or combinations of parabolic shape in case of a bouncing object. So a graph can be a full parabolic shape or a part of depending on the question. Teachers must assist in this regard

Acceleration vs time graph

These two are the graphs of acceleration vs time depending on which direction you have taken as positive or negative.

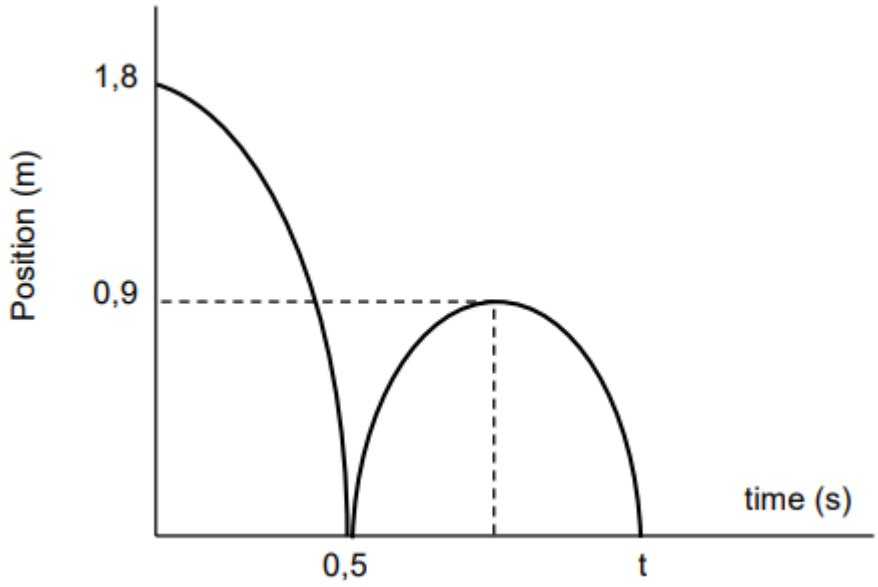
Remember: The gradient of velocity vs time graph will give acceleration.





QUESTION 1(WC Sept 2015)

The position-time graph is given for a ball which is thrown down from a vertical height of 1,8 m and bounces once on reaching the ground. The contact time between the ball and the floor can be ignored.



1.1 Calculate the initial velocity with which the ball was thrown. (3)

1.2 At what speed does the ball strike the ground? (3)

1.3 At what speed did the ball leave the ground after bouncing? (3)

1.4 Calculate the value of time t. (4)

1.5 Sketch a velocity-time graph to represent the motion of the ball. Indicate the following values on the graph:

• The initial velocity at which the object was thrown.

• The velocity at which the ball strikes the ground.

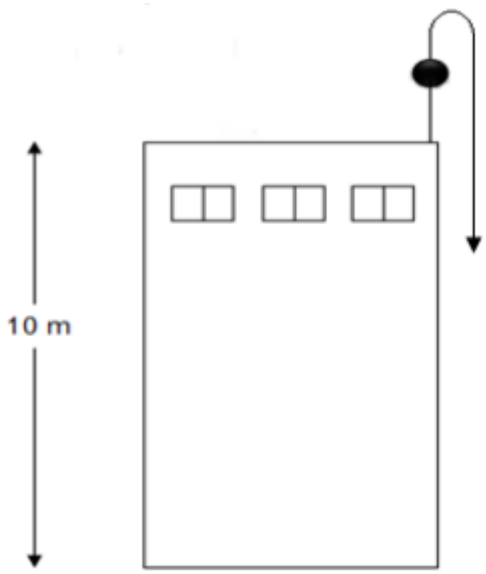
• The velocity at which the ball bounces off the ground.

• The time at which the ball strikes the ground for the first time.

• The time, t, when the ball strikes the ground after the first bounce. (6)

QUESTION 2 EC SEPT 2015

A ball is thrown vertically upwards at a velocity of 4 m.s-1 from the roof of a building with a of height 10 m. The ball strikes the ground and rebounds to a height of 3 m. Ignore the effects of friction.



2.1 Calculate the:

2.1.1 Time taken for the ball to reach its maximum height. (3)

2.1.2 Maximum height the ball reaches above the ground. (4)

2.2 The ball strikes the ground 1,09 s after it was thrown and remains in contact with the ground for 0,2 s before bouncing upwards.

Sketch a graph (not to scale) of position versus time representing the entire motion of the ball.

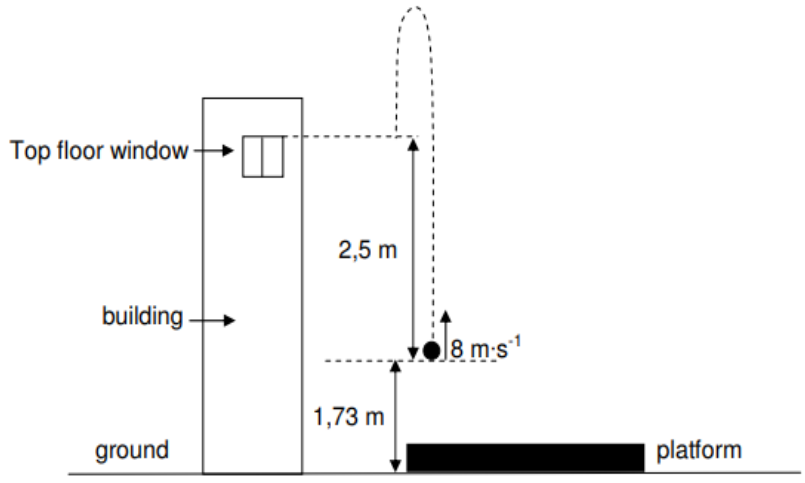
USE THE GROUND AS ZERO REFERENCE.

Indicate the following on the graph:

- Height from which the ball was thrown
- Maximum height of the ball from ground
- Height reached by the ball after bouncing
- Time the ball strikes the ground
- Contact time of the ball with the ground (5)

QUESTION 3(CWED SEPT 2014)

Sandile, who is standing on a platform, throws a small metal ball vertically upward, from a height of 1,73 m above the ground, into the air at 8 m·s-1. The ball travels pass the top of the building and returns to Sandile's hand which is still at 1,73 m above the ground. Ignore the effects of friction.



3.1 With what speed does the ball strike Sandile's hand? (1)

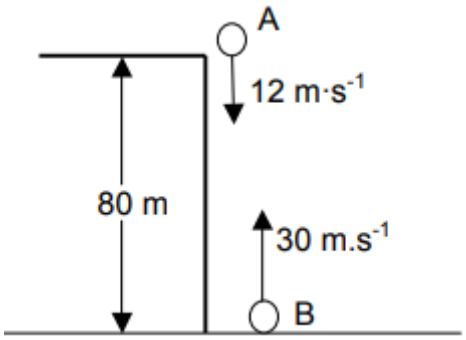
3.2 Using an equation of motion and NOT energy principles, calculate the maximum height that the ball reaches above the ground. (4)

3.3 If a window on the top floor of the building is at a height of 2,5 m above Sandile's hand, calculate the time taken for the ball, from the moment it was thrown, to pass the top of the window on its return to Sandile's hand. (5)

3.4 Taking upward direction as positive, draw a sketch graph of position versus time graph of the ball's motion from the moment it left Sandile's hand until it lands back into his hands. Indicate all relevant position values. Use Sandile's hand as reference. (5)

QUESTION 4 (FS SEPT 2015)

Ball A is thrown vertically downwards from the top of a building, 80 m high, at a velocity of 12 m·s-1. At the same instant a second identical ball B is thrown upwards at a velocity of 30 m·s-1. Ball A and ball B pass each other after 2,135 s. Ignore all effects of air friction.



4.1 Give the direction of the acceleration of ball B while moving upwards. (1)

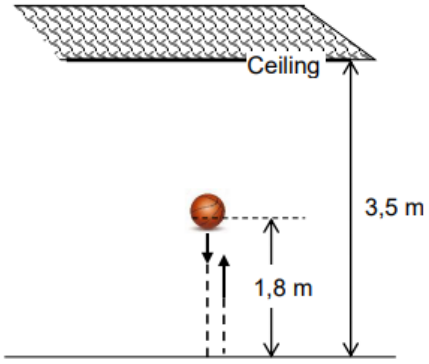
4.2 Calculate the velocity of ball B the moment it passes ball A. (3)

4.3 Calculate the distance between ball A and B 2,5 s after it was projected. (6)

4.4 Sketch a position-time graph for the motion of ball A till it reaches the ground as well as for the motion of ball B until it passes ball A. Use the ground as zero position. Clearly indicate the time at which the balls pass each other. (3)

QUESTION 5((MSED Sept 2015)

A girl stands on a platform in a classroom. She throws a ball vertically downwards to the floor hoping that the ball, after it bounced on the floor, will hit the ceiling of the classroom. She throws the ball with a speed of 8 m·s-1 from a height of 1,8 m above the floor. Ignore the effects of air friction.



5.1 Write down the magnitude and direction of the acceleration of the ball immediately after the ball left her hand. (2)

5.2 Is the motion of the ball, while it is moving downwards towards the floor, free fall? Explain the answer. (2)

5.3 Calculate the magnitude of the velocity with which the ball hits the floor. (4)

5.4 How long does it take the ball to hit the floor? (3)

The ball bounces INELASTICALLY on the floor where the speed of the ball DECREASES by 20%. The ball is in contact with the floor for 0,01 s.

5.5 Determine by means of calculations, whether the ball will reach the ceiling after it bounced. (5)

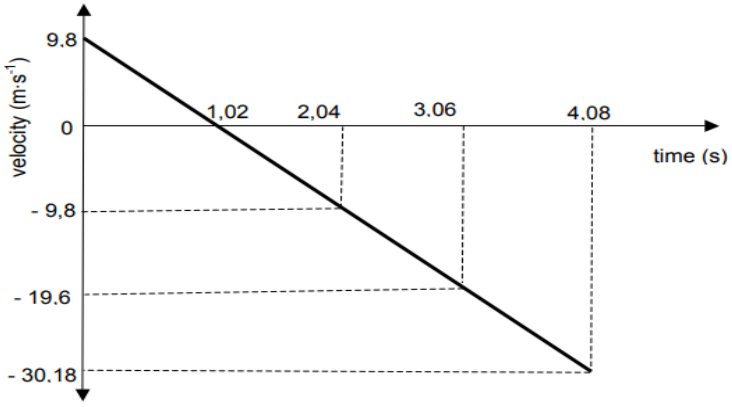
5.6 Sketch a velocity-time graph for the motion of the ball, from the time the ball is thrown until it reaches the maximum height after the bounce.

Clearly show the following on the graph:

- The initial velocity of the ball.
- The velocity and time when the ball hits the floor.
- The velocity and time when the ball leaves the floor. (4)

QUESTION 6 (NC SEP 2015)

A boy throws a ball vertically into the air from the top of a building. The ball strikes the ground after 4,08 s. The velocity-time graph below represents the entire motion of the ball. Ignore the effects of air friction.



6.1 Explain what is meant by a projectile. (2)

6.2 What is the acceleration of the ball at time 1,02 s? (2)

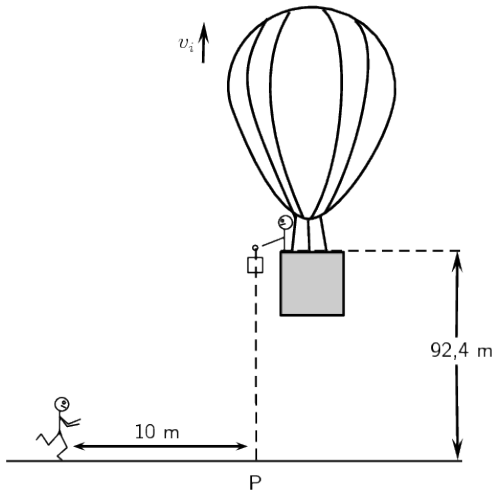
6.3 Calculate the displacement of the ball. (4)

6.4 Sketch a position versus time graph for the entire motion of the ball. Indicate the following on the graph:

- Initial position
- Maximum height
- Final position
- Time (t) values (4)

QUESTION 7(Nov 2011)

A hot-air balloon is moving vertically upwards at a constant speed. A camera is accidentally dropped from the balloon at a height of 92,4 m as shown in the diagram below. The camera strikes the ground after 6 s. Ignore the effects of friction.



7.1 At the instant the camera is dropped, it moves upwards. Give a reason for this observation. (1)

7.2 Calculate the speed at which the balloon is rising when the camera is dropped. (4)

7.3 Draw a sketch graph of velocity versus time for the entire motion of the camera.

Indicate the following on the graph:

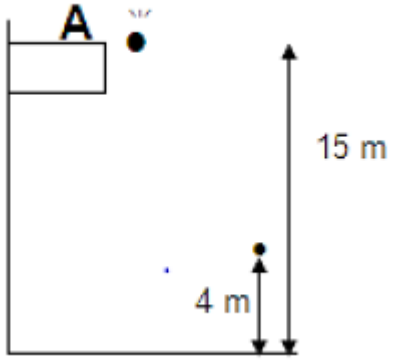
- Initial velocity
- Time at which it reaches the ground (4)

7.4 If a jogger, 10 m away from point P as shown in the above diagram and running at a constant speed of 2 m·s-1, sees the camera at the same instant it starts falling from the balloon, will he be able to catch the camera before it strikes the ground?

Use a calculation to show how you arrived at the answer. (5)

QUESTION 8(EC Sept 2014

A cricket ball, mass 156 g, is dropped from point A on a tall building, 15 m high. It strikes the concrete pavement and it then bounces to a maximum height of 4 m.



8.1 Calculate the velocity with which the cricket ball strikes the pavement. (3)

8.2 If the effects of air friction are NOT ignored during the fall of the cricket ball, how would the value you calculated in QUESTION 2.1 change? Write **down HIGHER, LOWER or STAYS THE SAME**. (1)

8.3 The cricket ball is in contact with the concrete pavement of 0,8 s. Ignore the effects of air friction. Take **DOWNWARD motion as POSITIVE**.

8.3.1 Calculate the impulse of the cricket ball on the pavement. (8)

8.3.2 Calculate the (net) average force exerted by the pavement on the cricket ball. (4)

8.4 Sketch the position versus time graph for the motion of the cricket ball from the moment it is dropped until it reaches its maximum height after the bounce.

USE **POINT A** AS THE ZERO POSITION.

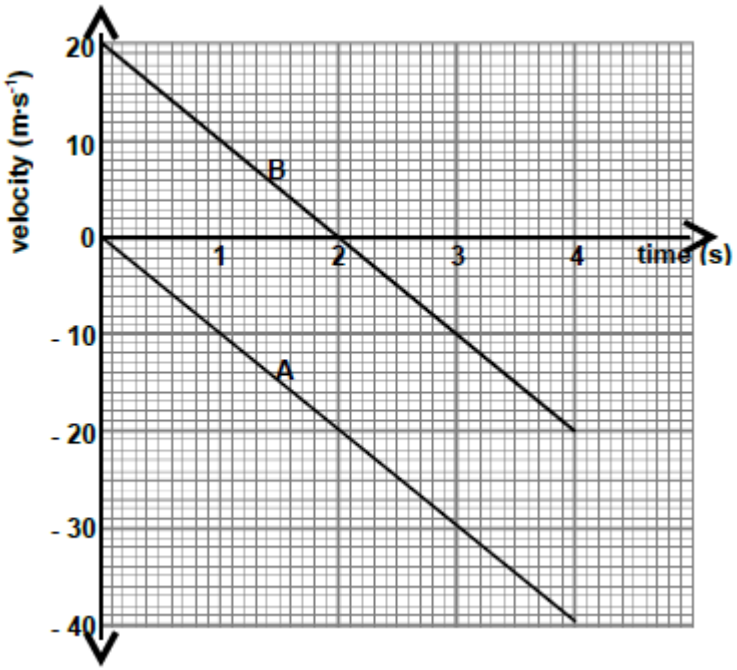
Indicate the following on the graph:

- The height from which the cricket ball is dropped
- The height reached by the cricket ball after the bounce
- Time with which the cricket ball is in contact with the concrete pavement (4)

8.5 The cricket ball is now replaced with a softer ball of similar mass. State how the (net) average force exerted by the concrete pavement on the softer ball compares with your answer in QUESTION 8.3.2. (Write down only GREATER, SMALLER or STAYS THE SAME). Use physics principles to explain your answer. (3)

QUESTION 9(DBE Feb-Mar 2011)

The velocity-time graph shown below represents the motion of two objects, A and B, released from the same height. Object A is released from REST and at the same instant object B is PROJECTED vertically upwards. (Ignore the effects of friction.)



9.1 Object A undergoes a constant acceleration. Give a reason for this statement by referring to the graph. (No calculations are required.) (2)

9.2 At what time/times is the SPEED of object B equal to 10 m·s-1? (2)

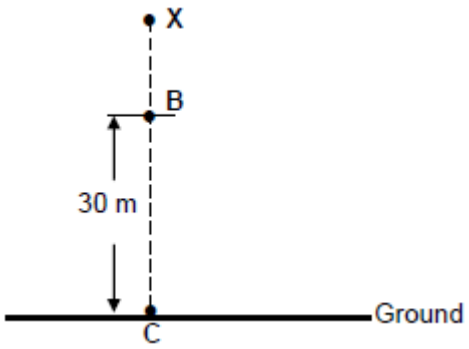
9.3 Object A strikes the ground after 4 s. USE EQUATIONS OF MOTION to calculate the height from which the objects were released. (3)

9.4 What physical quantity is represented by the area between the graph and the time axis for each of the graphs A and B? (2)

9.5 Calculate, WITHOUT USING EQUATIONS OF MOTION, the distance between objects A and B at t = 1 s. (5)

QUESTION 10

An object is released from rest from a point X, above the ground as shown in the diagram below. It travels the last 30 m (BC) in 1,5 s before hitting the ground. Ignore the effects of air friction.



10.1 Name the type of motion described above. (1)

10.2 Calculate the:

10.2.1 Magnitude of the velocity of the object at point B (4)

10.2.2 Height of point X above the ground (5)

After hitting the ground, the object bounces once and then comes to rest on the ground.

10.3 Sketch an acceleration-time graph for the entire motion of the object. (3)

QUESTION 11(IEB NOV 2017)

A group of students decided to measure the acceleration due to gravity. They carried out an experiment by dropping a small steel ball (mass 10 g) from different heights and measured the time taken (t) for the ball to fall through the particular height (h).

h (m)	t(s)	$t^2(s^2)$
0,4	0,27	0,07
0,7	0,40	0,16
1,2	0,47	0,22
1,7	0,60	0,36
2,1	0,64	0,41
2,5	0,72	0,52

The students decided to plot h vs t^2.

11.1 Why is it necessary to plot h vs t^2 rather than h vs t? (3)

11.2 Use the data in the table to plot a graph of h (y-axis) vs t^2 (x-axis) on the graph paper provided on the Answer Sheet. (6)

11.3 Calculate the gradient of the graph. Indicate the values you used for this calculation on your graph. (4)

11.4 Write an equation of motion that describes the relationship between h and t^2. (2)

11.5 Use your answer from Question 3.4 and your knowledge that the equation y = mx + c describes a straight line to determine the acceleration due to gravity. (2)

11.6 The students repeated the experiment with a ball of twice the mass. Describe the graph of h vs t^2 for the heavier mass in comparison with the graph plotted for the 10 g ball. Briefly explain your answer. (2)

WORK ENERGY AND POWER

Concepts to be taught and for learners to understand:

Work

- Define the work done on an object by a constant force F as FΔx cosθ, where F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement. (**Work is done by a force on an object – the use of 'work is done against a force', e.g. work done against friction, should be avoided.**)
- Draw a force diagram and free-body diagrams.
- Calculate the net/total work done on an object.
- Distinguish between *positive net/total work done* and *negative net/total work done* on the system.

Work-energy theorem

- **Work-energy theorem**: The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy.
  In symbols: $W_{net} = \Delta K = K_f - K_i$.
- Apply the work-energy theorem to objects on horizontal, vertical and inclined planes (for both frictionless and rough surfaces).

Conservation of energy with non-conservative forces present

- **Conservative force** is a force for which the work done in moving an object between two points is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulomb forces).
- **Non-conservative force** is a force for which the work done in moving an object between two points depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc.
- **Principle of conservation of mechanical energy**: The **total** mechanical energy (sum of gravitational potential energy and kinetic energy) in an **isolated system remains constant**.

- (A system is isolated when the resultant/net external force acting on the system is zero.)
- Solve conservation of energy problems using the equation:

$$\mathbf{W_{nc} = \Delta K + \Delta U}$$

- Use the relationship above to show that in the absence of non-conservative forces, mechanical energy is conserved.

Power

- **Power** is the rate at which work is done or energy is expended.

In symbols: $\mathbf{P = \frac{W}{\Delta t}}$, where **P** is Power in Watts(W), **W** is the work done in Joules (J) and $\mathbf{\Delta t}$ is the change in time in seconds (s).

- Calculate the power involved when work is done.
- Perform calculations using $P_{av} = F \times v_{av}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

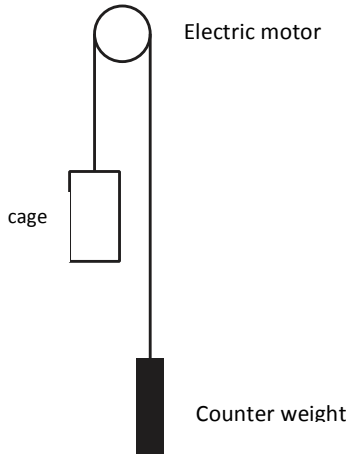
HINTS:

- Know that in a free body diagram, the object of interest is drawn as a dot and all the forces acting on it are drawn as arrows pointing away from the dot. All the forces acting on an object must be labelled using appropriate symbols.
- Know that a force diagram is a picture of the object(s) of interest with all the forces acting on it drawn in as arrows. (i.e the weight should be drawn from the centre of the body and the normal force should be from the surface.
- Revise and emphasise trigonometric ratios.
- Energy conversion when calculating power should be emphasised.
- All the definitions, principles and laws should be stated as they are in the CAPS document.
- All the equations should be copied as they are from the data sheet.

NEP ASSESSMENT ACTIVITIES

JECT BOOKLET

. A lift system is made up of an electric motor, a cage and its counterweight as shown in the diagram below.



The counterweight moves vertically downwards as the cage moves upwards. The cage and counterweight move at the same constant speed.

The cage of mass 1 500 kg moves vertically upwards at a constant speed, covering 80 m in 4 minutes. The counterweight has a mass of 1 100 kg. The electric motor provides the power needed to operate the lift system. Ignore the effects of friction.

.1 Define the term power in words. (2)

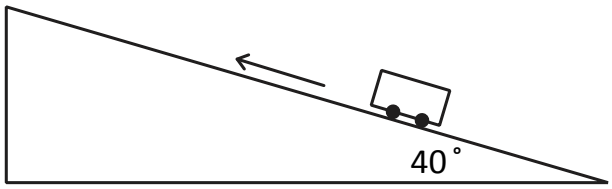
.2 Calculate the work done by the:

1.2.1 Gravitational force on the cage. (2)

1.2.2 Counterweight on the cage. (2)

.3 Calculate the average power required by the motor to operate the lift system in 4 minutes. Assume that there are no energy losses due to heat and sound (5)

. A car of mass 800 kg drives up a rough inclined plane of 40° as shown in the diagram below.



.1 What is the net work done on the car if the car moves up the inclined plane at constant velocity? (1)

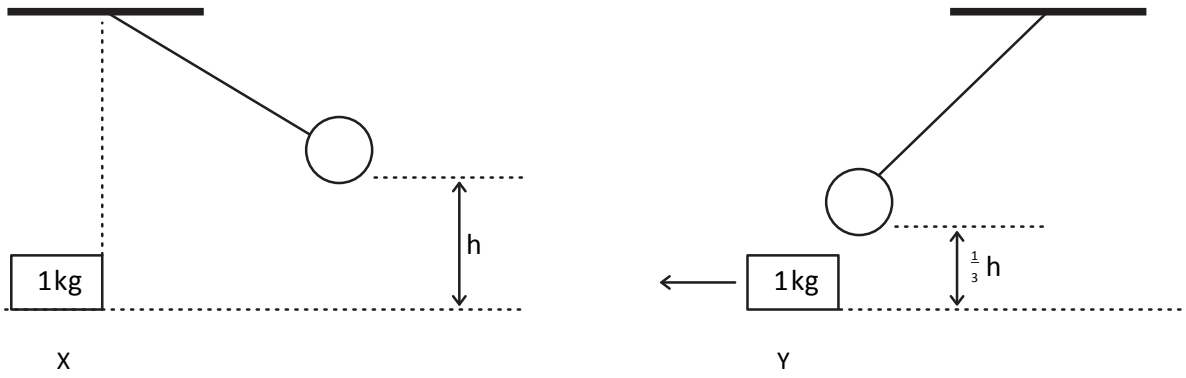
.2 Draw a labelled free body diagram showing all the forces acting on the car as it drives up the inclined plane. (4)

.3 The car now starts from rest at the base of the slope and accelerates up the slope. The car's engine exerts a force of 8 000 N and the coefficient of kinetic friction between the wheels of the car and surface is 0,28.

2.3.1 State the work-energy theorem in words.

2.3.2 Use energy principles to calculate the magnitude of the velocity of the car after moving a distance of 40 m up the incline. (8)

A pendulum with a bob of mass 3 kg is held stationary at a height h metres above the ground. When released, it collides with a block of mass 1 kg which is stationary at point X above the ground. The diagrams below are not drawn to scale.



The bob swings past X and comes to rest momentarily at a position $\frac{1}{3}$h

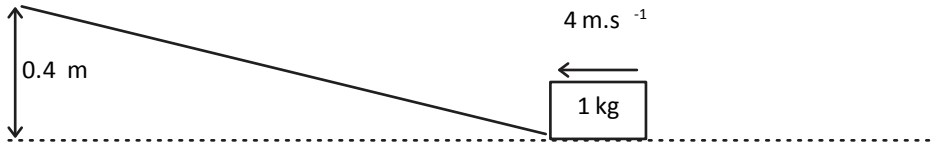
Immediately after the collision the 1 kg block begins to move from X to Y at a constant speed of 4,m.s^{-1} . Ignore frictional effects and assume that no loss of mechanical energy occurs during the collision.

3.1 Calculate the:

3.1.1 Kinetic energy of the block immediately after the collision. (3)

3.1.2 Height h. (4)

3.2 The block moves from point Y at a velocity of 4m.s $^{-1}$ up a rough inclined plane to point Z. The speed of the block at point Z is 1,5 m.s $^{-1}$. Point Z is 0,4 m above the horizontal, as shown in the diagram below. During its motion from Y to Z a uniform frictional force acts on the block.



Use energy principles to calculate the work done by the frictional force when the 1 kg block moves from point Y to point Z.

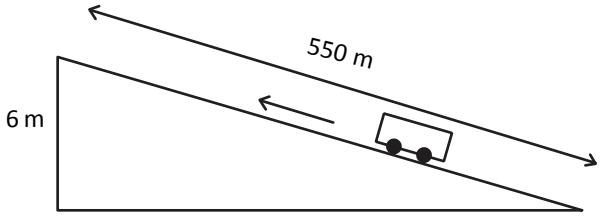
(4)

4 A race car rides at a certain average speed and completes the 845 m course in 80 s.

To maintain this speed, a constant driving force of 290 N acts on the race car.

4.1 Calculate the average power developed by the race car for this motion.

The same race car is driven on a track with an incline. Starting from rest, the race car travels a distance of 550 m up the incline which has a vertical height of 6 m, as shown below.

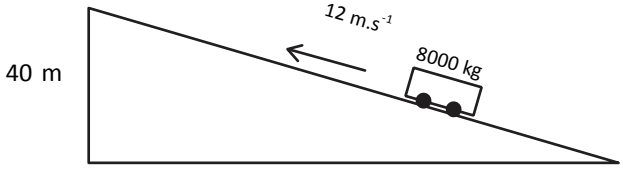


The total frictional force acting on the race car is 300 N. The mass of the race car is 340 kg. The average driving force of the race car as it moves up the incline is 420 N.

4.2 Draw a labelled free-body diagram for the race car on the incline. (4)

4.3 Use energy principles to calculate the speed of the race car at the end of the 550 m driv (6)

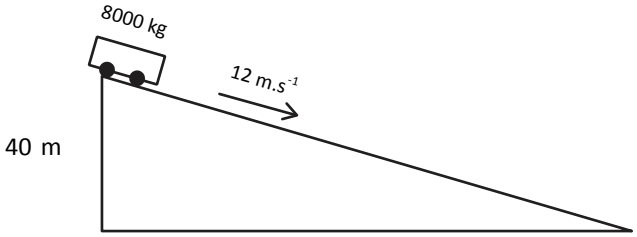
5 A truck with a total mass of 8 000 kg travels up a straight incline at a constant velocity of 12m s. $^{-1}$. At the top of the incline, the truck is at a height of 40 m above its starting point. The work done by frictional forces is 6×10^4 J.



5.1 Use energy principles to calculate the work done by the engine of the truck to get it to the top of the incline. (5)

5.2 Calculate the average power delivered by the engine of the truck if the truck takes 60 s to reach the top of the incline. (3)

5.3 The truck now returns down the same incline with a constant velocity of 12 m.s^{-1}.



How will the work done by the engine of the truck on reaching the bottom of the incline compare to that calculated in question 6.3? Write down greater than, smaller than or equal to. Give a reason for the answer. (2)

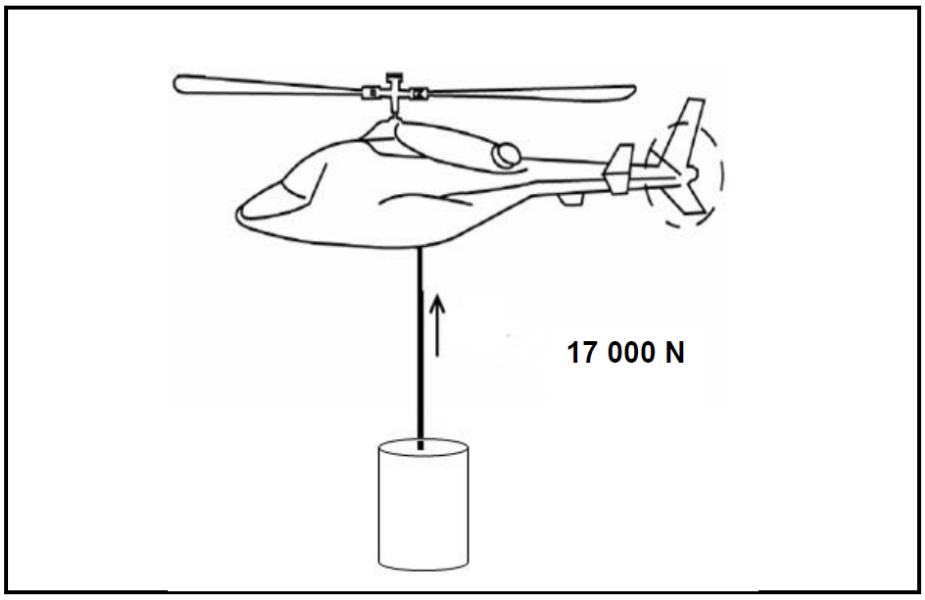
EC SEPT 2015

Question 6

During a fire extinguishing operation, a helicopter remains stationary (hovers) above a dam while filling a bucket with water. The bucket, of mass 80 kg, is filled with 1 600 kg of water. It is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 2 m.s-1. The tension in the cable is 17 000 N.

Assume there is no sideways motion during the lift.

Air friction is NOT ignored.

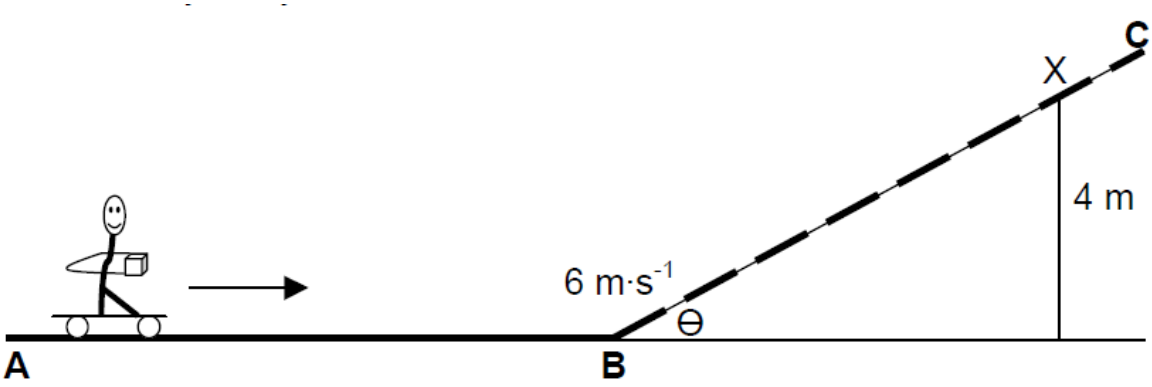


6.1 Draw a labelled free body diagram showing ALL the forces acting on the bucket of water, while being lifted upwards. (3)

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

FS SEPT 2015

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



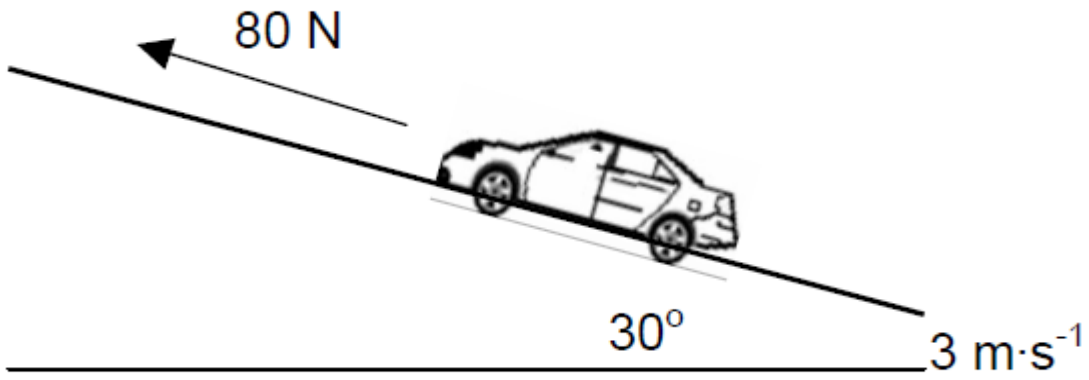
7.1.1 In which direction must the parcel be thrown to cause a maximum increase in the velocity of the boy? (1)

7.1.2 Name and define in words the law in physics that you have applied in QUESTION 7.1.1 (3)

On reaching point **B** at a velocity of 6 m·s-1, the boy on the roller-skates, with total mass 57 kg, continues to move up a rough section **BC** of the track and comes to rest at position X, height 4m. The magnitude of the frictional force acting on the roller-skates, is 40 N.

7.1.3 Calculate value Θ of the inclined plane. (6)

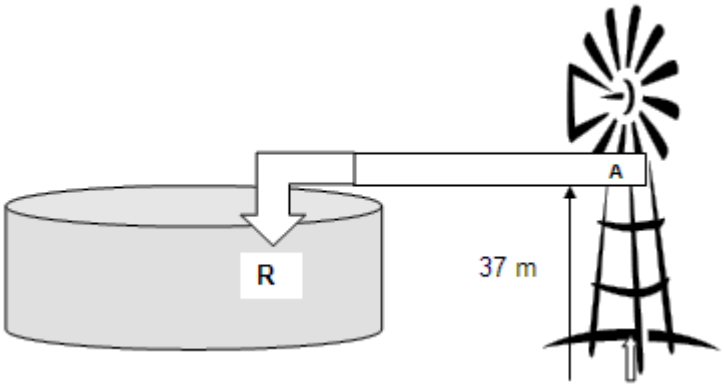
7.2 A remote controlled car is driven up an inclined plane at 300 to the horizontal as shown below. The car of mass 4 kg, experiences an average forward force of 80 N. A frictional force of 15 N is acting on the car as it moves up the plane. The speed of the car at the bottom of the inclined plane is 3 m·s-1.



Use energy principles to calculate the speed of the car after it has travelled 5 m up the inclined plane. (7)

EC SEPT 2014

8. A windmill is used on a farm to pump water out of a well that is 37 m deep. The water flows past point A, 37 m above the well to the dam with a constant velocity of 2 m•s-1.



8.1 Calculate how much energy is necessary to pump 90 kg of water out of the well to point **A**. (4)

8.2 It is necessary to pump 90 kg of water per minute. What is the maximum power that the windmill must produce? (3)

8.3 4.3 The farmer wants to modernise the farm. The farmer decides to buy a 0,5 kW petrol water pump.

8.3.1 Will the petrol water pump be able to produce the required power? (YES or NO) (1)

8.3.2 4.3.2 Why would you advise the farmer to rather use a windmill instead of a petrol water pump? (1)

WAVES, SOUND & LIGHT

- Pulse is a single disturbance.
- Wave is a repeated disturbance.
- Period is the time taken to complete a single wave.
- Frequency is the number of vibrations passing through a point in one second.
- Unit for frequency is Hertz (Hz).
- Can be calculated using: v= f.λ or $f = \frac{1}{T}$.

TYPES OF WAVES

1. Electromagnetic waves
2. Mechanical waves

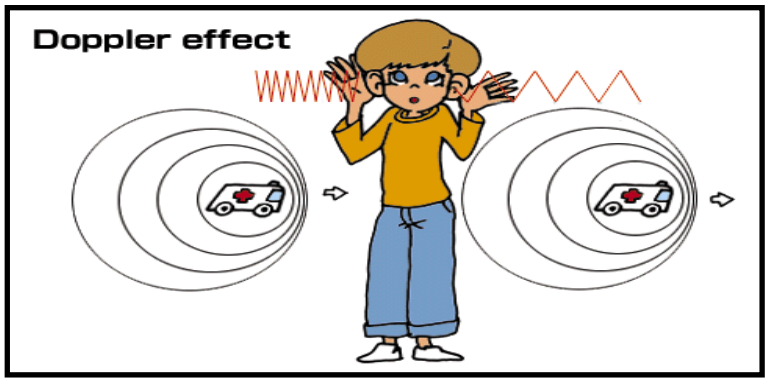
Types of Mechanical Waves

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

DOPPLER EFFECT

It is the change in frequency (or pitch) of the sound detected by a listener, because the sound source and the listener have different velocities relative to the medium of sound propagation.

When the source of a sound is moving towards the listener, the pitch sounds higher than that of the source. When the source moves away from the listener the pitch sounds lower. This is known as the DOPPLER EFFECT.

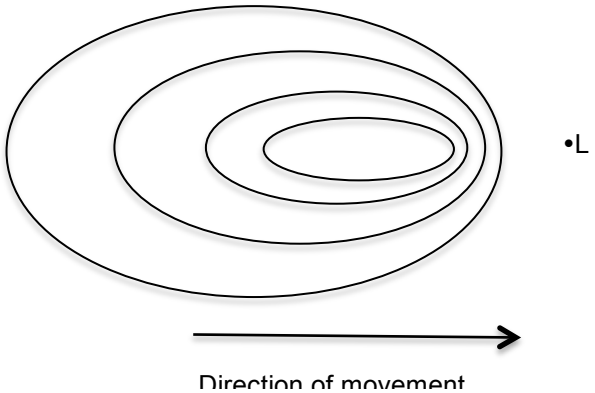


Sketches of wave fronts

Source moving towards a stationary listener

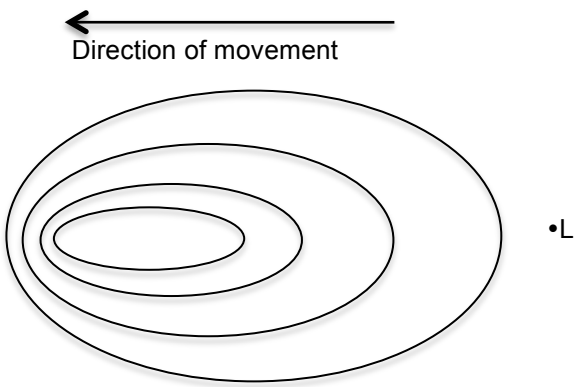
- Wavelength decreases/ waves are compressed
- Frequency increases
- Velocity constant

- Pitch of sound increases



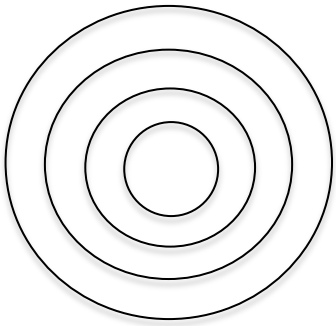
Source moving away from a stationary listener

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



Stationary source & listener / Listener inside a moving source

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



Equation of Doppler Effect

$$f_L = \frac{v \pm v_L}{v \pm v_S} \bullet f_S$$

f_L : frequency heard by the listener in Hz
f_s : frequency produced by the source in Hz
v : speed of sound in a medium (e.g. air, water) in $m.s^{-1}$
v_L : velocity of the listener in $m.s^{-1}$
v_s : velocity of the source in $m.s^{-1}$

Applications of Doppler Effect

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

Red Shift

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

Worked Examples

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

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

Solution
1. C

Question 2

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

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

2.2 Calculate the speed of the car. (4)

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

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

2.3.2 Identify the type of shift seen by the astronomer. (1)

2.3.3 Is the distant galaxy moving towards or away from our Solar System. (1)

Solution

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

2.2

$$f_L = \frac{v \pm v_L}{v \pm v_S} \bullet f_S$$

$$0{,}93f_S = \frac{335 - 0}{335 + v_S} \bullet f_S$$

$$0{,}93(335 + v_S) = 335$$

$$v_S = 25{,}22 m.s^{-1}$$

2.3.1 Absorption (line spectrum) √√

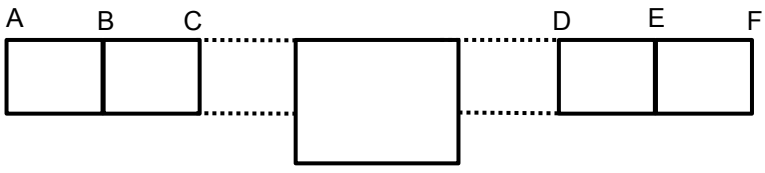
2.3.2 Red-shift √√

2.3.3 Away from √√

ACTIVITIES

Question 3

3.1 A fire engine races towards a burning building CD with the sirens blaring. Two pedestrians, **X** and **Y**, hear the fire engine and stand still to watch.

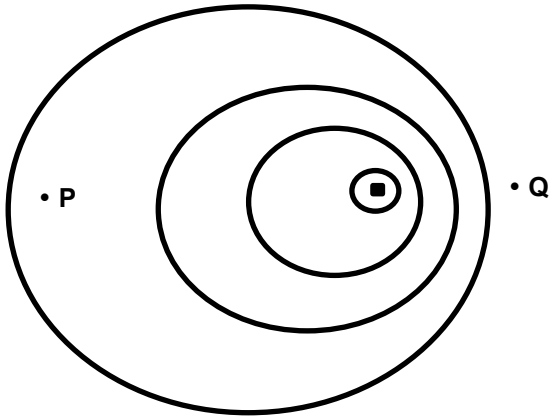


Pedestrian **X** is standing at point **B** and pedestrian **Y** is standing at point **E**.
X hears a higher pitch and **Y** hears a lower pitch.

3.1.1 Write down the NAME of the phenomenon which explains why the pedestrians hear different frequencies. (1)

*3.1.2 In which direction (**E to D** or **D to E**) is the fire engine travelling? (1)

The diagram below shows the wave fronts of the sound produced from the siren as a result of the motion of the fire engine.



*3.1.3 On what side of the diagram (**P** or **Q**) is pedestrian **Y** standing when he hears the lower pitch? Provide reasons why pedestrian Y hears the siren at a lower pitch by referring to **speed of sound**, **wavelength** and **frequency**. (4)

The siren emits sound of frequency 440 Hz. Assume the speed of sound in air to be 330 $m \cdot s^{-1}$.

*3.1.4 Calculate the frequency of sound heard by pedestrian **X** if the fire engine is travelling at 20 $m \cdot s^{-1}$. (3)

3.1.5 Consider pedestrian **X and sketch a graph of apparent frequency (f_L) versus velocity (v_S) of the sound source. (NO NUMERICAL VALUES NEEDED). (2)

3.2 A helium line from the spectrum of the sun has a frequency of 5,10 x 10^{14} Hz. The frequencies of the same helium line from the Earth, which are observed in the line emission spectrum of two stars, are:

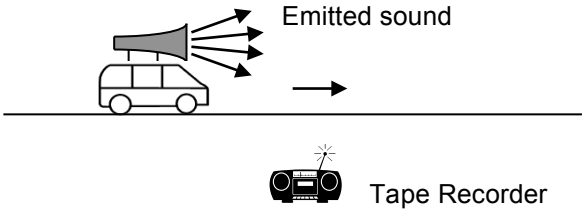
Star **A**: 5,12 x 10^{14} Hz
Star **B**: 5,02 x 10^{14} Hz

3.2.1 Which ONE of the stars (**A** or **B**) has a red shift? Give a reason for the answer. (2)

3.2.2 In which direction does star **A** move? State only: **Away from the Earth** or **Towards the Earth**. (1)

QUESTION 4

In the diagram, a vehicle with a siren attached to its roof is travelling to the right. The siren emits a continuous note of frequency 450 Hz. Upon listening to a recording on the tape recorder, the siren appeared to be emitting 2 sounds of different frequencies, 464 Hz and 437 Hz.



4.1 Name the phenomenon which would have led to the recording of the two different notes. (1)

4.2 State and very briefly describe one useful application of this phenomenon (as it applies to sound or light). (3)

4.3 Use the information in the text to determine the magnitude of the velocity at which the vehicle was travelling.
Take the speed of sound to be 340 $m.s^{-1}$. (4)

4.4. Explain (in terms of the wave fronts being produced) why the observed frequencies are respectively higher and lower than the frequency of the source. (4)

QUESTION 5

An ambulance approaches an accident scene at a constant velocity. The siren of the ambulance emits sound waves with a constant, unknown frequency. A detector at the scene measures the frequency as 1,07 times the frequency of the siren.

5.1 State the DOPPLER EFFECT for sound in words. (2)

*5.2 Calculate the speed at which the ambulance approaches the accident scene. Use the speed of sound in air as 340 $m•s^{-1}$. (5)

5.3 Explain, in terms of wave motion, why the frequency detected by the detector is higher than the frequency of the source. (2)

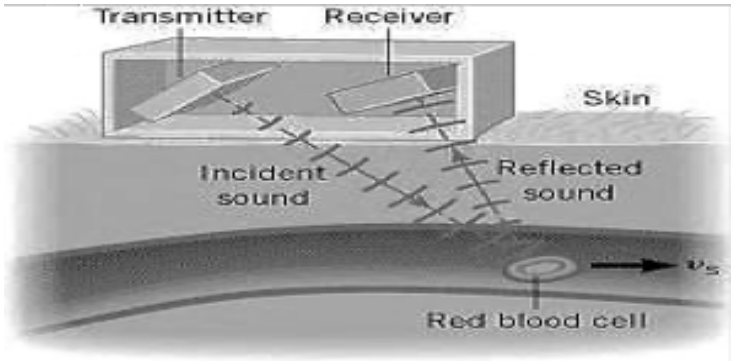
5.4 State TWO uses of the Doppler flow meter in humans. (2)

*5.5 A line in a hydrogen spectrum has a frequency of $7,55 \times 10^{14}$ Hz when measured in a laboratory. The same line in the light of a star has a frequency of $7,23 \times 10^{14}$ Hz.

Is this star moving TOWARDS or AWAY from the Earth?
Explain your answer. (2)

QUESTION 6

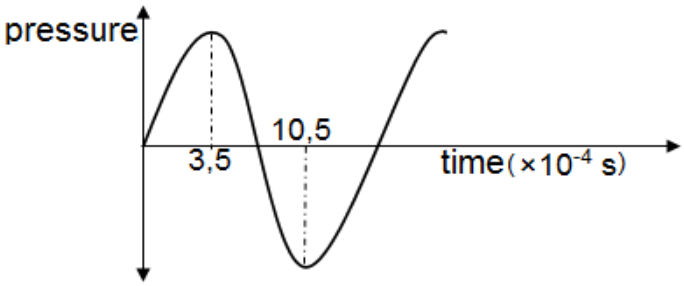
Use the diagram below to answer the following questions.



6.1 Identify the medical device shown in the diagram. (1)
6.2 Explain briefly how the device functions and what it may be used for. (2)
*6.3 A fire truck with its siren on, moves away at constant velocity from a person standing next to the road. The person measures a frequency which is 90% of the frequency of the sound emitted by the siren of the fire truck.
6.3.1 Name the phenomenon observed. (1)
6.3.2 If the speed of sound in air is 340 $m \cdot s^{-1}$, calculate the speed of the fire truck. (4)

QUESTION 7

A man mounts a siren on the roof of his car. The siren produces a constant frequency of 600 Hz. He drives the car at a constant speed up and down a straight road while a stationary listener takes some readings. After a while,
the listener obtains the following pressure-time graph from the readings taken.



7.1 Determine the period of the detected wave. (2)
7.2 Calculate the frequency of the detected sound wave. (3)
7.3 State the *Doppler Effect* in words. (2)
7.4 Calculate the speed of the moving car. (5)
(Take the speed of sound in air as 340 $m.s^{-1}$)

QUESTION 8

A man standing on the sidewalk notices that the sound of a racing car changes when the car moves towards him at a constant speed of 200 km.h^{-1} compared to when the car is moving away from him.

Assume that the speed of sound in air is 340 m.s^{-1}.

8.1 Name and state the phenomenon illustrated above. (3)

8.2 Convert 200 km·h^{-1} to m·s^{-1}. (2)

8.3 If the frequency of sound that the man will hear when the car is approaching him is 298,84 Hz, calculate the frequency of sound produced by the car. (5)

8.4 State TWO uses of the Doppler flow meter in medical field. (2)

QUESTION 9

Some motion-sensor burglar alarms installed in homes make use of ultra-sound waves that have a frequency of 30 kHz. Waves sent out from the device are reflected by all objects in a room. If the objects are stationary then the reflected waves reach the device with the same frequency as the outgoing wave (30 kHz). If an object moves, the frequency of the reflected waves is altered. Such a change in frequency will trigger the alarm.

(Take the speed of sound in air as 340 m·s^{-1} when answering these questions).

9.1 Name and state the scientific phenomenon upon which this technology is based. (3)

9.2 Convert 30 kHz to Hz. (1)

9.3 Calculate the wavelength of the waves being generated by the device. (3)

*9.4 How will the frequency of a wave detected by the device change when it is reflected off an object moving towards the device? (Write only INCREASES, DECREASES or REMAINS THE SAME). (1)

*9.5 A wave reflected off a moving object in the room is detected at a frequency of 29 500 Hz. Calculate the velocity of the object. (6)

QUESTION 10

You are on holiday in a Game Park that has lions. To protect the visitors from being attacked by the lions in this Game Park, each lion is fitted with a device that emits sound waves at a frequency of 398 Hz. The visitors are given detectors which measures the frequency of the emitted sound waves from the device fitted in the lions when the lion is a certain distance from the visitors.

On a particular occasion, the detector that you are holding in your hand registers a reading of 408 Hz, while you are sitting in your room.

10.1 Name the effect that could be used to explain the difference between the frequency of the waves emitted by the device fitted to the lions and the frequency registered by the detector that you have. (1)

10.2 Briefly explain how the frequency registered by the detector is supposed to help protect the visitors from being attacked by the lion. (3)

10.3 Use the given information to calculate the speed with which the lion is moving if the speed of sound in air is 340 $m.s^{-1}$. (6)

ELECTROSTATICS

REVISION: GRADE 10 WORK

Static electricity is stationary electricity i.e there is no movement of electrical charges. **Electrostatics** is the study of static electricity where we try to find out what effect do charges at rest have on one another.

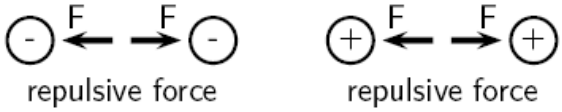
TYPES OF CHARGES:

1. **Positive charge** – A positive charge on an object originates with the removal or shortage of electrons
2. **Negative charge** – A negative charge on an object originates with the addition or surplus of electrons.

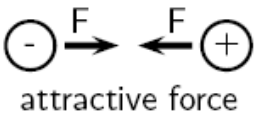
N.B . **Neutral object** - when the number of electrons (negative charges) is equal to the number of protons (positive charges).

Charged objects exert forces on each other:

- Like charges repel each other – **Repulsion**



- Unlike charges attract each other – **Attraction**



Objects can be charged by

- **Friction:**
  - A plastic ruler becomes positively charged when it is rubbed with a dry cloth because the plastic ruler transfers electrons to the cloth
  - A glass rod becomes negatively charged when rubbed with a dry cloth because the dry cloth transfers electrons to the glass rod.
- **Touch:**
  - When a charged object touches an uncharged object, then both objects obtain the same charge if they are identical.

The law of conservation of charge

The algebraic sum of the charges remains constant in a closed system.

Unit of charge

- Charge is measured in units called coulombs (C).
- A coulomb of charge is a very large charge.
- In electrostatics we therefore often work with charge in micro coulombs (1 μC = 1 × 10^{-6} C) and nano coulombs (1 nC = 1 × 10^{-9} C).

Coulomb's law

The force of attraction or repulsion that two charges at rest exert on each other is directly proportional to the product of the two charges and inversely proportional to the square of the distance between their centres.

$$F_{net} = \frac{KQ_1Q_2}{r^2}$$

Where:

F is the force in Newtons (N)

Q_1 and Q_2 are charges in coulombs (C)

r is the distance between the two charges in metres (m)

k is proportionality constant (Coulombs Law constant) with the value of $9x10^9 N{\cdot}m^2.C^{-2}$

Worked Example 1

Two point-like charges carrying charges of +3 nC and −5 nC are 2m apart. Determine the magnitude of the force between them and state whether it is attractive or repulsive.

Solution 1

Step 1: Data

F =

Q_1 = +3 nC = +3 × 10^{-9}C

Q_2 = -5 nC = −5 × 10^{-9}C

r = 2 m

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

Step 2: Suitable Equation

$$F = \frac{kQ_1Q_2}{r^2}$$

Step 3: Determine the magnitude of the force

$$F = \frac{kQ_1Q_2}{r^2}$$

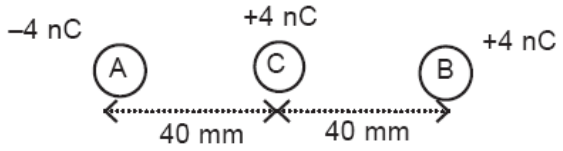
$$= \frac{(9,0 \times 10^{9})(3 \times 10^{-9})(5 \times 10^{-9})}{(2)^2}$$

$$= 3,38 \times 10^{-8}\text{N}$$

Thus the magnitude of the force is $3,38 \times 10^{-8}$N. However since both point charges have opposite signs, the force will be attractive.

Worked example 2

Two tiny spheres A and B with charges – 4 nC and +4 nC respectively, are placed as in the sketch. They are fixed while a third charge C of + 4 nC has its centre placed at at a distance of 40 mm from the centres of both A and B. 1 nC = 1 nano coulomb = 1 x 10^{-9} C. (frictionless)



(a) Calculate the magnitude of the Coulombic force that exists between charge A of – 4 nC and the charge C of +4 nC charge.
(b) In which direction will the sphere C move?
(c) Calculate the magnitude of the acceleration with which the sphere C will **start** moving from its position as indicated, if it has a mass of 200 g.

Solution 2

Draw a free body diagram showing the forces on C. For C, take as positive the direction to the left.
Let C react with A first, and then with B

$$F_{AC} = \frac{kQ_1Q_2}{r^2} = \frac{9 * 10^{9} x 4 * 10^{-9} x 4 * 10^{-9}}{(40 * 10^{-3})} = 9 * 10^{-5}\text{N to the left (Attractive)}$$

(b) $F_{AB} = 9x10^{-5}$N to the left (Repulsive)

(c) $a = \frac{F_{res}}{m} = \frac{18x10^{-5}}{200x10^{-3}} = 9x10^{-4}$ m.s^{-2}

ELECTRIC FIELD AROUND CHARGES

Electric field

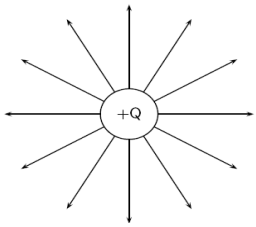
An electric field is a region around a charge where any other charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.

Some important points to remember about electric fields:

- They originate and end perpendicularly to the surface of the charged objects.
- Field lines never cross.
- They are most dense (closer to each other) where the field is the strongest and is least dense (further from each other) where the field is the weakest.
- They surround the charged object in three dimensions. We only draw a few lines in one plane
- There is a uniform field (except at the end points) between two oppositely charged parallel plates.

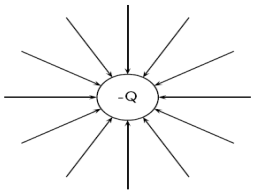
Electric field lines around a positive point charge:

- For a positive point charge, field lines are drawn away from the charge.

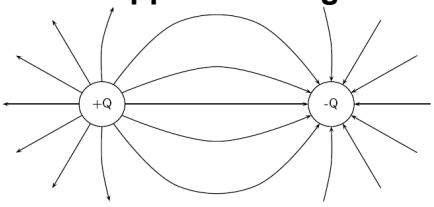


Electric field lines around a negative point charge:

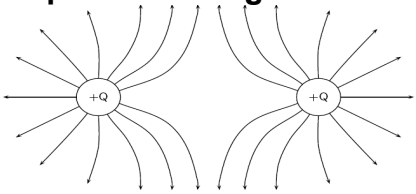
- For a negative charge, field lines are drawn towards the charge.



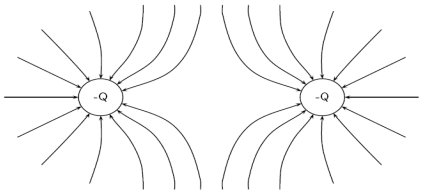
Electric field lines of two equal but opposite charges:



Electric field lines of two equal positive charges:



Electric field lines of two equal negative charges:



Strength of an electric field
The test charge placed at a point in electric field will experience a force; the magnitude of the force experienced will depend on the distance of the test charge(q) away from the charge(Q) setting the field.

The magnitude of the electric field (electric field strength) at a point in an electric field is the force per positive unit charge (thus + 1C) at that point.

Electric field strength= $\frac{\text{force}}{\text{charge}}$

Or in symbols, $E = \frac{F}{q}$

Unit: if the electrostatic force **F** acts on the charge in Newton (N), the charge q is in coulomb (C), then the electric field strength (E) is in $N \cdot C^{-1}$ (Newton per Coulomb). As we will see later, the electric field strength can also be measured in Volt per metre ($V \cdot m^{-1}$).
Direction: electric field strength is a vector quantity because it has magnitude and direction. A direction of electric field strength E at a specific point in an electric field is the same as the direction of the electrostatic force that a positively charged particle will experience at that point. The positively charged particle will thus move in the direction of the field and a negatively charged particle will move against the field.

The force experienced by a test charge when placed in an electric field is given by;

$$F=qE$$

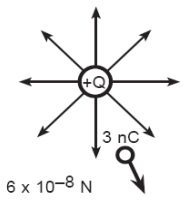
Worked example 3
If the magnitude of the electric field strength (**intensity**) is 3×10^{6} N • C^{-1} at a point, calculate the magnitude of the force acting on a charge of – 7 nC placed at that point.

$$F = qE$$

$$= 7 \times 10^{-9} \times 3 \times 10^{6}$$

$$= 0.021 \text{ N}$$

Electric field strength at a point due to a number of point charges



The force between two electric charges is given by:

$F = \frac{kQq}{r^2}$ (If we make the one charge Q and the other q.)

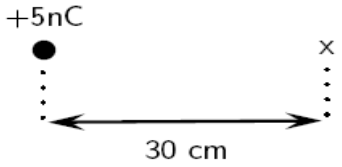
Therefore, the electric field can be written as

$E = \frac{kQ}{r^2}$ (where Q is the charge setting the field)

N. B. As with Coulomb's law calculations, do not substitute the sign of the charge into the equation for electric field. Instead, choose a positive direction, and then either add or subtract the contribution to the electric field due to each charge depending upon whether it points in the positive or negative direction, respectively

Worked Example 4

Question: Calculate the electric field strength 30cm from a 5nC charge.



Solution 4

Step 1: Data.

Q = +5nc = $+5 \times 10^{-9}$ C

r = 30 cm = 0.30 m

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

Step 2: **Select a suitable equation**

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

Step 3: substitute into equation:

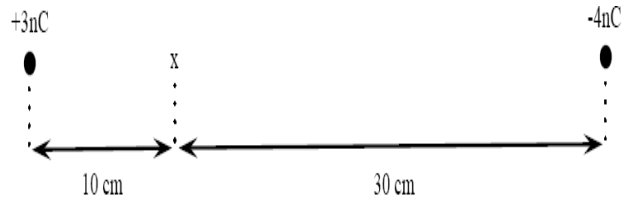
$$E = \frac{kQ}{r^2}$$

$$= \frac{(9 \times 10^{-9})(5 \times 10^{-9}}{(0, 3)^2}$$

$$= 5 \times 10^{-16}\ N \cdot C^{-1}$$

Worked example 5

R and S are two points in the electric field of a small negatively charged sphere Q, Two charges of Q_1 = +3nC and Q_2 = −4nC are separated by a distance of 40cm. What is the electric field strength at a point that is10cm from Q_1 and 30cm from Q_2? The point lies between Q_1 and Q_2.



Solution 5
Step 1: **Determine what is required:**
We need to calculate the electric field a distance from two given charges.

Step 2: **Determine what is given:**
We are given the magnitude of the charges and the distances from the charges.

Step 3: Determine how to approach the problem:
We will use the equation:

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

We need to work out the electric field for each charge separately and then add them to get the resultant field.

Step 4: **Substitute into an equation:**
We first calculate E at x due to **Q_1:**

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

$$= \frac{(9 \times 10^9)\,(3 \times 10^{-9})}{(0,\,1)^2}$$

$$= 2,70 \times 10^3\ \text{N}\cdot\text{C}^{-1}$$

Then for **Q_2:**

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

$$= \frac{(9 \times 10^9)\,(4 \times 10^{-9})}{(0.3)^2}$$

$$= 4,00 \times 10^2\ \text{N}\cdot\text{C}^{-1}$$

We need to add the two electric fields because both are in the same direction.
The field is away from Q_1 and towards Q_2.
Therefore,

$$E_{total} = 2,70 \times 10^3 + 4,00 \times 10^2 = 3,10 \times 10^3\ \text{N}\cdot\text{C}^{-1}$$

Electrical potential energy and Electric potential
The electrical potential energy of a charge is the energy it has because of its position relative to other charges that it interacts with. The potential energy of a charge Q_1 relative to a charge Q_2 a distance r away is calculated by:

Worked example 6
What is the electric potential energy of a 7nC charge that is 2 cm from a 20nC?

$$U = \frac{kQ_1Q_2}{r}$$

Solution 6
Step 1: Data.
Q_1 = 7nC = 7×10^{-9} C

Q_2 = 2OnC = 20×10^{-9} C
r = 2cm = 2×10^{-2} m

Step 2: **Suitable equation:**

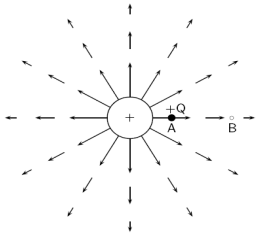
Step 3: Substitute into an equation

$$U = \frac{kQ_1Q_2}{r}$$

$$= \frac{9 \times 10^9 (7 \times 10^{-9})(20 \times 10}{2 \times 10^{-2}}$$

$$= 6{,}30 \times 10^{-5} \text{ J}$$

Electric potential
The electric potential at a point is the electrical potential energy per unit charge, i.e. the potential energy a +1C test charge would have if it were placed at that point.
Consider a positive test charge +q that is free to move, placed at A in the electric field of another positive point charge.



The test charge moves towards B under the influence of the electric field of the other charge.
In the process the test charge loses electrical potential energy and gains kinetic energy. Thus, at A, the test charge has more potential energy than at B – A is said to have a higher electrical potential than B. to move the charge from B back to A EXTERNAL WORK MUST BE DONE.

POTENTIAL DIFFERENCE

- The potential difference between two points in an electric field is defined as the work required to move a unit positive test charge from the point of lower potential to that of higher potential.

OR

- The electrical potential difference is the difference in electrical potential energy per unit charge between two points ($V = \frac{W}{Q}$).

Unit: The electrical potential difference is measured in volts (**V**). Using the equation $V = \frac{W}{Q}$ the unit will be joule per coulomb ($J \cdot C^{-1}$) which is the same as volt, thus electrical potential difference is also called voltage.

Worked example 7:
What is the potential difference between two points in an electric field if it takes 600J of energy to move a charge of 2C between these two points?

Solution 7
Step 1: **Data**.

Step 2: Suitable equation:

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

Step 3: Substitution:

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

$$= \frac{600}{}$$

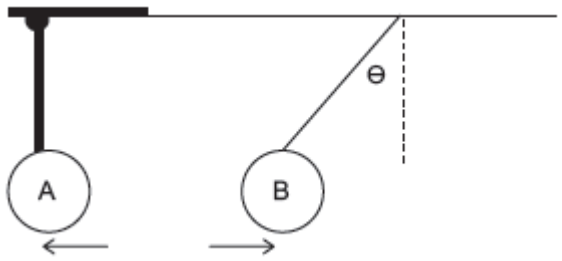
$$= 300V$$

LONG QUESTIONS

QUESTION 1

Two 49 g plastic balls are set up as shown below so that one is **fixed** vertically but can slide horizontally (A) and one is hanging from a strong thread (B). Ball B has a fixed negative charge but ball A is able to have its positive charge varied.

A learner wants to find the relationship between the product of the charges and the force of attraction. He varied the charge on the fixed ball A and then measured the angle(θ) the thread made with the vertical, having adjusted the distance between the balls so that it was always 3,7 cm. He was then able, through simple trigonometry, to calculate the horizontal electrostatic force of attraction using this angle (F_h = 0,49 tan θ). The results are tabulated below



Charge on ball A (nC) (+)	Angle to vertical (°)	Force of attraction = 0,49tanθ (x 10^{-2} N)
10	5,0	4,3
20	9,5	8,2
30	14,8	12,9
40	19,4	17,3
50	23,5	**X**
60	27,7	25,7

1.1 Write a hypothesis for this investigation. (3)

1.2 Calculate the missing value, **X**. (2)

1.3 What is the independent variable in this experiment? (1)

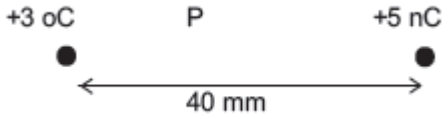
1.4 Give two controlled (fixed) variables in this experiment. (2)

1.5 Draw a fully labelled free body diagram for the forces acting on B. (3)

1.6 What is the relationship between the charge on ball A and the force of attraction? (1)

QUESTION 2

Two small conducting spheres which carry charges of +3 nC and +5 nC are placed at a distance of 40 mm apart as shown in the diagram below.



2.1 Define an electric field. (2)

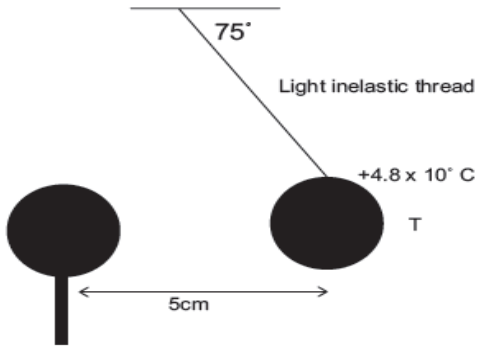
2.2 Draw the electric field that would surround these two small conducting spheres. Show the conducting spheres as small circles. (2)

2.3 Along the line joining the two small spheres, there is a point **P**, which is **10 mm** from the **+3 nC** charge. Show that the magnitude of the resultant or net electric field strength at **P** is **2,2 x 105 N.C^{-1}**. (8)

2.4 An electron is placed at point **P**. Calculate the force experienced by the electron due to the electric field. (4)

QUESTION 3

Tshepo and Mary suspend a graphite-coated polystyrene sphere **T** from the ceiling by means of a very light inelastic thread. The sphere carries a charge of **+4, 8 × 10^{-8} C** and has a mass of **2g**. Tshepo now brings an insulated stand, on which an **identically charged** sphere **S** is mounted, close to sphere **T**. Sphere **T** settles in an equilibrium position so that the centres of the spheres are **5 cm** apart, as indicated in the diagram



3.1 Briefly explain why the polystyrene spheres need to be coated with graphite. (1)

3.2 Define the magnitude of the electric field at a point. (2)

3.3 Draw the electric field lines around sphere **S** (3)

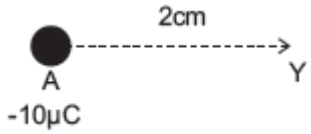
3.4 Draw a free body of the forces acting on sphere **T** (4)

3.5 Calculate the **magnitude** and **direction** of the electrostatic force that sphere S exerts on sphere **T**. (3)

3.6 Calculate the electric field strength at **S** (3)

QUESTION 4

A charged sphere **(A)** holding a charge of **−10μC**, is held fixed in position on a horizontal, insulated surface.

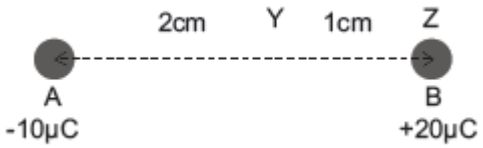


4.1 What is meant by the term 'electric field'? (2)

4.2 How many electrons were lost or gained in order for sphere A to gain its charge? (2)

4.3 Calculate the magnitude and direction of the electric field strength at position Y, 2 cm away from the point charge A. (4)

A second point charge (B) holding a charge of +20μC, is placed at position Z, 1cm to the right of Y, on the horizontal, insulated surface and is free to move. Objects A and B each have a mass of 10mg.



4.4 Draw the electric field lines that represent the resultant electric field that is set up by the two point charges A and B (3)

4.5 State *Coulomb's law*. (2)

4.6 Calculate the electrostatic force that B will experience due to A. (4)

4.7 In order to prevent B from moving, a third point charge (C) is placed **1 cm** to the right of B. Calculate the charge that must be placed on C in order to hold stationary. (4)

QUESTION 5

A helium nucleus has three types of forces acting within it namely ***electrostatic***, ***gravitational*** and ***nuclear forces***. The question that puzzled scientists for a long time was what stopped the nucleus from falling apart due to the strong electrostatic repulsion between the two protons?'

5.1 Draw the electrostatic field between the two protons in the nucleus. (2)

The charge and mass of a proton are **+1,6x10-19 C** and **1,67x10-27 kg** respectively.
In the helium nucleus the two protons are **8,4x10-16 m** apart.

5.2 Calculate the force of electrostatic repulsion between the protons. (3)

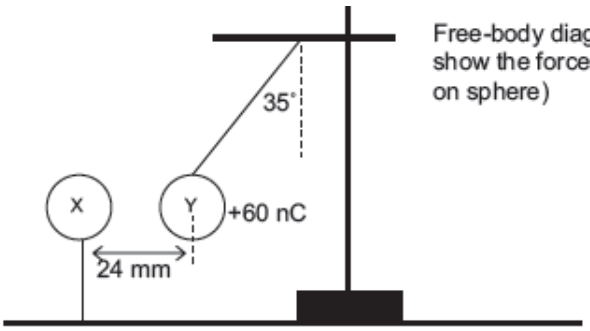
5.3 Calculate the force of gravitational attraction between the protons. (3)

5.4 Is the nuclear force present in the nucleus one of attraction or repulsion? (1)

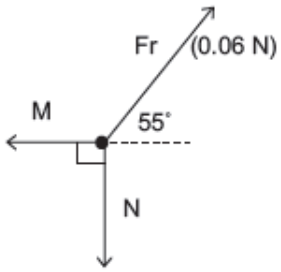
5.5 By how many powers of ten do the electrostatic and gravitational forces differ by? (1)
5.6 Which of the three forces has to be the largest? Give a reason for your answer. (2)

QUESTION 6

Two small charged polystyrene spheres, **X** and **Y**, are in equilibrium as shown in the diagram below. Sphere **X** stands on an insulated pole. Sphere **Y**, which has a charge of **+60 nC**, is suspended by means of a light inextensible thread. The tension (**FT**) in the thread is **0,06 N**. The angle between the thread and the vertical is **35°.** The distance between the centre of sphere **X** and the centre of sphere **Y** is **24 mm**,



Free-body diagram to show the forces acting on sphere)



6.1 The free body diagram represents the forces acting on sphere Y. Provide labels (2)
6.2 Does sphere X have a positive **OR** a negative charge? Give a reason for your answer. (2)
6.3 Calculate the magnitude of the horizontal component of the tension in the thread. Give your answer to 3 decimal places. (2)

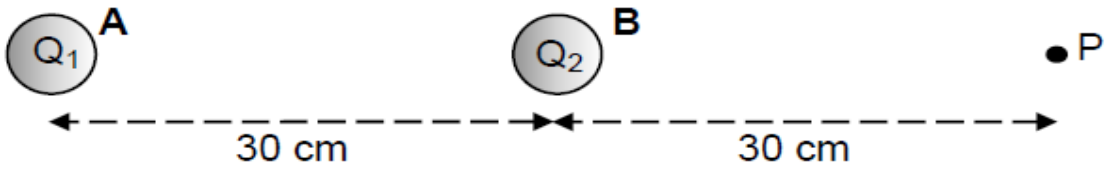
6.4 What is the magnitude of force **M**? (1)

6.5 State *Coulomb's Law.* (2)

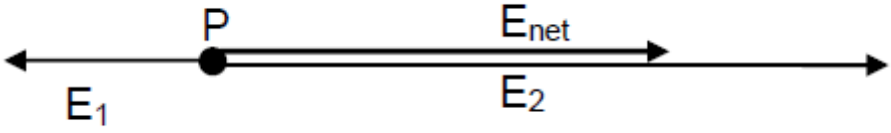
6.6 Calculate the magnitude of the charge on sphere **X**. (4)

QUESTION 7 GP 2015

Two identical conducting spheres **A** and **B** with charges of $\mathbf{Q_1}$ and $\mathbf{Q_2}$ respectively are placed in fixed positions along the same straight line as shown in the diagram below. Spheres **A** and **B** are placed 30 cm from each other. Point **P** is positioned 30 cm to the right of sphere **B** on the same straight line.



The charge on sphere **B** is positive. The net electric field $\mathbf{E_{net}}$ at point **P** as a result of the two charges $\mathbf{Q_1}$ and $\mathbf{Q_2}$ is towards the right as shown in the diagram below.



7.1 What is the sign of the charge on sphere **A**? Give a reason for the answer. (3)

7.2 The net electric field at point P is 1 600 $N \cdot C^{-1}$ to the right and the charge on sphere B has a magnitude of +12 nC. (7)
Calculate the magnitude of the charge on sphere A.

A proton is placed at point **P** without changing the charges and positions of spheres **A** and **B**.

7.3 Calculate the net electrostatic force experienced by the proton. (4)

QUESTION 8 DOE FEB/MAR 2016

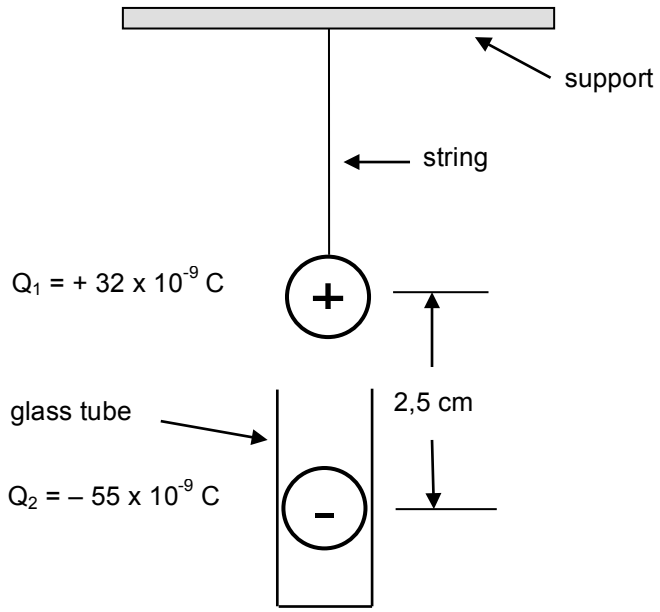
A sphere Q_1, with a charge of -2,5 µC, is placed 1 m away from a second sphere $\mathbf{Q_2}$, with a charge +6 µC. The spheres lie along a straight line, as shown in the diagram below. Point **P** is located a distance of 0,3 m to the left of sphere $\mathbf{Q_1}$, while point **X** is located between $\mathbf{Q_1}$ and Q_2. The diagram is not drawn to scale.

8.1 Show, with the aid of a VECTOR DIAGRAM, why the net electric field at point **X** *cannot be zero.* (4)

8.2 Calculate the net electric field at point **P**, due to the two charged spheres $\mathbf{Q_1}$ and Q_2. (6)

QUESTION 9

A small sphere, Q_1, with a charge of + 32 x 10^{-9} C, is suspended from a light string secured to a support. A second, identical sphere, Q_2, with a charge of – 55 x 10^{-9} C, is placed in a narrow, cylindrical glass tube vertically below Q_1. Each sphere has a mass of 7 g. Both spheres come to equilibrium when Q_2 is 2,5 cm from Q_1, as shown in the diagram. Ignore the effects of air friction.



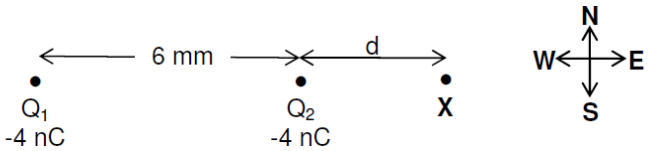
9.1 Calculate the number of electrons that were removed from Q_1 to give it a charge of + 32 x 10^{-9} C. Assume that the sphere was neutral before being charged. (3)

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

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

QUESTION 10

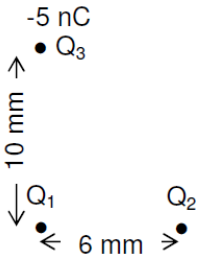
In the diagram below, a point charge, Q_2, with a charge of -4 nC is placed 6 mm east of an identical point charge Q_1. Point **X** is a distance **d** east of Q_2.



10.1 Draw the net electric field pattern due to charges Q_1 and Q_2. (3)

10.2 The electric field at point **X**, due to ONLY Q_1, is 4,44 x 10^5 N·C^{-1} west. Calculate the distance **d**. (5)

A charge Q_3 of -5 nC is now placed 10 mm due north of charge Q_1.



10.3 Write down Coulomb's law in words. (2)
10.4 Calculate the net force that the charge Q_1 will experience due to the charges Q_2 and Q_3. (7)

ELECTRIC CIRCUITS

LAW

1. State Ohm's law in words: The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.

DEFINITIONS

1. emf is the work done per unit charge by the source (battery). It is equal to the potential difference measured across the terminals of a battery when no charges are flowing in the circuit.
2. Potential difference across the ends of a conductor is the energy transferred per unit electric charge flowing through it.
3. Terminal potential difference is the voltage measured across the terminals of a battery when charges are flowing in the circuit.
4. Current strength is the rate of flow of charge.
5. Resistance is the ratio of the potential difference across a resistor to the current in the resistor.
6. Internal resistance is the opposition to the flow of charge within the battery or cell.
7. One ohm (Ω) is equal to one volt per ampere.
8. Power is the rate at which work is done or energy is transferred.

EQUATIONS

$Q = I\Delta t$ or $I = \frac{Q}{\Delta t}$	$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots$	$R = r_1 + r_2 + r_3 + \ldots$
$R = \frac{V}{I}$	$W = Vq$ or $V = \frac{W}{Q}$	$P = \frac{W}{\Delta t}$
$W = VI\Delta t$	$W = I^2R\Delta t$	$W = \frac{V^2\Delta t}{R}$

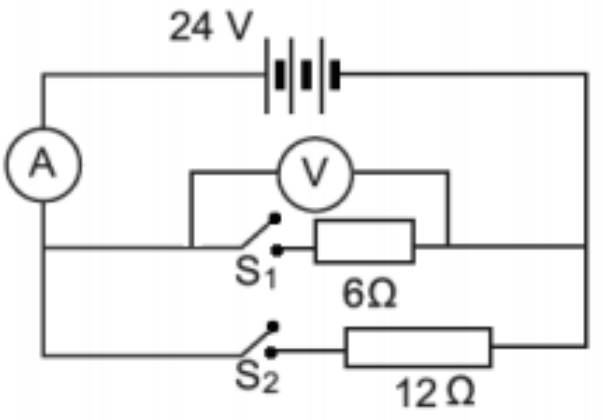
$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$
$\varepsilon = V_{load} + V_{internal\ resistance}$	$\varepsilon = IR_{ext} + Ir.$	$\varepsilon = I(R + r)$

EXAMPLES
PHYSICAL SCIENCES GRADE 10 RESOURCE PACK (GOOGLE DRIVE)

1. A 12 V battery supplies a maximum of 120 J of energy when charge passes through it. Calculate the amount of charge passing through the battery. (4)

$V = \frac{W}{Q}$ √
12 √ = $\frac{120}{Q}$ √
Q = 10C √ (4)

2. When three cells are connected in series, the total emf of the battery is 24 V. Two resistors are connected in parallel with switches S1 and S2 as shown in the diagram below, and connected to the battery. An ammeter (A) reads the current passing through the battery and voltmeter(V) reads the potential difference across the 6 Ω resistor. The cells and ammeter have negligible resistance. The voltmeter has a very high resistance.



2.1 Explain what it means when we say: 'The emf of the battery is 24 V. (2)

The work done per unit charge by the battery is 24 J.C^{-1} √√

2.2 What is the reading on the voltmeter when switch S1 is open? (1)

24 V accuracy; SI units √

2.3 What is the reading on the voltmeter when S1 is closed? (1)

24 V accuracy; SI units √

2.4 What is the reading on the voltmeter when S1 and S2 are closed? (1)

24 V accuracy; SI units √

2.5 Calculate the equivalent resistance of the two resistors in parallel. (4)

$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ √

$\frac{I}{R} = \frac{I}{6} + \frac{I}{12}$ √

$\frac{I}{R} = \frac{3}{12}$

$R = \frac{12}{3}$ √

R = 4 Ω √

3.1. Explain what is meant by "the current is 2 A". (2)

Current strength is the rate of flow of charge. √√

3.2 Calculate the charge that passes through a resistor when a steady current of 2 A is maintained for 2 minutes. (4)

Q = I Δt √

Q = 2 √ x (2X60) √

Q = 240 C √

3.3 Explain what is meant by "the potential difference across the resistor is 4 V". (2)

Potential difference across the ends of a conductor is the energy transferred per unit electric charge flowing through it. √√

3.4 Calculate the energy transferred when a potential difference of 4 V is connected across a resistor, and a steady current of 2 A passes through it for 2 minutes. (3)

W = Vq √

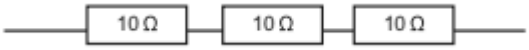
W = 4 x 240 √

W = 960 J √

3.5 Explain what is meant by resistance in an electric circuit. (2)

Resistance is the ratio of the potential difference across a resistor to the current in the resistor. √

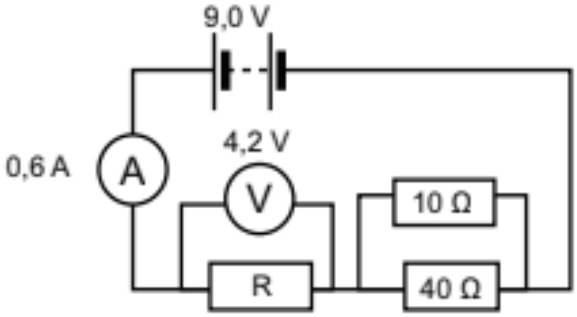
4. All the resistors in the following diagrams are identical. Each resistor has a resistance of 10 Ω.



Calculate the effective resistance. (3)

$R = r_1 + r_2 + r_3$ √
$R = 10 + 10 + 10$ √
$R = 30\ \Omega$. √

5. In the circuit diagram shown below, two resistors of 10 Ω and 40 Ω are connected in parallel. A resistor R of unknown resistance is connected in series with the parallel combination. The ammeter reads 0,6 A. The battery has an emf of 9,0 V, and it has no internal resistance. The voltmeter connected across resistor R reads 4,2 V.



5.1 Calculate the effective resistance of the parallel resistors. (3)

$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ √

$\frac{I}{R} = \frac{I}{10} + \frac{I}{40}$ √

$\frac{I}{R} = \frac{5}{40}$

$R = \frac{40}{5}$

$R = 8\Omega$ √

5.2 Explain what is meant by: "A parallel circuit is a current divider." (2)

The current splits up according to the ratio of the resistances in the parallel branches { e.g. if the ratio is 10:40 then the current will split up in the ratio of 40:10.] √√

5.3 Using the fact that the parallel circuit is a current divider, calculate the

current through the 10 Ω resistor. (4)

The main current is 0,6 A. √
{The ratio of the resistances is 10:40 therefore the current plits into 50 parts. √
The current through the 10 Ω resistor
= 40 x 0,06 √
= 0,48A√

5.4 Explain what is meant by: "A series circuit is a potential divider." (2)

The potential difference across each resistor (component) in a series circuit divides according to the ratio of their resistances. √√

5.5 Hence, calculate the resistance of the unknown resistor R. (4)

Ratio of pd = 4,8 V ; 4,2 V √
= 8 : 7 √
Ratio of resistances = 8 ; R = 8 : 7 √
R = 7 Ω√

5.6 How is the reading on the ammeter affected when the 10 Ω resistor is removed from the circuit? Just answer: increases, decreases, or remains the same. Explain (4)

Decreases √

Removing the 10 Ω resistor causes resistor R and the 40 Ω resistor to be connected in series. √

This increases the effective resistance of the whole circuit, √

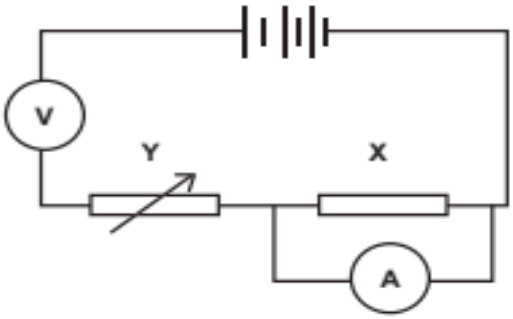
and therefore there is more opposition to the flow of charge i.e. the current decreases. √

PHYSICAL SCIENCES WORKSHEET BOOKLET GRADE 11 TERM 3(GOOGLE DRIVE)

6. State Ohms law. (2)

State Ohm's law states that the potential difference across a conductor is directly proportional to the current in the conductor at constant temperature. √√

7. Tshepo and Mo are given a conductor X and asked to conduct an investigation to determine whether or not conductor X is ohmic. They set up a circuit as shown below. Ignore the internal resistance of the battery.



7.1. Identify two errors made by Tshepo and Mo when connecting the circuit shown above. (2)

They connected the voltmeter in series, not in parallel; √

They connected the ammeter in parallel, not series. √

7.2. What is the function of component Y in this investigation? (2)

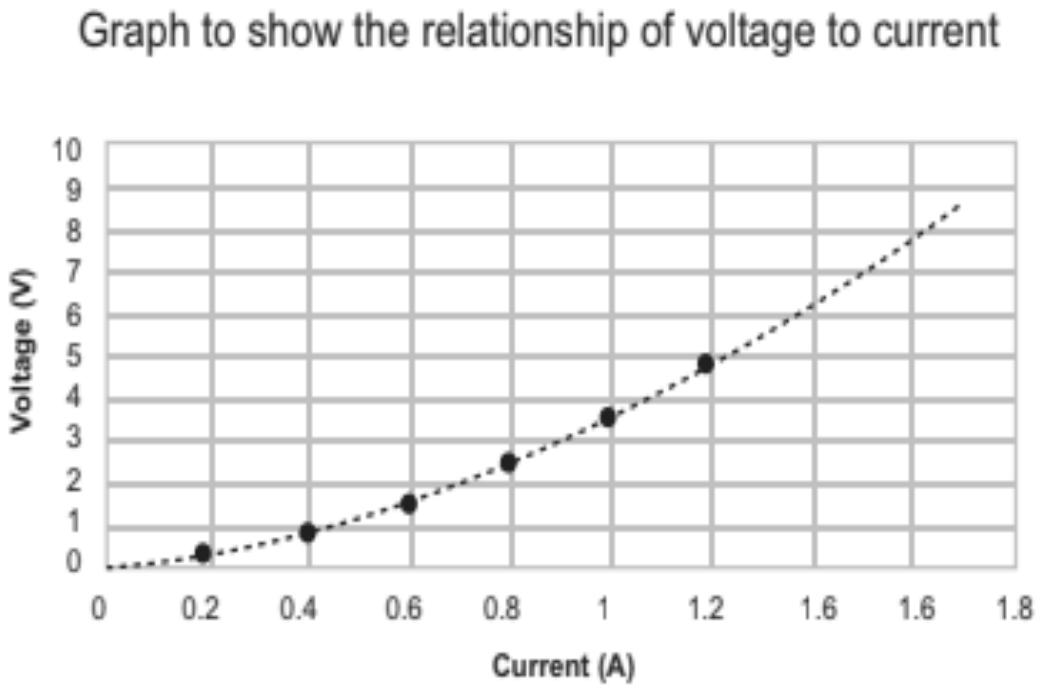
To vary the resistance. √√

7.3. Tshepo and Mo collect the following pairs of ammeter and voltmeter readings during their investigation:

I (A)	V (V)
0,2	0,55
0,4	1,10
0,6	1,65
0,8	2,20
1,0	3,30
1,2	5,00

Plot a graph of potential difference (y-axis) versus current (x-axis) on graph paper.

Draw a line which best fits all the plotted points. (6)



7.4. Calculate the gradient of the graph when the current in conductor X is less than 0,8 A. Provide an appropriate unit for your answer. (3)

Gradient = $\frac{0,25 - 0}{0.8 - 0}$ √

Gradient = 2,75 $V.A^{-1}$ √

Gradient = 2,75 Ω √

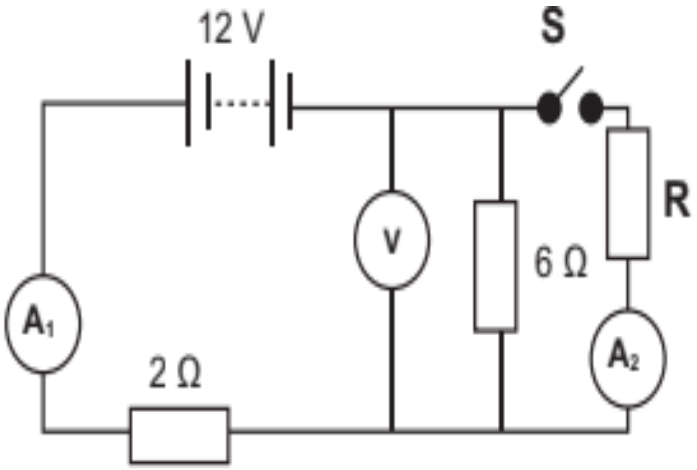
7.5. Is conductor X an ohmic conductor (for all currents) in this investigation? Justify your answer. (2)

Non-ohmic, √ *as it is not a straight line the whole way.* √

7.6. Explain the trend in your graph when the current in conductor X is greater than 0,8 A. (2)

As the current increases, the resistor gets hot √ *and the resistance increases.* √

8. In the circuit diagram below the battery has negligible internal resistance.



With the switch, S OPEN, determine the reading on

8.1 ammeter A1 (3)

$R = \frac{V}{I}$ √

$8 = \frac{12}{I}$ √

I = 1,5 A √

8.2 voltmeter V (3)

V = IR √

V = 1,5 x 6 √

V = 9V √

The switch S is now CLOSED, and the reading on the voltmeter V decreases.

8.3 If the reading on A1s three times that of A2, what is the resistance of resistor R? (4)

Let $A_2(I^2)$ BE X, therefore $A_1 = 3X$ √

$V_{6\Omega} = 6\ (3X - 1) = 12X$ √

$V_{6\Omega} = V_{R\ parallel} = 12X$

$R_R = \frac{V_R}{I2}$

$R_R = \frac{12X}{X}$ √

$R_R = 12\ \Omega$ √

OR

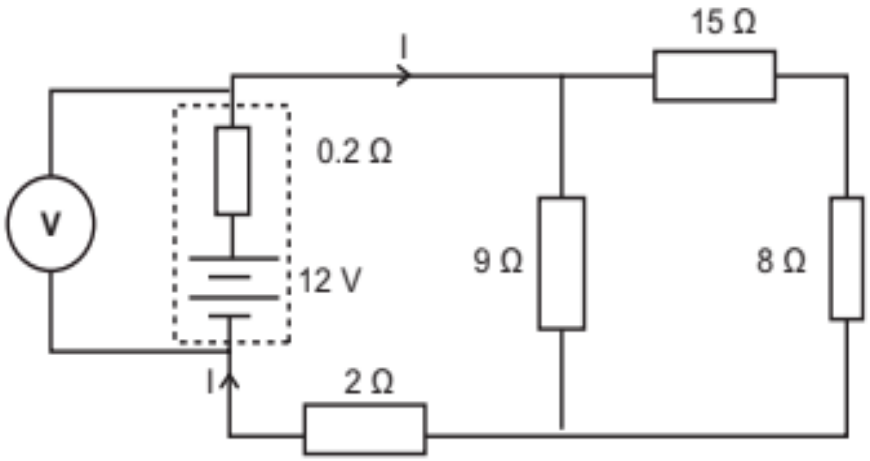
$A_1 = 3A_2$ √

So $I_{6\Omega} = 2I_R$ √

$R_R = 2\ R_{6\Omega}$; √

$R_R = 12\ \Omega$ √

9. The battery in the circuit below has an emf of 12 V and an internal resistance of 0,2 Ω. The resistance of the connecting wires can be ignored.



9.1 Calculate the current through the battery. (6)

$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ √

$\frac{I}{R} = \frac{I}{9} + \frac{I}{23}$ √

$\frac{I}{R} = \frac{32}{207}$

R = 6,4

$\varepsilon = I(R + r)$ √

12 = I(2 + +6,47+ 0,2) √

I = 1,38A √

9.2 How will the reading on the voltmeter be affected if the 9 Ω resistor is removed and replaced with a conducting wire of negligible resistance? Explain the answer. (4)

The parallel network has been short-circuited by the conducting wire.

Resistance in the circuit has decreases. √

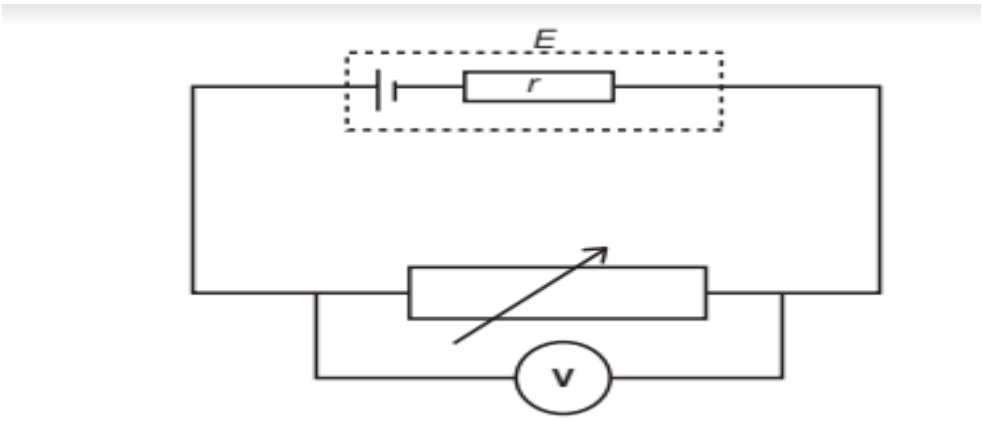
Current through the battery will increase. √

There will be more volts lost across the internal resistance of the battery. √

There are less volts available across the external circuit.

The voltmeter reading will decrease. √

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

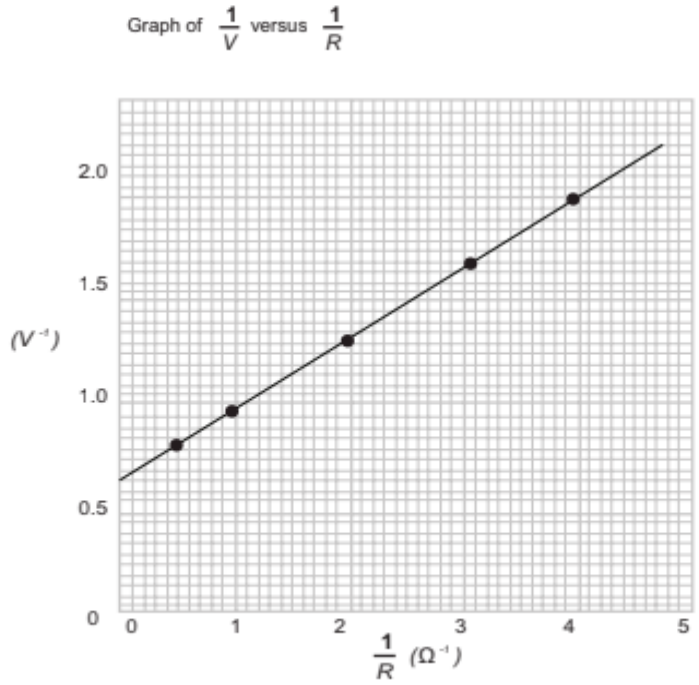


The circuit consists of a cell of emf and internal resistance r. A voltmeter is placed across a variable resistor which can be set to known values R.

The equation used by the learners is:

$$\frac{1}{V} = \frac{r}{ER} + \frac{1}{E}$$

They obtain the graph below.



110.1. Write down a mathematical relationship for the slope of the graph. (1)

$$\frac{1}{V} = \frac{r}{ER} + \frac{1}{E}$$

$$\frac{1}{V} = \frac{r}{E} \cdot \frac{1}{R} + \frac{1}{E}$$

$y = mx + c$

slope = $\frac{r}{E}$ √

Use the information in the graph and calculate the:

10.2. Emf of the cell (2)

y intercept = $\frac{1}{E}$

0,65 √ = $\frac{1}{E}$

E = $\frac{I}{0,65}$

E = 1,54 V √

10.3. Internal resistance of the cell (3)

Slope = $\frac{2,25 - 0,65}{4,8 - 0}$ √

Slope = $\frac{1.6}{4,8}$

Slope = $\frac{1}{3}$

Slope = $\frac{r}{E}$

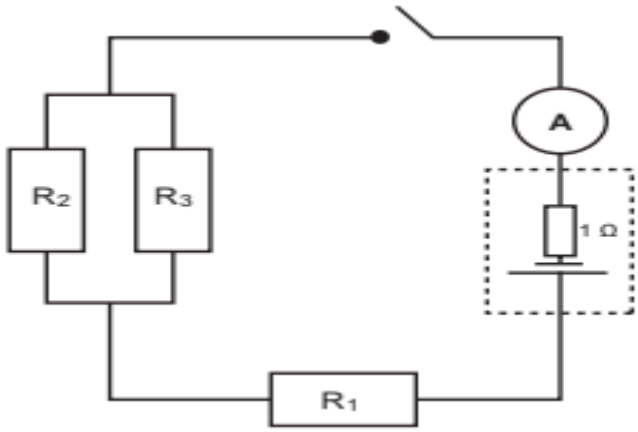
$\frac{1}{3} = \frac{r}{1,54}$

3r = 1(1,54) √

R = 0,51 Ω√

11. In the electrical circuit shown below, the battery has an emf of 6 V and an internal resistance of 1 Ω. The total external resistance of the circuit is 9 Ω.

minutes. (1 1 unit k = W h.) (4)



11.1.Calculate the current in R_1 when the switch is closed. (3)

$\varepsilon = I(R + r)$ √
$6 = I\ (9 + 1)$ √
$I = 0{,}6$ A √

11.2. The power dissipated in resistor R_1 is 1,8 W. The resistance of resistor R_3 is 4 times that of resistor R_2 . ($R_3 = 4\ R_2$). Calculate the resistance of resistor R_2 . (5)

$P = I^2R_1$

$1.8 = (0{,}6)2\ R_1$ √

$R_1 = 5\ \Omega$

$R_P = 9 - 5$

$R_P = 4\ \Omega$ √

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\frac{I}{4} = \frac{I}{R_2} + \frac{I}{4R_2}$$ √

$20 = 4\ R_2$
$R_2 = 5\ \Omega$√

12. A hair dryer operates at a potential difference of 240 V and a current of 9,5 A.
It takes a learner 12 minutes to completely dry her hair. Eskom charges energy usage at R1,47 per unit. Calculate the cost of operating the hairdryer for the 12 minutes.
(1 unit =1 KW.h) (4)

P = VI

P = (240)(9,5) √

P = 2 280 W √

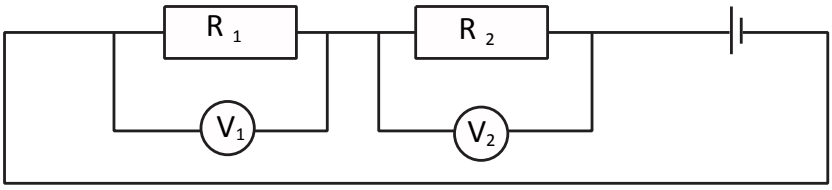
Cost = KW.h x price

Cost = 2,280 √ x $\frac{12}{60}$ √ x1,47

Cost = R0, 67

QUESTIONS

1. In the circuit diagram below, the resistance of resistor R_2 is TWICE the resistance of resistor R_1 . The two resistors are connected in series and identical high-resistance voltmeters are connected across each resistor. The readings on the voltmeters are V_1 and V_2 respectively.



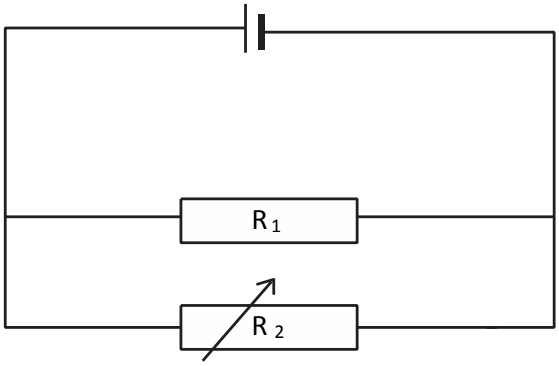
A $V_1 = 2V_2$

B $V_1 = \frac{1}{4}V_2$

C $V_1 = V_2$

D $V_1 = \frac{1}{2}V_2$ (2)

2.In the circuit given below the battery has negligible internal resistance. What will happen to the current through resistor R_1 if the resistance of the variable resistor, R_2 , is increased?



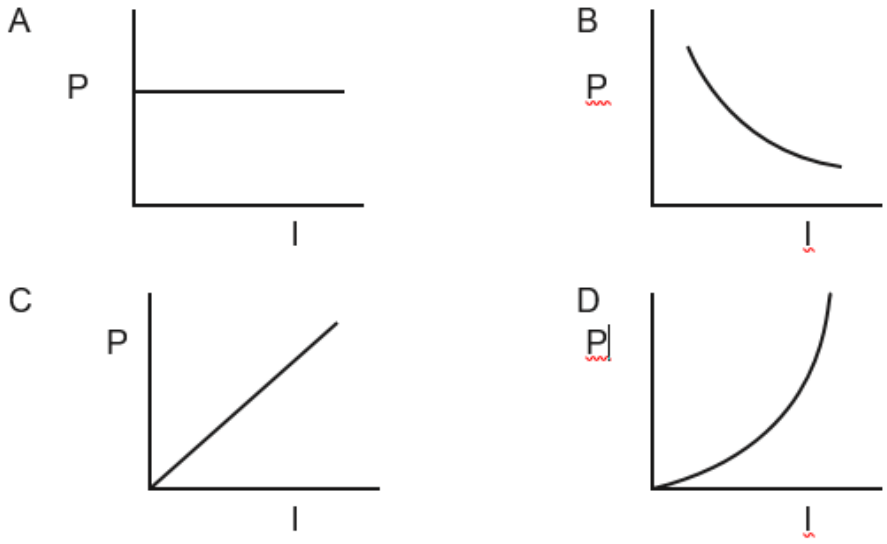
A It will decrease.

B It will increase.

C It will remain unchanged.

D t will decrease to a minimum value and then remain constant. (2)

3. Which one of the following graphs best represents the relationship between the electrical power and the current in a given ohmic conductor?



(2)

4. An ammeter is connected in series with a resistor in an electric circuit as it has

A a low resistance and measures potential difference

B a high resistance and measures current strength

C a low resistance and measures the rate of flow of charge

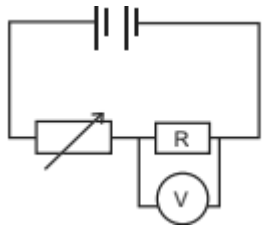
D a high resistance and measures the number of charges flowing through it each second (2)

5. When a lamp is connected to a 240 V source, the power dissipated is P. The same lamp is now connected to an 80 V source. Assume that the resistance of the lamp remains constant. The power dissipation will now be equal to:

A P B P/3

C P/6 D P/9 (2)

6. In the circuit represented by the diagram below, the resistance of resistor R is independent of temperature and the battery has negligible internal resistance.



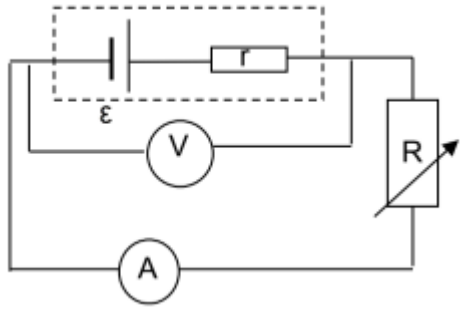
.

When the voltmeter reading is V, the power dissipated in resistor R is P. The rheostats adjusted such that the reading on the voltmeter becomes 2V. The power dissipated in resistor R, will then be equal to:

A1/4 P B P

C 2P D P (2)

7. In the circuit represented below, the resistance of the variable resistor is decreased.



...

How would this decrease affect the readings on the voltmeter and ammeter?

	Voltmeter reading	Ammeter reading
A	unchanged	Unchanged
B	decrease	Increase
C	decrease	Unchanged
D	Increase	Increase

(2)

SOLUTION

1.D

2. C

3. D

4. C

5.D

6. D

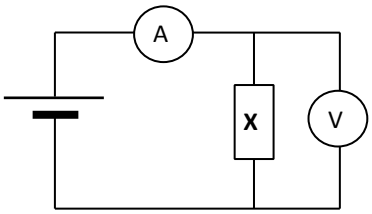
7. B (7x2 = 14)

ACTIVITIES

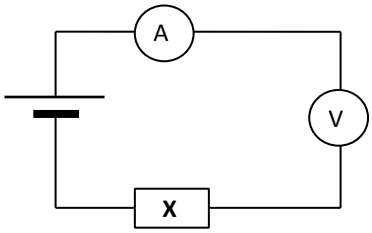
MULTIPLE CHOICE QUESTIONS

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

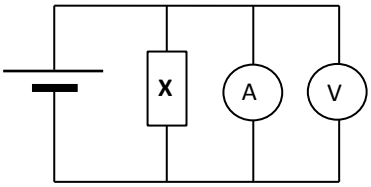
A



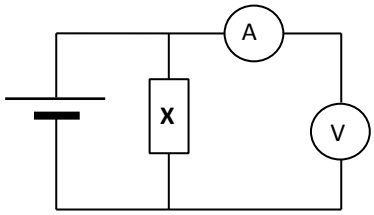
B



C



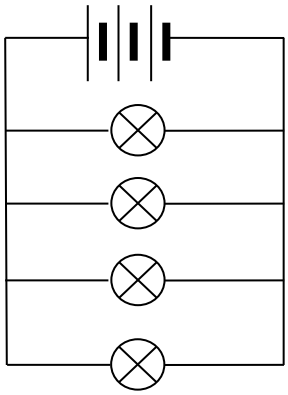
D



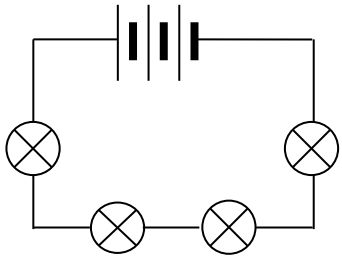
2. A set of identical light bulbs are connected as shown in the circuit diagrams below. The internal resistance of the battery is negligible.

In which ONE of these circuits will the light bulbs glow the brightest?

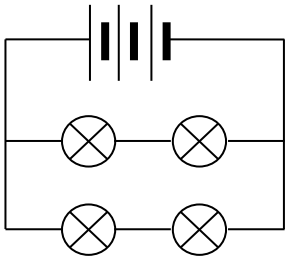
A



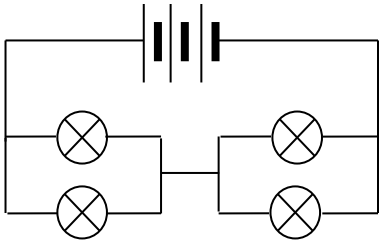
B



C



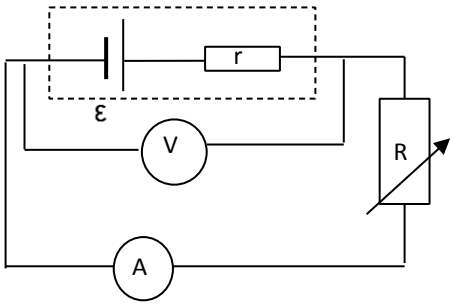
D



3. The unit of measurement of THE RATE OF FLOW OF CHARGE in a conductor is …

A. watt.
B. volt.
C. ampere.
D. coulomb.

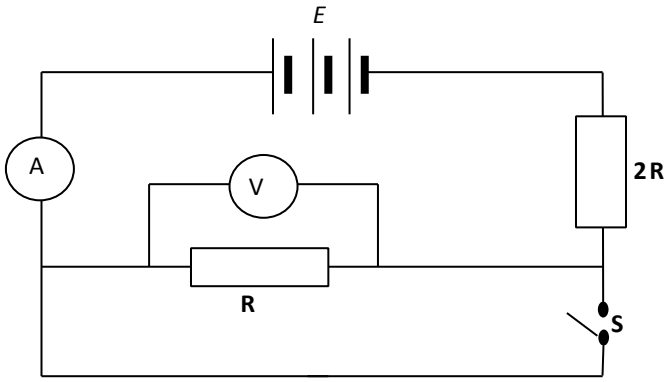
4. In the circuit represented below, the resistance of the variable resistor is decreased.



How would this decrease affect the readings on the voltmeter and ammeter?

	Voltmeter reading	**Ammeter reading**
A	unchanged	unchanged
B	decreases	increases
C	decreases	unchanged
D	increases	increases

5. In the circuit diagram below, the internal resistance of the battery and the resistance of the conducting wires are negligible. The emf of the battery is *E*.



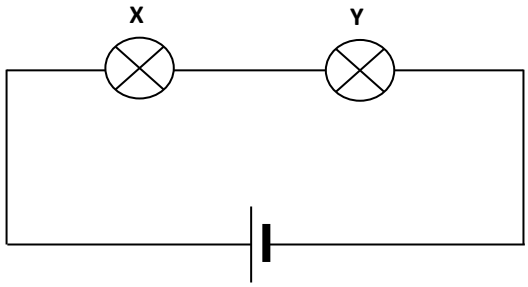
When switch **S** is closed, the reading on voltmeter V, in volts, is ...

A 0
B $\frac{1}{3}$ E
C $\frac{2}{3}$ E
D E

5. Which ONE of the following is the unit of measurement for the rate of flow of charge?

A watt
B coulomb
C volt
D ampere

6. The diagram below shows two light bulbs, **X** and **Y**, connected in series to a battery with negligible internal resistance.



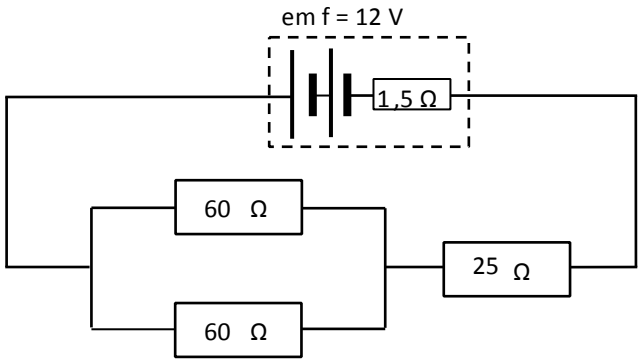
If bulb **X** glows brighter than bulb **Y**, then the …

A current through bulb **X** is smaller than that through bulb **Y**.
B resistance of bulb **X** is smaller than that of bulb **Y**.
C resistance of bulb **X** is greater than that of bulb **Y**.
D current through bulb **X** is greater than that through bulb **Y**.

STRUCTURED QUESTIONS

QUESTION 1

In the circuit represented below, two 60 Ω resistors connected in parallel are connected in series with a 25 Ω resistor. The battery has an emf of 12 V and an internal resistance of 1,5 Ω.



Calculate the:

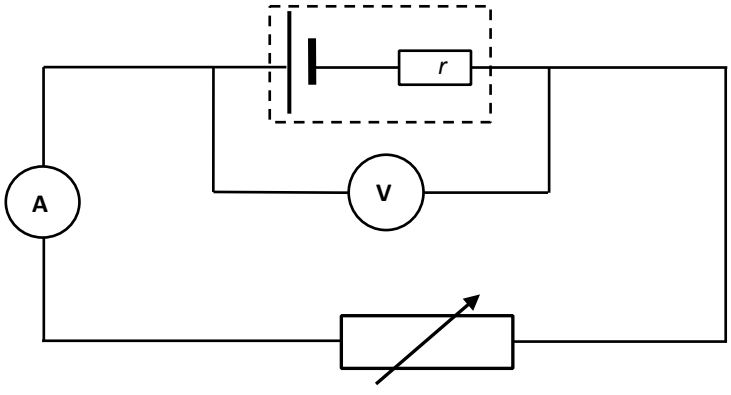
1.1 Equivalent resistance of the parallel combination

1.2 Total current in the circuit

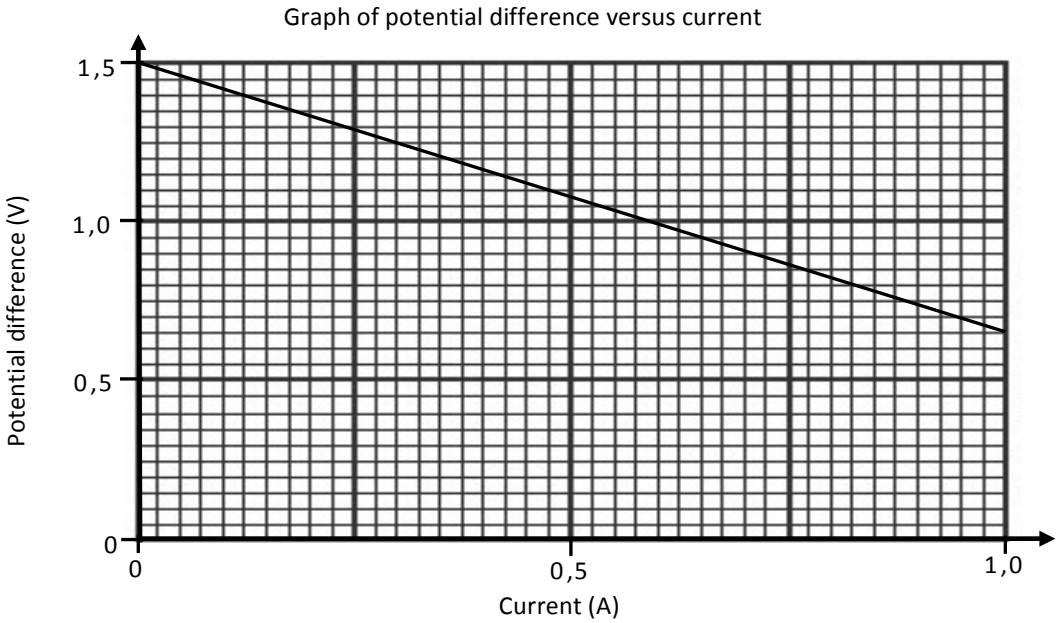
1.3 Potential difference across the parallel resistors

QUESTION 2

Learners conduct an investigation to determine the emf and internal resistance (*r*) of a battery. They set up a circuit as shown in the diagram below and measure the potential difference using the voltmeter for different currents in the circuit.



The results obtained are shown in the graph below.



2.1 Use the graph to determine the emf of the battery.

2.2 Calculate the gradient of the graph.

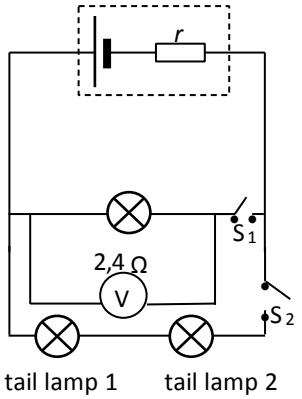
2.3 Which physical quantity is represented by the magnitude of the gradient of the graph?

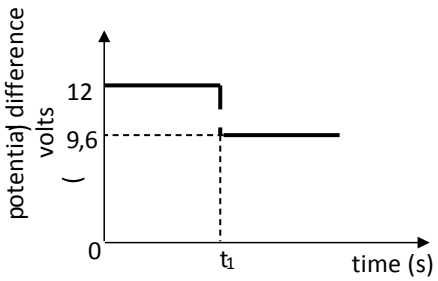
2.4 How does the voltmeter reading change as the ammeter reading increases? Write down INCREASES, DECREASES or REMAINS THE SAME. Use the formula emf = IR + Ir to explain the answer.

QUESTION 3

The headlamp and two IDENTICAL tail lamps of a scooter are connected in parallel to a battery with unknown internal resistance as shown in the simplified circuit diagram below. The headlamp has a resistance of 2,4 Ω and is controlled by switch **S_1**. The tail lamps are controlled by switch **S_2**. The resistance of the connecting wires may be ignored.

The graph alongside shows the potential difference across the terminals of the battery before and after switch **S_1** is closed (whilst switch **S_2** is open). Switch **S_1** is closed at time t_1.





3.1 Use the graph to determine the emf of the battery.

3.2 WITH ONLY SWITCH **S_1** CLOSED, calculate the following:

3.2.1 Current through the headlamp

3.2.2 Internal resistance, *r*, of the battery

BOTH SWITCHES S_1 AND S_2 ARE NOW CLOSED. The battery delivers a current of 6 A during this period.

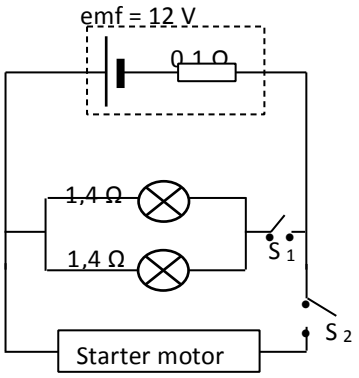
3.3 Calculate the resistance of each tail lamp.

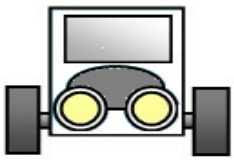
3.4 How will the reading on the voltmeter be affected if the headlamp burns out? (Both switches S_1 and S_2 are still closed.)

Write down only INCREASES, DECREASES or REMAINS THE SAME. Give an explanation.

QUESTION 4

The headlights of a car are connected in parallel to a 12 V battery, as shown in the simplified circuit diagram below. The internal resistance of the battery is 0,1 Ω and each headlight has a resistance of 1,4 Ω. The starter motor is connected in parallel with the headlights and controlled by the ignition switch, S_2. The resistance of the connecting wires may be ignored.





4.1 State Ohm's law in words.

4.2 With only switch S_1 closed, calculate the following:

4.2.1 Effective resistance of the two headlights

4.2.2 Potential difference across the two headlights

4.2.3 Power dissipated by one of the headlights

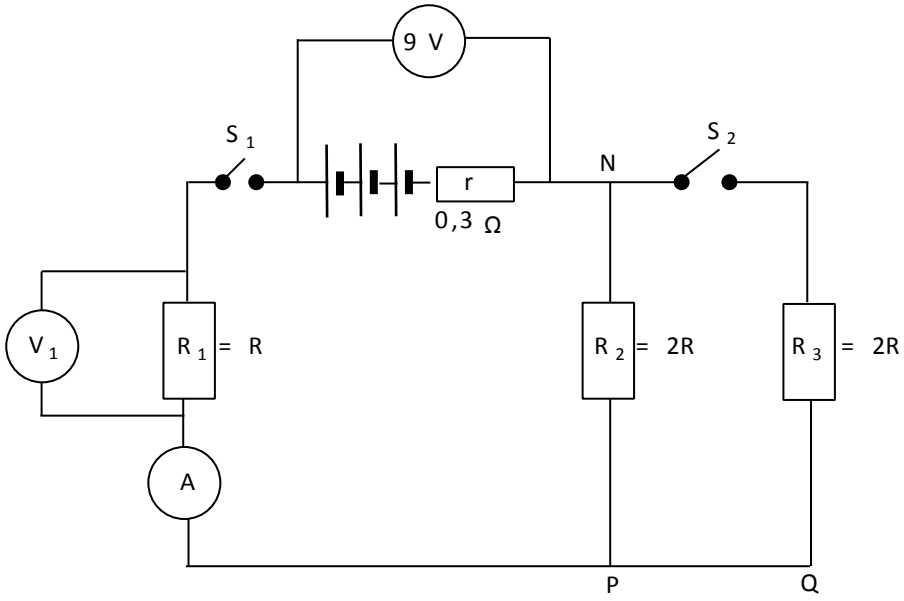
Ignition switch S_2 is now closed (whilst S_1 is also closed) for a short time and the starter motor, with VERY LOW RESISTANCE, rotates.

4.3 How will the brightness of the headlights be affected while switch S_2 is closed? Write down INCREASES, DECREASES or REMAINS THE SAME. Fully explain how you arrived at the answer.

QUESTION 5

Three resistors, R_1, R_2 and R_3, are connected to a battery, as shown in the circuit diagram below.

The internal resistance of the battery is 0,3 Ω. The resistance of R_2 and R_3 is equal. The resistance of R_1 is half that of R_2. When both switches are open, the voltmeter across the battery reads 9 V.



5.1 What is the value of the emf of the battery? Give a reason for your answer.

5.2 When **only switch S_1 is closed**, the reading on the ammeter is 3 A. Calculate the resistance of R_1.

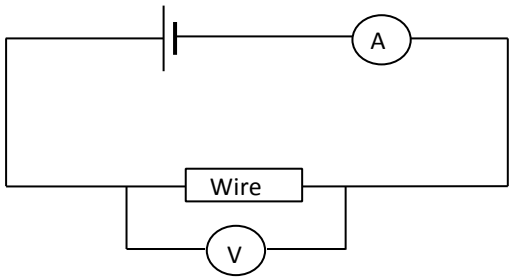
Both switches **S_1** and **S_2** are now closed.

5.3 How will the resistance of the circuit change? Write down only INCREASES, DECREASES or REMAINS THE SAME.

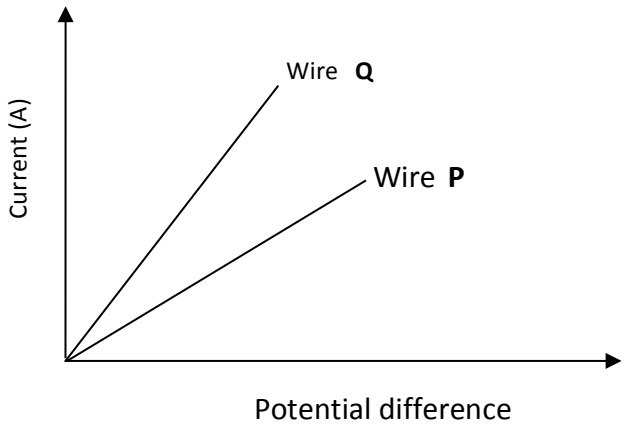
5.4 A conducting wire of negligible resistance is connected between points **Q** and **N**. What effect will this have on the 'lost volts'? Explain the answer.

QUESTION 6

Learners investigate the conducting ability of two metal wires **P** and **Q**, made of different materials. They connect ONE wire at a time in a circuit as shown below.



The potential difference across each wire is increased in equal increments, and the resulting current through these wires is measured. Using the measurements, the learners obtained the following sketch graphs for each of the wires.

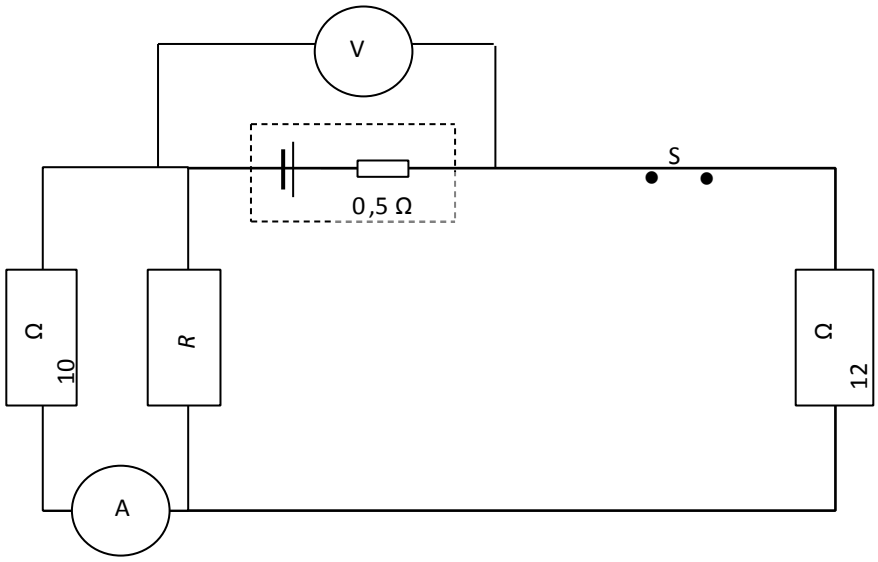


6.1 Name TWO variables that the learners would have controlled in each of experiments.

6.2 Which one (**P** or **Q**) is the better conductor? Explain your answer.

QUESTION 7

A circuit is connected as shown below. The resistance of *R*, which is connected in parallel with the 10 Ω resistor, is unknown. With switch S closed, the reading on voltmeter V decreases from 45 V to 43,5 V. The internal resistance of the battery is 0,5 Ω.



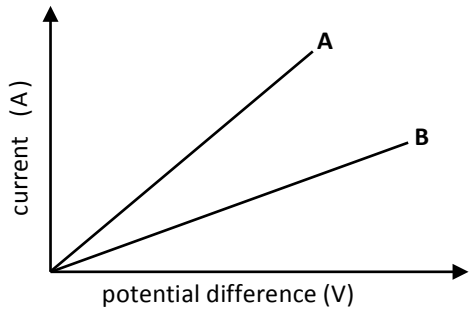
7.1 Calculate the reading on ammeter A. Show ALL your calculations.

7.2 Determine the resistance of resistor *R*.

7.3 How will the reading on voltmeter V change if resistor *R* burns out? Give a reason for your answer.

QUESTION 8

Learners use Ohm's law to determine which ONE of two resistors **A** and **B** has the greater resistance. For each resistor, they measure the current through the resistor for different potential differences across its ends. The graph below shows the results obtained in their investigation.



The learners are supplied with the following apparatus:

6 V battery

Voltmeter

Ammeter

Rheostat

Resistors **A** and **B**
Conducting wires

8.1 Draw a circuit diagram to show how the learners must use the above apparatus to obtain each of the graphs shown above.

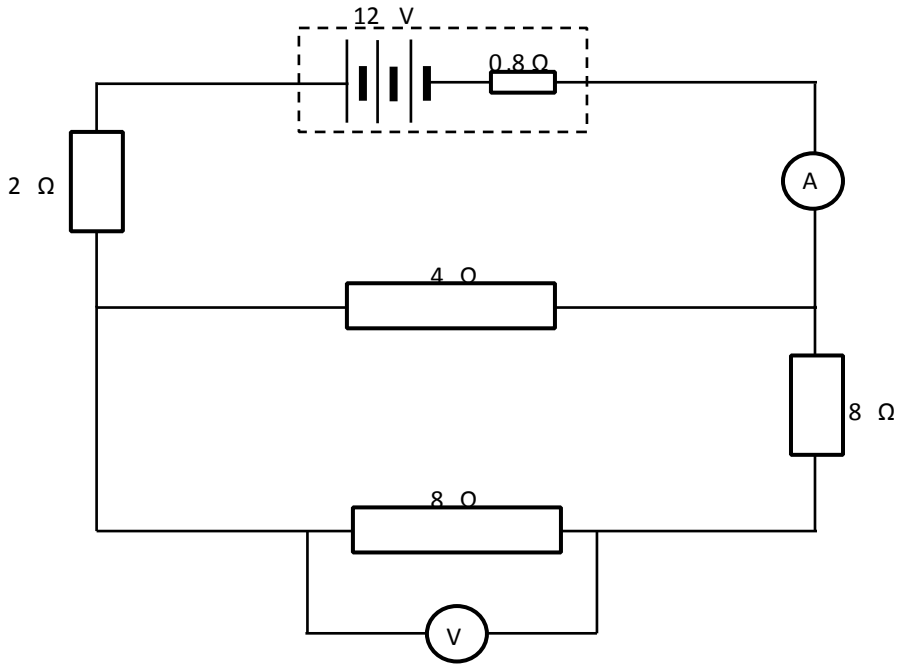
8.2 Write down ONE variable that must be kept constant during this investigation.

8.3 Which ONE of **A** or **B** has the higher resistance? Give an explanation for the answer.

QUESTION 9

In the circuit diagram below, the battery has an emf of 12 V and an internal resistance of 0,8 Ω.

The resistance of the ammeter and connecting wires may be ignored.



Calculate the:

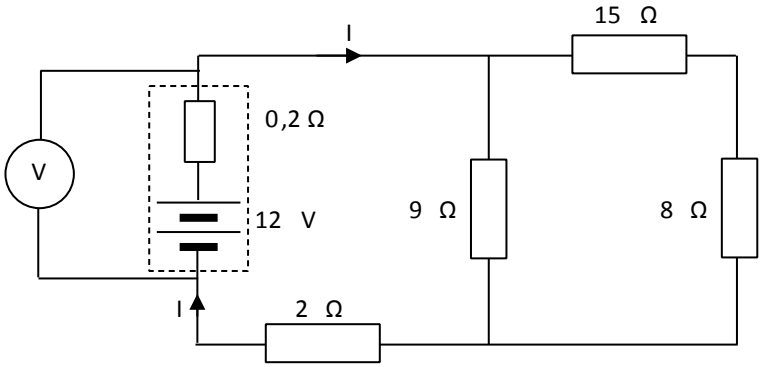
9.1 Effective resistance of the circuit

9.2 Reading on the ammeter

9.3 Reading on the voltmeter

QUESTION 10

The battery in the circuit below has an emf of 12 V and an internal resistance of 0,2 Ω. The resistance of the connecting wires can be ignored.

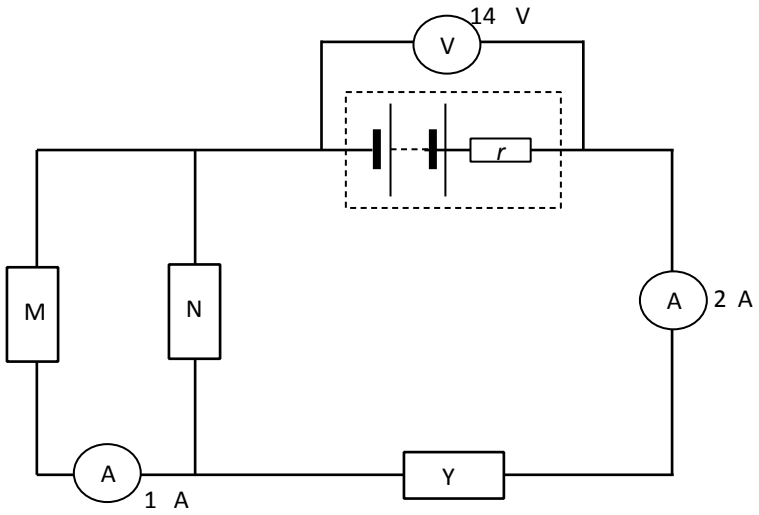


10.1 Calculate the current, I, that flows through the battery.

10.2 How will the reading on the voltmeter be affected if the 9 Ω resistor is removed and replaced with a conducting wire of negligible resistance? Explain your answer.

QUESTION 11

The circuit diagram below shows a battery, with an internal resistance *r*, connected to three resistors, **M**, **N**, and Y. The resistance of **N** is 2 Ω and the reading on voltmeter V is 14 V. The reading on ammeter A_1 is 2 A and the reading on ammeter A_2 is 1 A. (The resistance of the ammeters and the connecting wires may be ignored.)



11.1 State Ohm's law in words.

11.2 How does the resistance of **M** compare with that of **N**? Explain how you arrived at the answer.

11.3 If the emf of the battery is 17 V, calculate the internal resistance of the battery.

11.4 Calculate the potential difference across resistor **N**.

11.5 Calculate the resistance of **Y**

ELECTRODYNAMICS

This is the study of the relationship between electricity, magnetism and mechanical phenomena.

Electrical machines

1. Generator
2. Motor

MOTOR

- Converts electrical energy to mechanical energy
- Principle in which a motor operates is called **motor effect**

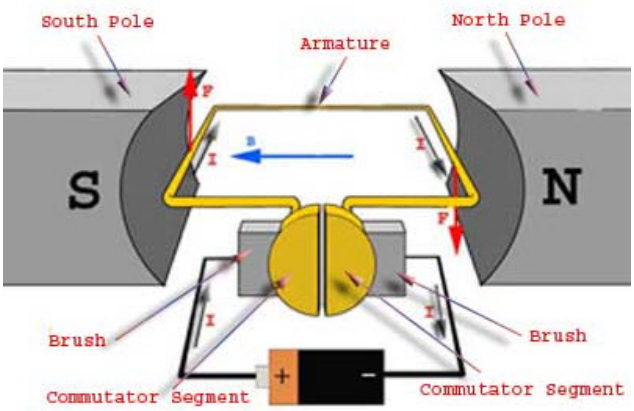
Two types of motor:

1. DC motor
2. AC motor

DC(Direct Current) current flowing in one direction
AC(Alternating Current) current that changes direction

DC MOTOR

- Has split ring commutator
- DC- direct current



Direction of the magnetic field: from N – S
Current direction is the direction of flow of the conventional current

Flemings rule - used to predict the direction of the force acting on the conductor in a magnetic field

Function of the split ring

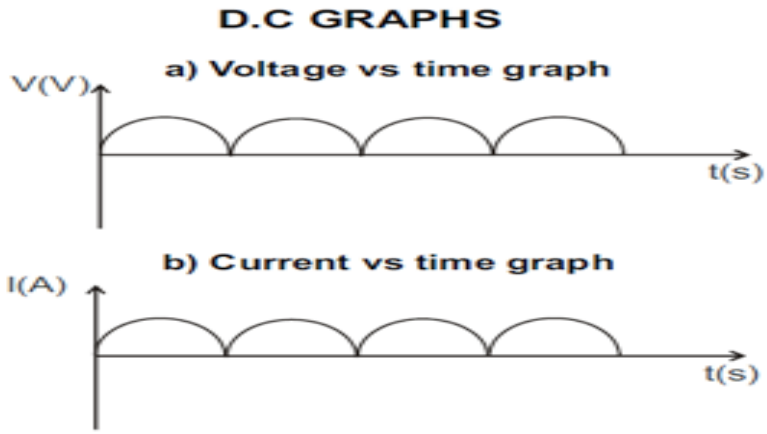
1. Changes the direction of the
2. Maintains constant direction of rotation of the coil

Function of carbon brush

- Makes electrical contact with the commutator

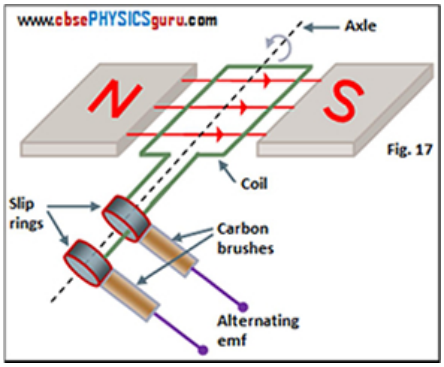
Two types of graphs:

1. Potential difference vs time
2. Current vs time



AC MOTOR

- Has slip rings

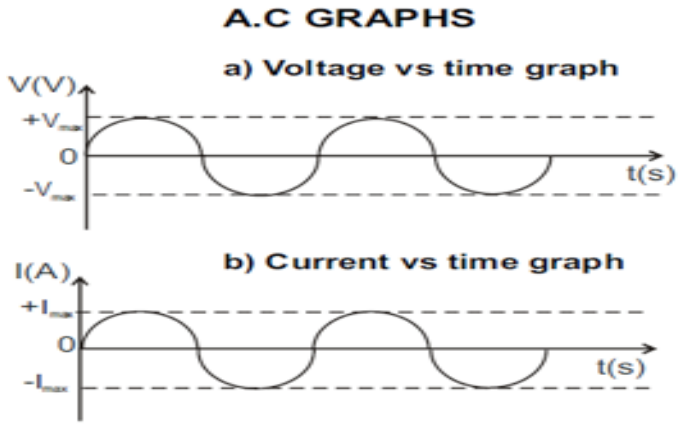


Function of a slip ring

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

Two types of graphs:

1. Potential difference vs time
2. Current vs time



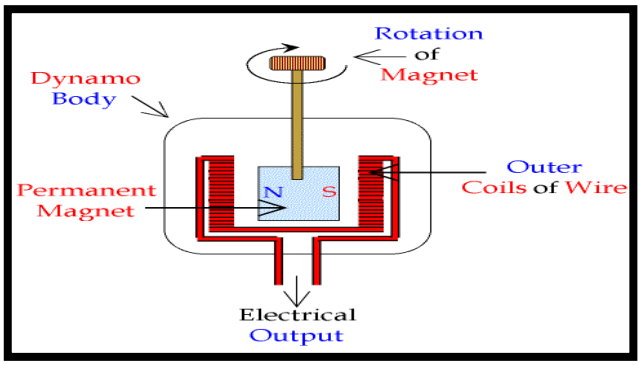
Ways to improve efficiency of a motor

1. Increase current in the coil
2. Use a stronger magnet
3. Increase number of turns in the coil

GENERATOR

Converts mechanical energy to electrical energy
Principle on which generators operate is called **electromagnetic induction** or **Faradays law**
Electromagnetic induction: is a process where the relative motion between the magnetic field and the conductor induces current in the conductor

How does it work??



An emf/current is induced across the ends of a coil by a changing magnetic field that cuts through the windings of the coil.

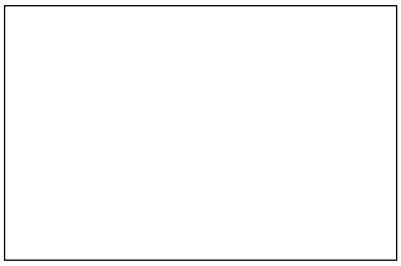
Faradays law

- States that the induced emf is equal to the rate of change of magnetic flux
- Or the induced emf is directly proportional to the rate of change of magnetic flux.
- emf= $\frac{-N\Delta\Phi}{\Delta t}$
- Magnetic flux(Φ) is a measure of the number of field lines passing an area
- Φ= BA

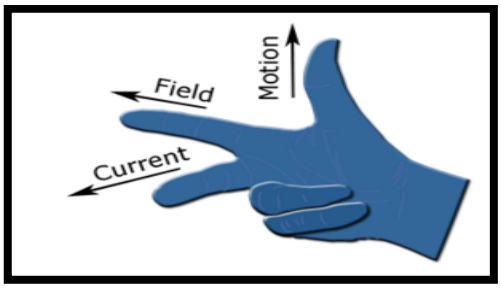
Types of generators

1. DC generator
2. AC generator

DC generator
-has split rings
-also called dynamo



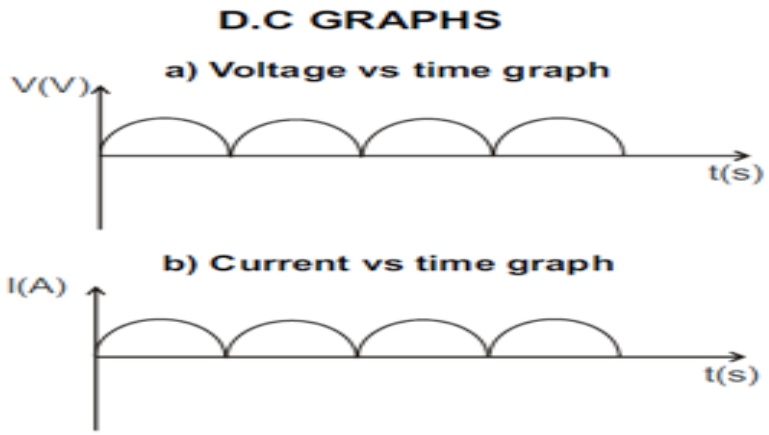
Determining the direction of the induced current.



Flemings Right Hand Dynamo Rule

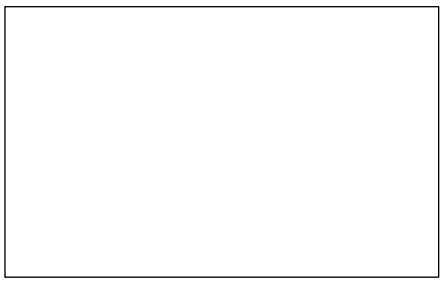
Two types of graphs:

1. Potential difference vs time
2. Current vs time



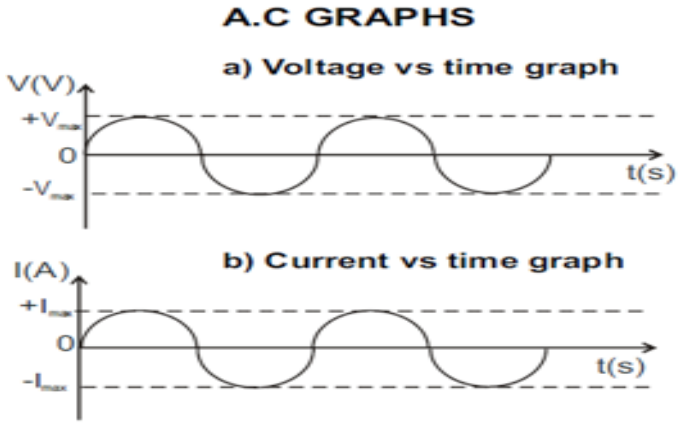
AC GENERATOR

- Has slip rings
- Also called alternator



<u>Two types of graphs:</u>

1. Potential difference vs time
2. Current vs time



<u>Ways to improve efficiency of a generator</u>

1. Increase the speed of rotation
2. Use a stronger magnet

3. Increase number of turns in the coil

Advantages of AC over DC

1. Can be transmitted over long distances without energy loss
2. The potential difference(voltage) can be increased or decreased
3. It is easier to convert AC to DC than the reverse

Eskom uses AC at power stations because it can be stepped up during the transmission and less energy is lost during the transmission.

Uses of AC Generators

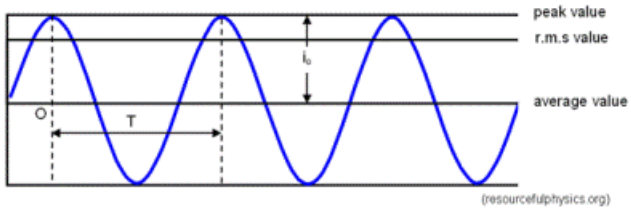
The main generators in nearly all electric power plants are AC generators. This is because a simple electromagnetic device called a transformer makes it easy to increase or decrease the voltage of alternating current. Almost all household appliances utilize AC.

Uses of DC Generators

Factories that do electroplating and those that produce aluminium, chlorine, and some other industrial materials need large amounts of direct current and use DC generators. So do locomotives and ships driven bydiesel-electric motors. Because commutators are complex and costly, many DC generators are being replaced by AC generators combined with electronic rectifiers.

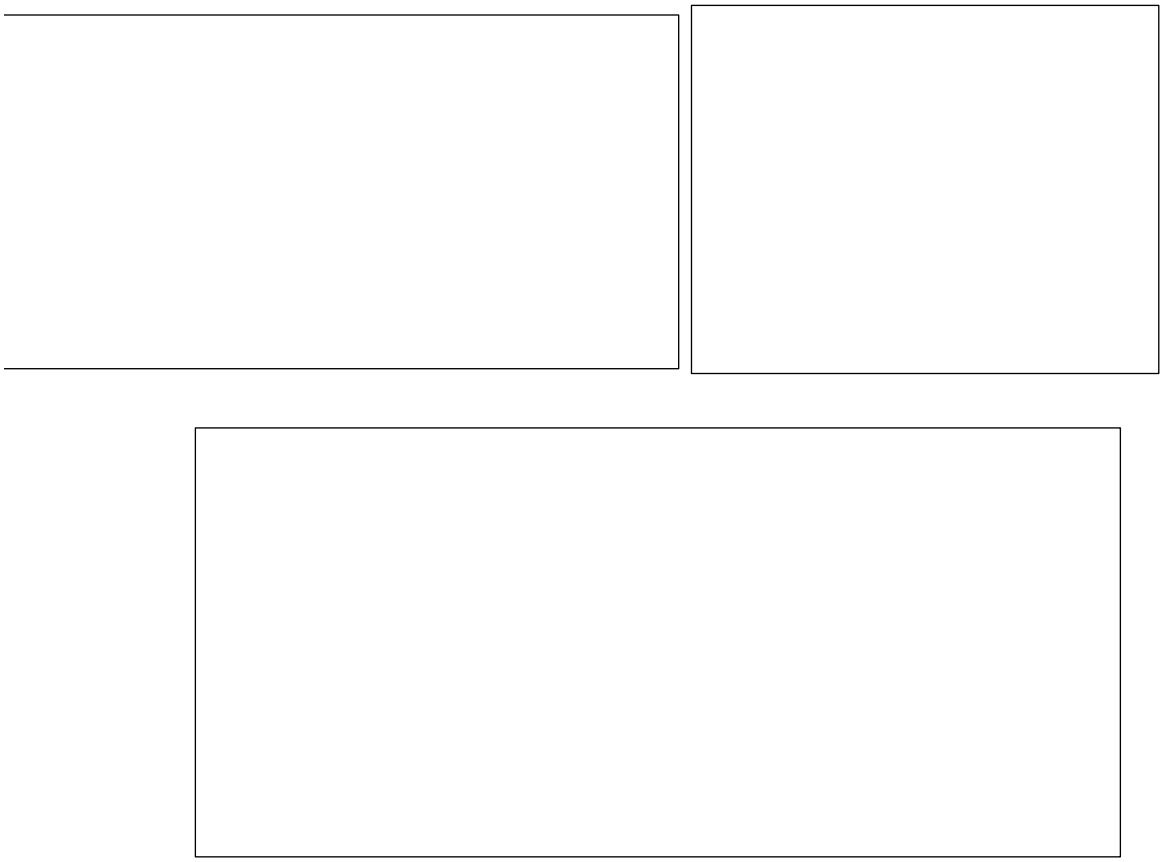
Alternating current

- Define the term *rms* for an alternating voltage or an alternating current. The rms value of AC is the DC potential difference/current which dissipates the same amount of energy as AC.



Solve problems using $I_{rms} = \frac{I_{max}}{\sqrt{2}}$, $V_{rms} = \frac{V_{max}}{\sqrt{2}}$.

Solve problems using $P_{ave} = I_{rms}V_{rms} = \frac{1}{2} I_{max}V_{max}$ (for a purely resistive circuit), $P_{ave} = I^2_{rms}R$ and $P_{ave} = \frac{V^2_{rms}}{R}$.



Note that V_{av} and I_{ave} are both zero so they convey little information about the actual behavior of V and I. a more useful and appropriate type of average is called rms (root mean squared) is used.

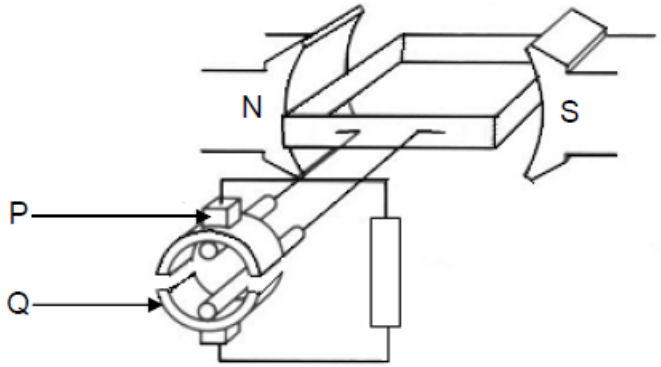
In SA our mains supply is 220V (rms) AC (50 Hz). What is the peak or maximum voltage?

$$\begin{aligned} V_{\max} &= \sqrt{2} \times V_{rms} \\ &= \sqrt{2} \times 220V \\ &= 311.13V \end{aligned}$$

STRUCTURED QUESTIONS

QUESTION 1 March 2013(DBE)

AC generators and DC generators differ in their construction and the type of current they deliver. The simplified sketch below represents a DC generator.



1.1 Which component (P or Q) enables this generator to produce DC (1)

1.2 What structural change must be made to this generator to change it to an AC Generator? (1)

1.3 Briefly explain why Eskom prefers using AC instead of DC for the long distance transmission of electricity? (2)

1.4 An AC generator delivers 240V_{rms} to a 60W light bulb. The peak current in the light Bulb is 0,35A

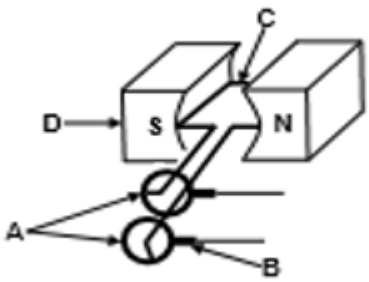
Calculate the:

1.4.1 rms current in the light bulb (3)

1.4.2 Resistance of the light bulb (3)

QUESTION 2 Nov 2013 (DBE)

The simplified sketch represents an AC generator. The main components are labelled A,B,C and D



2.1 Write down the name of component:

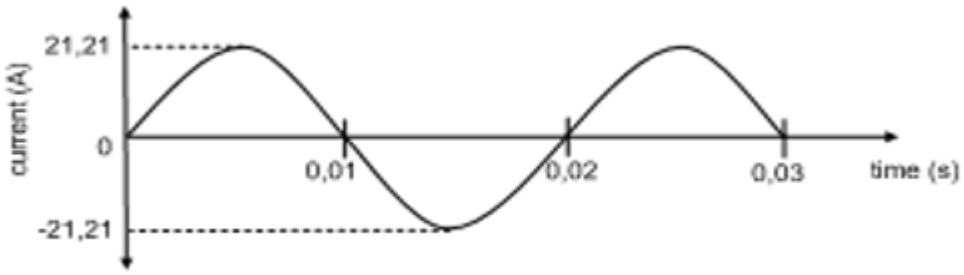
2.1.1 A (1)

2.1.2 B (1)

2.2 Write down the function of component B (1)

2.3 State the energy conversion which takes place in an AC generator. (1)

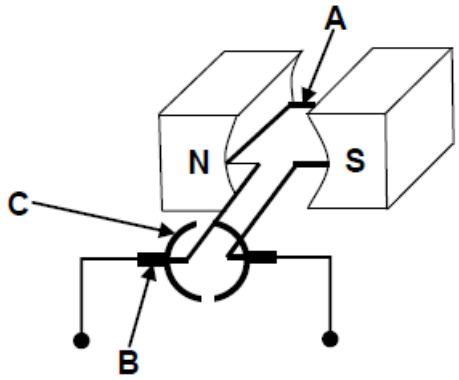
A similar coil is rotated in a magnetic field. The graph below shows how the alternating current produced by the AC generator varies with time.



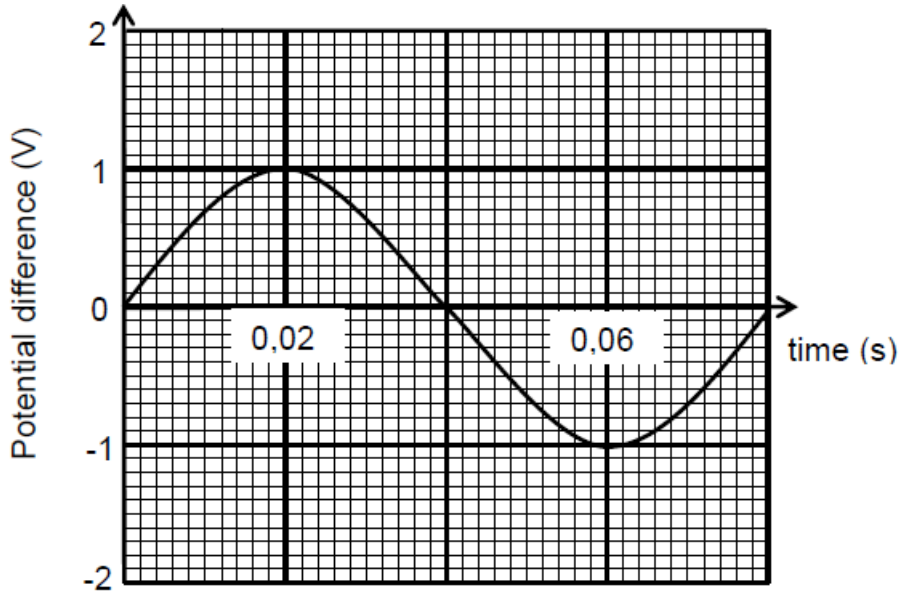
2.4 How many rotations are made by the coil in 0,03 seconds? (1)
2.5 Calculate the frequency of the alternating current. (3)
2.6 Will the plane of the coil be PERPENDICULAR or PARALLEL to the magnetic field at t= 0,015s? (1)
2.7 If the generator produces a maximum potential difference of 311V, calculate its average power output. (5)

QUESTION 3 March 2014(DBE)

3.1 A simplified diagram of an electric motor is shown below:



3.1.1 Name the components labelled A, B and C
Write down only the name of the component next to the letter (A-C) (3)
3.1.2 Write down the function of the component labelled B (1)
3.1.3 Is this motor an AC motor or a DC motor? (1)
3.1.4 Give a reason why component A experiences a magnetic force when a current passes through it. (2)
3.2 A coil is rotated in a magnetic field. The varying induced emf obtained is represented in the graph below:



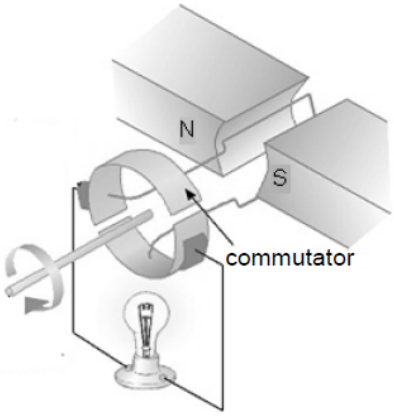
3.2.1 Calculate the induced rms potential difference (3)

3.2.2 The coil is now rotated at twice the original speed
Write down the period of the new wave (2)

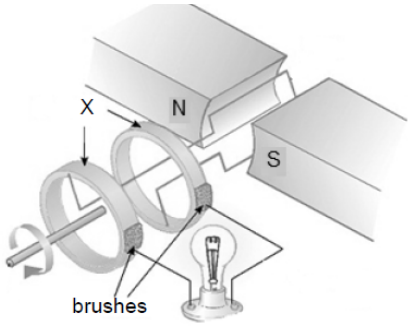
3.2.3 Calculate the average power generated if the generator produces a maximum current of 2A (4)

QUESTION 4 Nov 2014(DBE)

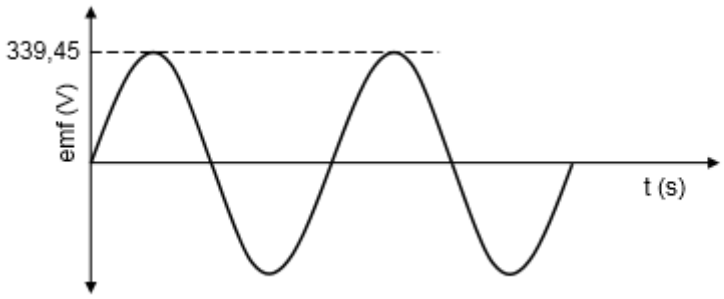
The diagram below represents a simplified version of an electrical machine used to light up a bulb.



4.1 Name the principle on which the machine operates? (1)
4.2 State one way in which to make this bulb burn brighter (1)
Some changes have been made to the machine and a new device is obtained as shown below

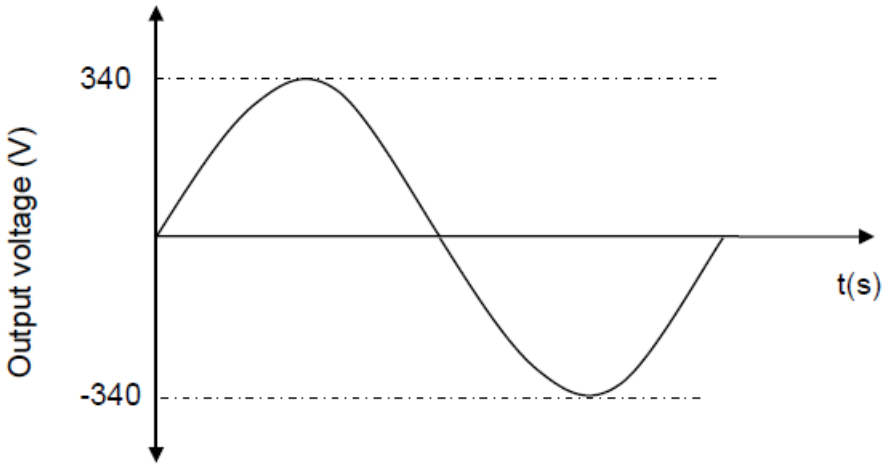


4.3 Name part X in the new device (1)
4.4 The graph of output emf versus time obtained using the device in QUESTION 4.3 is shown below



4.4.1 Define the term *root mean square value* of an AC voltage (2)
4.4.2 Calculate the rms voltage (3)

QUESTION 5 March 2015(DBE)
The graph below shows the output voltage from a household AC generator for one cycle of rotation of the coils.



5.1 A 100 W light bulb is connected to this generator and it glows at its maximum brightness. Use the information from the graph to calculate the:

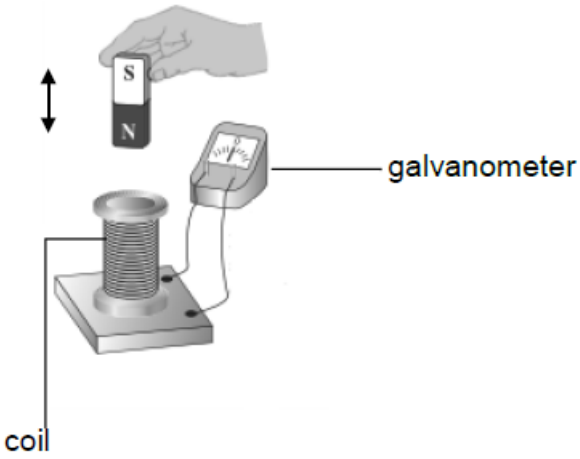
5.1.1 Resistance of the bulb (5)

5.1.2 rms current through the bulb (3)

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

QUESTION 6 Nov 2015 (DBE)

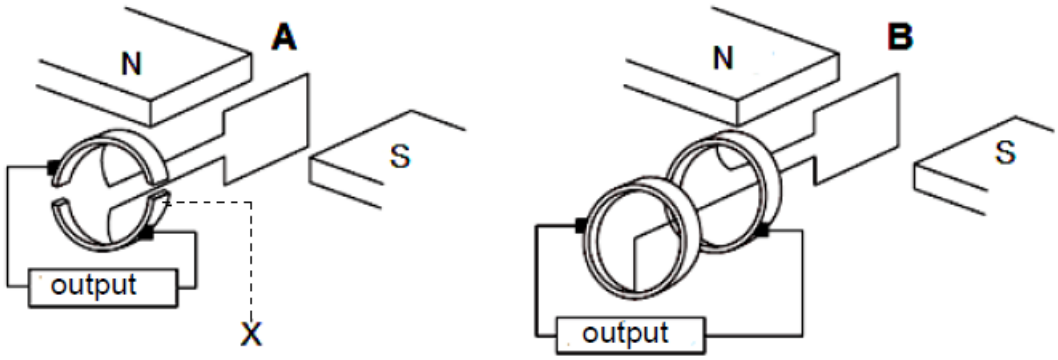
A teacher demonstrates how current can be obtained using a bar magnet, a coil and a galvanometer. The teacher moves the bar magnet up and down as shown by the arrow in the diagram below



6.1.1 Briefly describe how the magnet must be moved in order to obtain a LARGE deflection on the galvanometer

(2)

The two devices A and B, below operate on the principle described in QUESTION 6.1.1 above



6.1.2 Write down the name of the principle
(1)

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

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

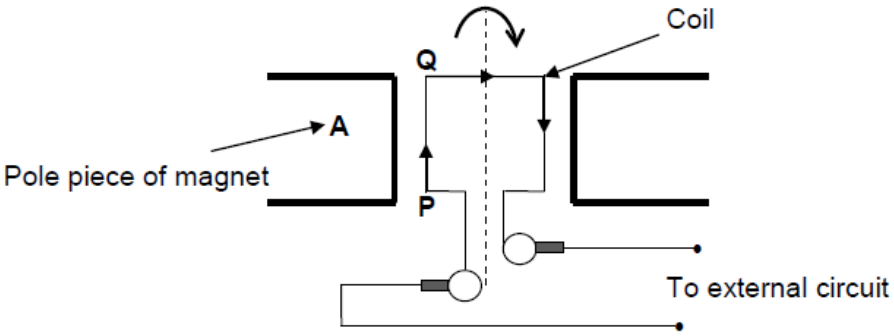
Calculate the:

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

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

QUESTION 7 March 2016(DBE)

7.1 A simplified sketch of an AC generator is shown below.



The coil of the generator rotates clockwise between the pole pieces of two magnets. At a particular instant, the current in the segment PQ has the direction shown above.

7.1.1 Identify the magnetic pole A
Only write NORTH POLE or SOUTH POLE (1)

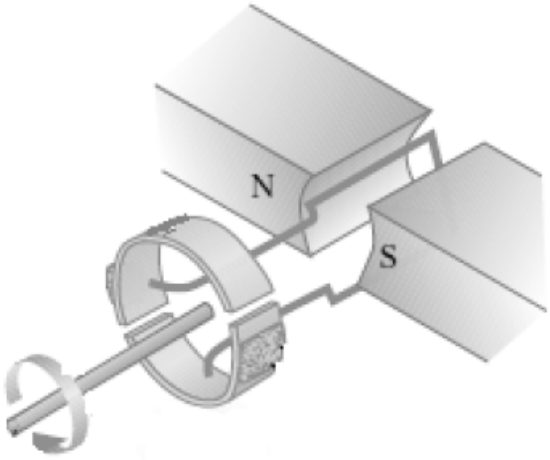
7.1.2 The coil is rotated through 180^0
Will the direction of the current in segment PQ be from P to Q or Q to P? (1)

7.2 An electrical device is connected to a generator which produces an rms potential difference of 220V. The maximum current passing through the device is 8 A.
Calculate the:

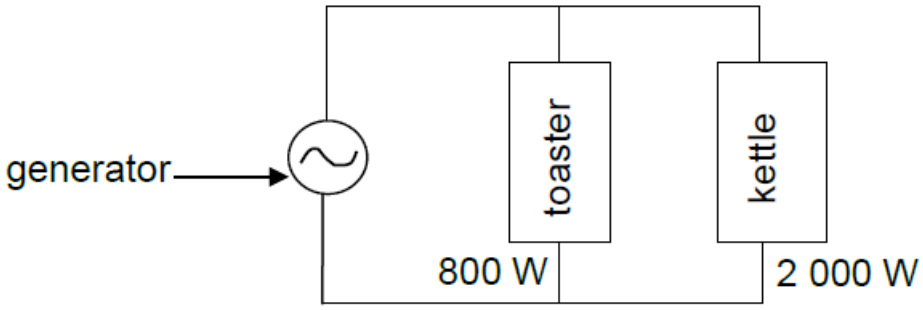
7.2.1 Resistance of the device (5)
7.2.2 Energy the device consumes in two hours (5)

QUESTION 8 Nov 2016 (DBE)

A generator is shown below. Assume that the coil is in a vertical position.



8.1.1 Is the generator above AC or DC? Give a reason for the answer.
(2)
8.1.2 Sketch an induced emf versus time graph for ONE complete rotation of the coil.
(The coil starts turning from the vertical position.)
(2)
8.2 An AC generator is operating at a maximum emf of 340V. It is connected across a toaster and a kettle, as shown in the diagram below.



The toaster is rated at 800W , while the kettle is rated at 2000W. Both are working under normal conditions.
Calculate the:
8.2.1 rms current through the toaster
(3)

8.2.2 Total rms current delivered by the generator
(4)

PHOTOELECTRIC EFFECT

The process that occurs when light shines on a metal and photoelectrons are **ejected** off the surface of the metal.

SIGNIFICANCE OF THE PHOTOELECTRIC EFFECT

It establishes the quantum theory and it illustrates the **particle nature of light.**

INTERACTION BETWEEN LIGHT AND MATERIALS

When light strikes or any electromagnetic radiation strikes the surface of an object, light or the electromagnetic radiation can be absorbed, reflected, transmitted or any combination of these effects. **Light is energy**, and when it strikes a metal, this energy is transferred to the electrons in the atoms. The amount of energy that is transferred depends on the material. Since the energy levels in metals are close together, almost all frequencies of light can be absorbed, exciting electrons into higher available energy levels.

When the frequency of the light is different to the natural energies of the electrons in the atom material, the light passes through and is therefore transmitted. In non-metals such as insulators, **energy gaps** between conduction bands and the valence bands are very large. So for an electron to move into the empty energy level in the conduction band requires a lot of energy. When light is **absorbed,** the **greatest** transfer of energy takes place. When light is **scattered**, very **little energy** transfer takes place. The absorbed energy is converted into internal energy, making the object hot. If no light is reflected or transmitted, the object will appear black. The colour of an object is determined by the **frequency** of the light it transmits.

THRESHOLD FREQUENCY OR CUT –OFF FREQUENCY

Only light of sufficiently high frequency can **eject electrons** from a metal plate. This minimum frequency required to eject the photoelectrons off the surface of a metal is called **threshold** or **cut off frequency (f_o).**

Increasing the intensity of the ultraviolet light causes more electrons to be ejected per second.

From the equation, **E = hf** where E is the amount of energy in J, h is Planck's constant = 6,63 x 10^{-34} J•s and f is the frequency of the incoming light in Hz.

WORK FUNCTION (W_o)

Energy is needed to remove an electron from a metal. For any metal, a minimum amount of energy, called the **work function (W_o)** is needed to remove an electron from the surface of a metal. The energy of the photon must be equal to or greater than the work function of the metal before electrons will be ejected.

The equation is:

$$W_o = hf_o$$

Where

W_o is work function in Joules (J),

h is Planck's constant= 6,63 x 10^{-34} J•s

f_o is the threshold frequency in Hertz (Hz).

The maximum kinetic energy of the ejected electrons can also be determined where

$$K_{max} = E - W_o$$

Thus, $E = W_o + K_{max}$

Where is the energy of the incoming light and can be determined from

E = hf and W_o is the work function of the metal and can be determined from $W_o = hf_o$.

The speed of the emitted electron or photoelectron can then be determined from $K_{max} = \frac{1}{2}mv^2$ where m is the mass of the electron which is given on the Data Sheet.

Thus, the equation can now become:

$$hf = W_o + \frac{1}{2}mv^2$$

Graphical Interpretation in Photoelectric Effect

- A change in the intensity of light **does not** affect the **maximum kinetic energy**. A graph of maximum kinetic energy against intensity is a simple horizontal line.
- A graph of maximum kinetic energy against frequency is a straight line with a positive gradient and a negative intercept on the *y* axis. The graph matches a relationship of the general form $y = mx + c$, where, in this case, *y* is the maximum kinetic energy and *x* is the frequency.
- The value of the gradient *m* is found by experiment to be 6.6×10^{-34} J s, and the value of the intercept when the metal is sodium is found to be -3.6×10^{-19}J.
- Thus for sodium: $E_{k\,max} = 6.6 \times 10^{-34}f - 3.6 \times 10^{-19}$J.
- The graph of maximum kinetic energy against frequency passes through the *x* axis at the lowest frequency at which the emission of electrons can take place. This frequency is called **threshold frequency**.

DUAL NATURE OF LIGHT

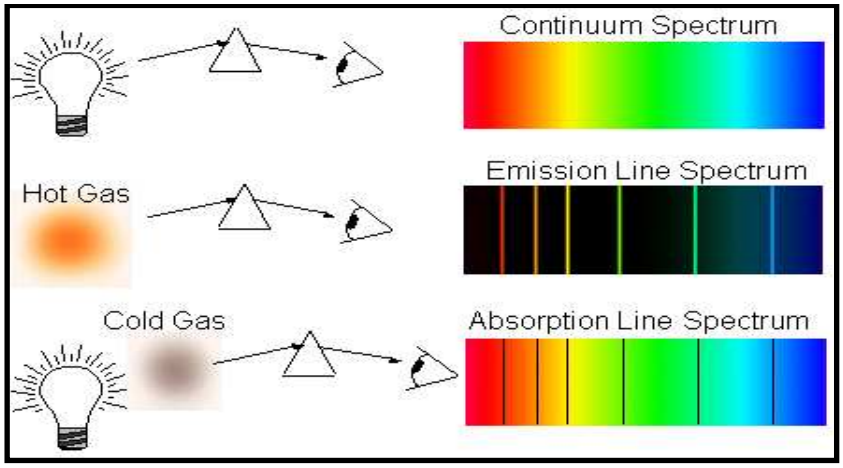
Light thus undergoes **refraction and diffraction** and this demonstrates its wave nature.

The photoelectric effect demonstrates the particle nature of light.

EMISSION AND ABSORPTION SPECTRA

There are three different types of spectra:

- Continuous emission spectra
- Line emission spectrum
- Line absorption spectrum



An electron may absorb energy and it can now move up one or more energy levels inside the atom. The electron is said to be **"excited".** When this electron returns to its ground state, a photon of energy is released. If the involved atoms in the discharge tube emit photons having only certain specific energies, it implies that the internal energy of the atom will only **increase or decrease** in steps, or that the internal energy of an atom is distinctive by certain discreet energy levels. If an electron gains internal energy, the electron jumps between **energy levels**. When an electron loses internal energy, it emits energy as a photon that contains energy.

$$\mathbf{E = E_2 - E_1}$$

Where, E is the energy of the photon $E_2 - E_1$ is the total internal energy between two energy levels which energy jump took place.

An atomic absorption spectrum is formed when certain frequencies of electro - magnetic radiation that passes through a medium e.g. a cold gas is absorbed.

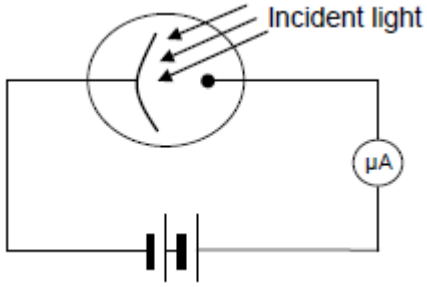
An atomic emission spectrum is formed when certain frequencies of electromagnetic radiation are emitted due to an atom's electrons making a transition from a high-energy state to a lower energy state.

LONG QUESTIONS

QUESTION 1 (DBE Feb-March 2016)

An investigation was conducted to determine the effects of changes in frequency intensity on the current generated in a photoelectric cell when light is incident on it.

The apparatus used in the investigation is shown in the simplified diagram below:



The results of the experiment are shown in the table below.

EXPERIMENT	FREQUENCY (Hz)	INTENSITY (Cd)	CURRENT (μA)
A	$4{,}00 \times 10^{14}$	10	0
B	$4{,}50 \times 10^{14}$	10	0
C	$5{,}00 \times 10^{14}$	10	0
D	$5{,}01 \times 10^{14}$	10	20
E	$5{,}01 \times 10^{14}$	20	40
F	$6{,}50 \times 10^{14}$	10	30

1.1. Define the term work function. (2)

1.2. Identify an independent variable. (1)

The threshold frequency for the metal used in the photocell is $5{,}001 \times 10^{14}$ Hz.

1.3 Define the term threshold frequency. (2)

1.4 Calculate the maximum speed of an emitted electron in experiment F. (5)

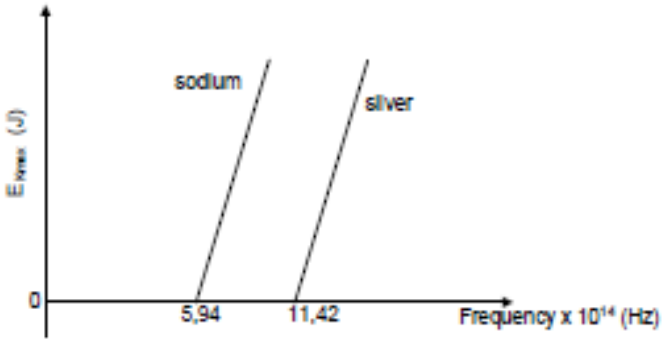
In experiments **D** and **E**, the current doubled when the intensity was doubled at the same frequency.

1.5 What conclusion can be made from this observation? (2)

QUESTION 2 (DBE November 2016)

2.1 A learner is investigating the photoelectric effect for two different metals, silver and sodium, using light of different frequencies. The maximum kinetic energy of the emitted

photoelectrons is plotted against the frequency of the light for each of the metals, as shown in the graph below.



2.1.1 Define the term threshold frequency. (2)

2.1.2 Which metal, sodium or silver, has the larger work function? Explain the answer. (3)

2.1.3 Name the physical constant represented by the slopes of the graphs. (1)

2.1.4 If light of the same frequency is shone on each of the metals, in which will the ejected photoelectrons have a larger maximum kinetic energy? (1)

2.2 In a different photoelectric experiment blue light obtained from a light bulb is shone onto a metal plate and electrons are released.

The wavelength of the blue light obtained from a light bulb is shone onto a metal plate and electrons are released.

2.2.1 calculate the number of photons that will be incident on the metal plate per second, assuming all the light from the bulb is incident on the metal plate. (5)

2.2.2 Without any further calculation, write down the number of electrons emitted per second from the metal. (1)

QUESTION 3 (DBE November 2015)

In an experiment to demonstrate the photoelectric effect, light of different wavelengths was shown onto a metal surface of a photoelectric cell. The maximum kinetic energy of the emitted electrons was determined for the various wavelengths and recorded in the table below.

Inverse of wavelength $1/\lambda$ (x 10^6 m^{-1})	Maximum kinetic energy $E_{k(max)}$(x10^{-19} J)
5.00	6.60
3.30	3.30

2.50	1.70
2.00	0.70

3.1 What is meant by the term photoelectric effect? (2)

3.2 Draw a graph of $E_{k(max)}$ (y-axis) versus 1/λ (x-axis) (3)

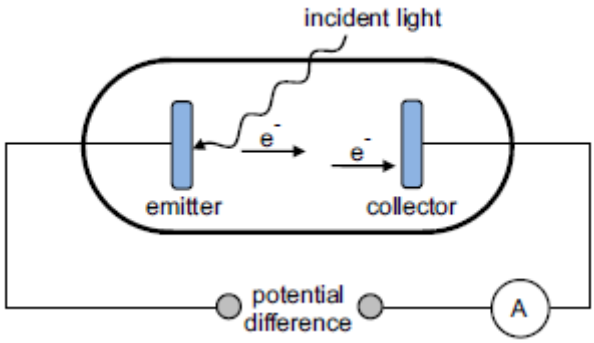
3.3 USE THE GRAPH to determine:

3.3.1 The threshold frequency of the metal in the photoelectric cell. (4)

3.3.2 Plank's constant. (5)

QUESTION 4

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

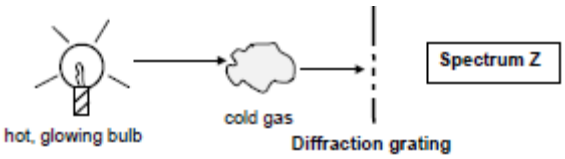


4.1 Name the phenomenon illustrated above. (1)

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

QUESTION 5 (DBE November 2017)

5.1 A teacher in a science class explains how different types of spectra are obtained. The teacher uses the simplified diagrams shown below for the explanation.



Name the type of spectrum of:

5.1.1 Y

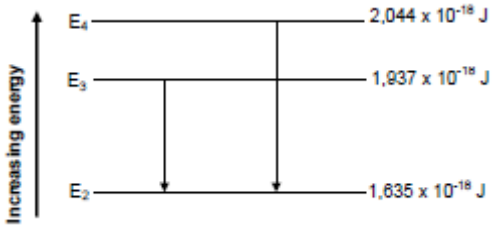
(1)

5.1.2 Z

(1)

5.2 In an excited atom, electrons can jump from lower energy levels to higher energy levels. They can also drop from higher energy levels.

The diagram below (not drawn to scale) shows some of the transitions for the electrons in an excited atom.



5.2.1 Do the transitions indicated in the diagram lead to ABSORPTION or EMISSION spectra? (1)

5.2.2 Calculate the frequency of the photon produced when an electron in an excited atom makes a transition from $\mathbf{E_4}$ to $\mathbf{E_2}$, as shown in the diagram.

(4)

The threshold frequency of a metal, Q is 4,4 x 10^{14} Hz

5.2.3 Calculate the kinetic energy of the most energetic electron ejected when the photon produced in QUESTION 5.2.2 is incident on the surface of metal Q.

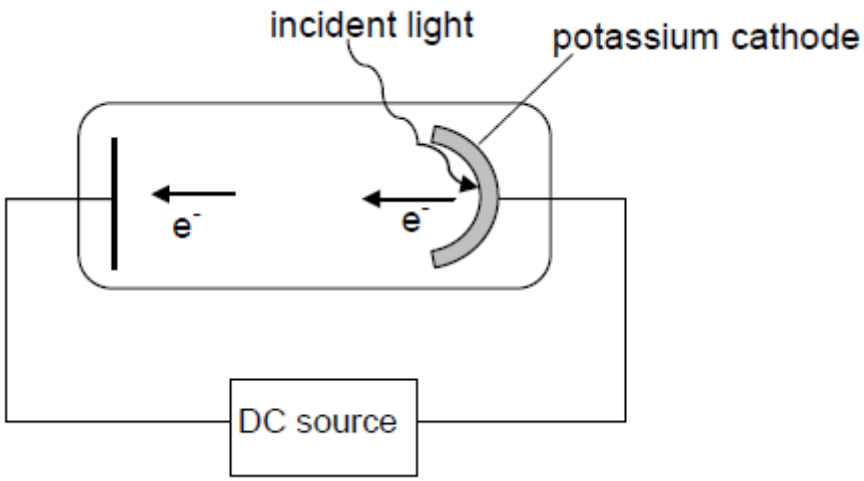
(4)

Another metal, R, has a threshold frequency of 7,5 x 10^{14} Hz.

5.2.4 Will the photon produced in QUESTION 5.2.2 be able to eject electrons from the surface of metal R? Write down only YES or NO. Give a reason for your answer. (2)

QUESTION 6 (DBE November 2014)

Ultraviolet light is incident onto a photocell with a potassium cathode as shown below. The threshold frequency of potassium is 5,548 x 10^{14} Hz.



6.1 Determine the term threshold frequency.

(2)

The maximum speed of an ejected photoelectron is 5,33 x 10^{5} m.s^{-1}

6.2 Calculate the wavelength of the ultraviolet light used.

(5)

The photocell is now replaced by another photocell with a rubidium cathode. The maximum speed of the ejected photoelectron is 6,10 x 10^{5} m.s^{-1} when the same ultraviolet light source is used.

6.3 How does the work function of rubidium compare to that of potassium?

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

(1)

6.4 Explain the answer to QUESTION 6.3.

(3)

QUESTION 7 (ieb November 2015)

In an experiment, light of different wavelengths was shone onto a metal surface. The kinetic energy of the emitted electrons was determined and recorded in a table:

λ (nm)	E_K (× 10^{-19} J)	1/λ (× 10^6 m^{-1})
200	6.72	5.00
300	3.30	3.33
400	1.68	2.50
500	0.66	2.00
600	0.05	1.67

7.1. Plot a graph of 1/λ (x axis) against EK (y axis). (7)

7.2. The photoelectric equation is

$$\frac{hc}{\lambda} = W_f + E_K$$

Rearrange this equation into a straight line form (appropriate for your graph), and use your graph to determine

7.2.1. The work function, W_0 (2)

7.2.2. Planck's constant, h (3)

ORGANIC CHEMISTRY

<u>Representing Chemical Change</u>

Balanced chemical equations

- Write and balance chemical equations.
- Interpret balanced reaction equations in terms of:
  - Conservation of atoms
  - Conservation of mass (use relative atomic masses)

Quantitative Aspects of Chemical Change

Molar volume of gases

- 1 mole of any gas occupies 22,4 dm^3 at 0 °C (273 K) and 1 atmosphere (101,3 kPa).

Volume relationships in gaseous reactions

- Interpret balanced equations in terms of volume relationships for gases, i.e. under the same conditions of temperature and pressure, equal number of moles of all gases occupy the same volume.

Concentration of solutions

- Calculate the molar concentration of a solution.

More complex stoichiometric calculations

- Determine the empirical formula and molecular formula of compounds.
- Determine the percentage yield of a chemical reaction.
- Determine percentage purity or percentage composition, e.g. the percentage $CaCO_3$ in an impure sample of seashells.
- Perform stoichiometric calculations based on balanced equations.
- Perform stoichiometric calculations based on balanced equations that may include limiting reagents.

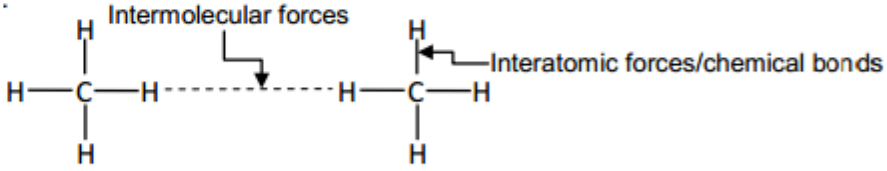
Intermolecular Forces

Intermolecular forces and interatomic forces (chemical bonds)

- Name and explain the different intermolecular forces (Van der Waal's forces):
  i. Dipole-dipole forces:
     Forces between two polar molecules
  ii. Induced dipole forces or London forces:
     Forces between non-polar molecules
  iii. Hydrogen bonding:
     Forces between molecules in which hydrogen is covalently bonded to nitrogen, oxygen or fluorine – a special case of dipole-dipole forces

- Describe the difference between intermolecular forces and interatomic forces (intramolecular forces) using a diagram of a group of small molecules; and in words.

  Example:



- State the relationship between intermolecular forces and molecular size. For non-polar molecules, the strength of induced dipole forces increases with molecular size.
- Explain the effect of intermolecular forces on boiling point, melting point and vapour pressure.

Boiling point:
The temperature at which the vapour pressure of a substance equals atmospheric pressure. The stronger the intermolecular forces, the higher the boiling point.
Melting point:
The temperature at which the solid and liquid phases of a substance are at equilibrium.
The stronger the intermolecular forces, the higher the melting point.

Vapour pressure:
The pressure exerted by a vapour at equilibrium with its liquid in a closed system.
The stronger the intermolecular forces, the lower the vapour pressure.

Viscosity:

- Viscosity is the property of the fluid to oppose relative motion between the two adjacent layers.
- The stronger the intermolecular forces, the higher the viscosity.
- As the temperature of the fluid increases, its viscosity decreases. The liquids used as the lubrication fluid and for number of other applications should be selected properly considering the operating temperatures.

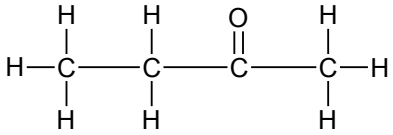
Organic Molecules

- Define organic molecules as molecules containing carbon atoms.

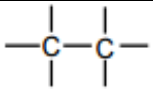
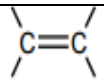
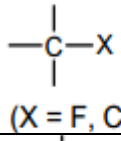
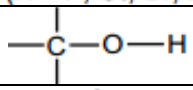
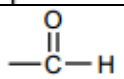
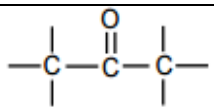
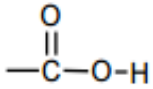
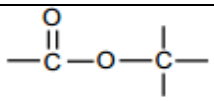
Organic molecular structures – functional groups, saturated and unsaturated structures, isomers

- Write down condensed structural formulae, structural formulae and molecular formulae (up to 8 carbon atoms, one functional group per molecule) for:
  - Alkanes (no ring structures)
  - Alkenes (no ring structures)
  - Alkynes
  - Halo-alkanes (primary, secondary and tertiary haloalkanes; no ring structures)
  - Alcohols (primary, secondary and tertiary alcohols)
  - Carboxylic acids
  - Esters
  - Aldehydes
  - Ketone
- Know the following definitions/terms:

Molecular formula: A chemical formula that indicates the type of atoms and the correct number of each in a molecule.
Example: C_4H_8O
Structural formula: A structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together.
Example:

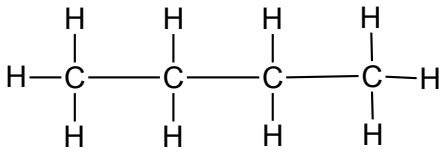


Hydrocarbon: Organic compounds that consist of hydrogen and carbon only.
Homologous series: A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH_2 group.
Saturated compounds: Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains.
Unsaturated compounds: Compounds with one or more multiple bonds between C atoms in their hydrocarbon chains.
Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

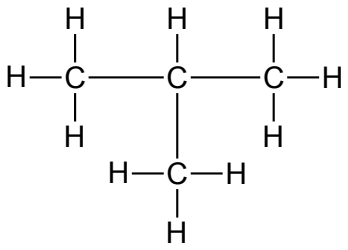
Homologous Series	**Structure of functional group**	
	Structure	**Name/Description**
Alkanes		Only C–H and C–C single bonds
Alkenes		Carbon-carbon double bond
Alkynes		Carbon-carbon triple bond
Haloalkanes	 (X = F, Cℓ, Br, I)	Halogen atom bonded to a saturated C atom.
Alcohols		Hydroxyl group bonded to a saturated C atom
Aldehydes		Formyl group
Ketones		Carbonyl group bonded to two C atoms
Carboxylic acids		Carboxyl group
Esters		-

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

- Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.
- Restrict structural isomers to chain isomers, positional isomers and functional isomers.
  - **Chain isomers**: Same molecular formula, but different types of chains, e.g. butane and 2-methylpropane.

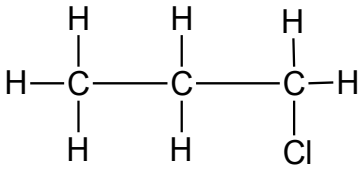


butane

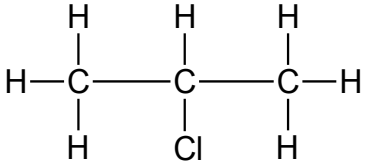


2-methylpropane

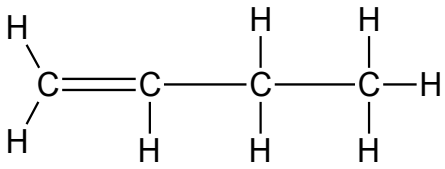
- **Positional isomers**: Same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain, e.g. 1-choropropane and 2-chloropropane or but-2-ene and but-1-ene



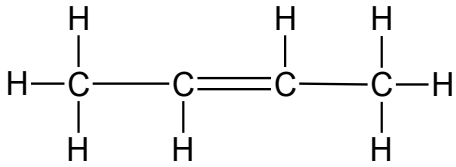
1-chromopropane



2-chromopropane

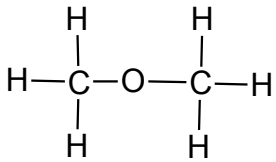


but-1-ene

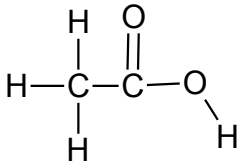


but-2-ene

- **Functional isomers**: Same molecular formula, but different functional groups, e.g. methyl methanoate and ethanoic acid



methyl methanoate



ethanoic acid

IUPAC naming and formulae

- Write down the IUPAC name when given the structural formula or condensed structural formula for compounds from the homologous series above, restricted to one functional group per compound, except for haloalkanes. For haloalkanes, maximum two functional groups per molecule.
- Write down the structural formula when given the IUPAC name for the above homologous series.
- Identify alkyl substituents (methyl- and ethyl-) in a chain to a maximum of THREE alkyl substituents on the parent chain.
- When naming haloalkanes, the halogen atoms do not get preference over alkyl groups – numbering should start from the end nearest to the first substituent, either the alkyl group or the halogen. In haloalkanes, where e.g. a Br and a Cℓ have the same number when numbered from different ends of chain,

Br gets alphabetical preference.

- When writing IUPAC names, substituents appear as prefixes written alphabetically (bromo, chloro, ethyl, methyl), ignoring the prefixes di- and tri.

Structure and physical properties (boiling point, melting point, vapour pressure, viscosity) relationships

- For a given example (from the above functional groups), explain the relationship between physical properties and:
  - Strength of intermolecular forces (Van der Waal's forces), i.e. hydrogen bonds, dipole-dipole forces, induced dipole forces
  - Type of functional groups
  - Chain length
  - Branched chains

Factors that influence the strength of IMF

1. **Surface area**
   Length of the carbon chain and **branched molecules**.
   For compounds that belong to the same homologous series, the larger the surface area the higher the Melting point, the Boiling point, the Viscosity and the lower the Vapour pressure.
   - The more branched the organic molecules are, the more compact it becomes.
   - The surface area is smaller and less Van der Waals forces are available.
   - The IMF are weaker resulting in lower boiling points and melting points.
   - The vapour pressure will increase.
2. **The type of functional group**
   For compounds with comparable molecular mass (C-chain length) the functional group will be the determining factor regarding the strength of the IMF. The more polar the functional group the stronger the IMF.

   Carboxylic acid > Alcohol > Ketone, Aldehyde & Ester > Alkyne, Alkane & Alkene

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

London forces	**Dipole-dipole forces**	**Hydrogen Bond**
Alkanes Alkenes Alkynes	Aldehydes Ketones Halo- alkanes Esters	Alcohols (1 site) Carboxylic acids (2 sites)

ORGANIC REACTIONS

Substitution and addition reactions

- Identify reactions as elimination, substitution or addition.
- Write down, using structural formulae, equations and reaction conditions for the following addition reactions of alkenes:
  - **Hydrohalogenation**:

The addition of a hydrogen halide to an alkene

  - **Halogenation**:

The reaction of a halogen (Br_2, $C\ell_2$) with a compound

  - **Hydration**:

The addition of water to a compound

  - **Hydrogenation**:

The addition of hydrogen to an alkene

- Write down, using structural formulae, equations and reaction conditions for the following elimination reactions:
  - **Dehydrohalogenation of haloalkanes**:

The elimination of hydrogen and a halogen from a haloalkane

- Write down, using structural formulae, equations and reaction conditions for the following substitution reactions:
  - **Hydrolysis of haloalkanes**

Hydrolysis: The reaction of a compound with water

  - Reactions of HX (X = Cℓ, Br) with alcohols to produce haloalkanes
  - **Halogenation of alkanes**

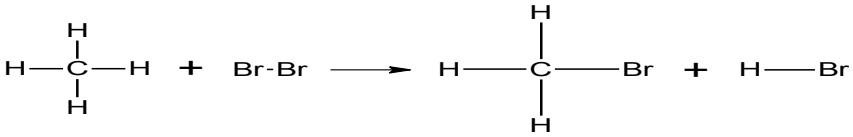
The reaction of a halogen (Br_2, $C\ell_2$) with a compound

- Distinguish between saturated and unsaturated hydrocarbons using bromine water.

REACTIONS OF ALKANES

1. SUBSTITUTION

Alkane → haloalkane



Conditions: Heat **OR** sunlight(uv)

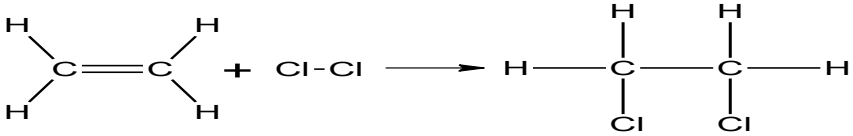
Reactants: alkane + X_2 (F, Cl, Br, I)

Type of substitution: halogenation(bromination)

Substitution reaction will only occur when the compound is saturated.

REACTIONS OF ALKENES

ADDITION REACTION 1 (Halogenation)



Conditions: Unreactive solvent

Type of addition: halogenation

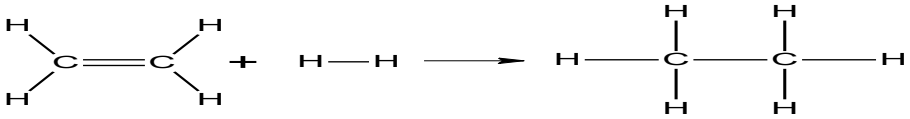
Reactants: alkene + X_2 (X = Cl, Br)

Product: haloalkane

Bromine test: to distinguish between **alkane** and **alkene**

- Add bromine water (orange-brown) to unknown substances.
- If bromine water discolours the substance is an alkene.
- $CH_2CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$

ADDITION REACTION 2 (Hydrogenation)



Conditions: Pt, Pd or Ni as catalyst

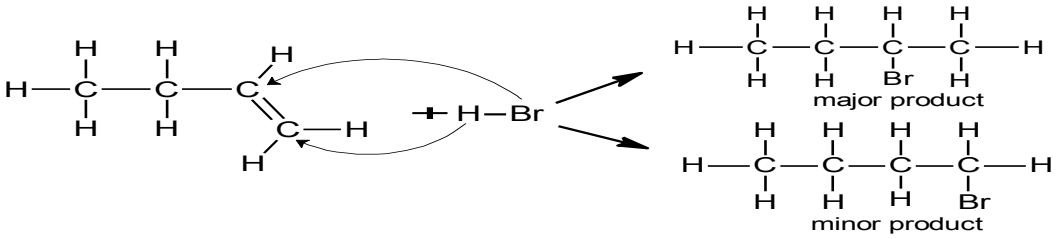
Type of addition: hydrogenation

Reactants: alkene + H_2

Product: Alkane

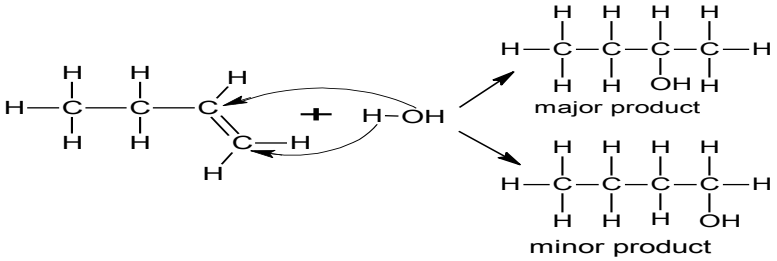
Application: Hydrogenation of unsaturated vegetable oils is used to manufacture margarine.

ADDITION REACTION 3 (Hydrohalogenation)



Conditions:No water; Unreactive solvent
Type of addition: hydrohalogenation
Reactants: alkene + HX (X = I, Br, Cl)
Product(s): haloalkane(s)
Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)

ADDITION REACTION 4 (Hydration)



Conditions: Excess H_2O; Acid (H_2SO_4 / H_3PO_4) as catalyst.
Type of addition: hydration
Reactants: alkene + H_2O **Product**: Alcohol(s)

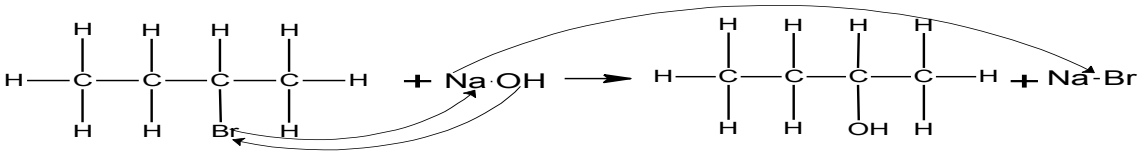
Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)
Addition reaction will only occur when the compound is unsaturated.

REACTIONS OF HALOALKANES

1. SUBSTITUTION :

Haloalkane → alcohol

2.1



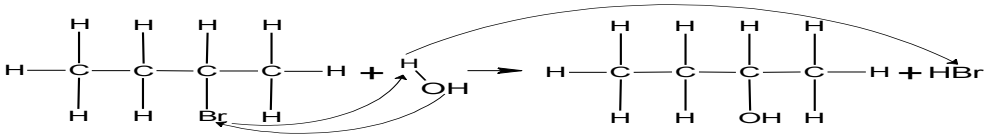
Conditions: Diluted strong base (NaOH/KOH/LiOH) + mild heat

Type of substitution: hydrolysis/ hydration

Reactants: Haloalkane in ethanol + diluted strong base

Products: Alcohol + NaBr/KBr/LiBr

2.2

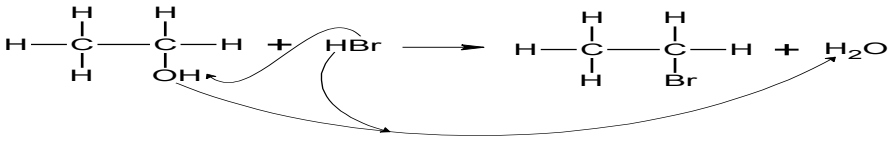


Conditions: Excess H_2O + mild heat
Type of substitution: hydrolysis
Reactants: Haloalkane + H_2O
Products: Alcohol + HBr

REACTIONS OF ALCOHOL

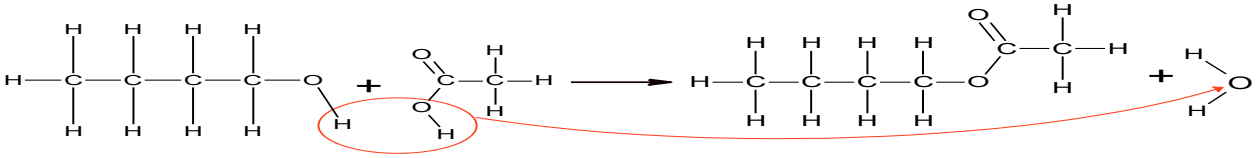
1. SUBSTITUTION

Alcohol → haloalkane



Conditions: Heat
Reactants needed: Alcohol + HX
For primary & secondary alcohols: NaBr + conc H_2SO_4 is used to prepare HBr in reaction flask.
For tertiary alcohols: HBr (or HCl) are directly applied.
Products: Haloalkane + H_2O

ESTERIFICATION



Conditions: Concentrated H_2SO_4 as catalyst + heat

Reactants: Alcohol + carboxylic acid + H_2SO_4
Products: Ester + water

- The process whereby esters is formed is called **esterification.**
- Esters form when an **alcohol** reacts with a **carboxylic acid** when **heated** (condensation reaction).
- The catalyst is **concentrated sulphuric acid (H_2SO_4)**, a **dehydrating agent** that **extracts** the **water.**
- The **homologous series** is an **esters** and the name, therefore, ends in "**-oate**".

The name of the example above is therefore, **butyl ethanoate.**

Plastics and polymers (ONLY BASIC POLYMERISATION as application of organic chemistry)

- Describe the following terms:
  Macromolecule: a molecule that consists of a large number of atoms
  Polymer: a large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern
  Monomer: small organic molecules that can be covalently bonded to each other in a repeating pattern
  Polymerisation: a chemical reaction in which monomer molecules join to form a polymer
  Plastics: synthetic materials derived from organic compounds
- Identify monomers from given addition polymers.
- Discuss the industrial uses of polythene.

QUESTION 1
MULTIPLE-CHOICE QUESTIONS

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

1.1 Which ONE of the compounds below is an aldehyde?

A CH_3CHO
B CH_3COCH_3
C CH_3COOH
D CH_3OH (2)

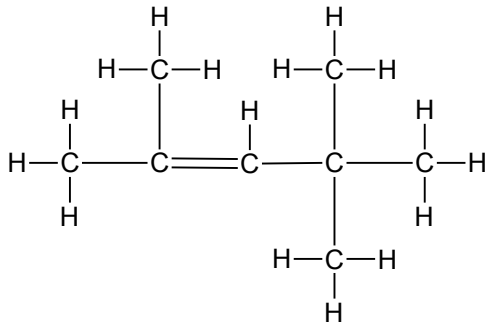
1.2 The reaction represented by the equation below takes place in the presence of a catalyst.

$$C_{13}H_{28(\ell)} \longrightarrow C_2H_{4(g)} + C_3H_{6(g)} + C_8H_{18(\ell)}$$

This reaction is an example of …

A addition.
B cracking.
C substitution.
D polymerisation. (2)

1.3 Consider the structural formula of an organic compound below.



Which ONE of the following is the correct IUPAC name of this compound?

A 2,2,4-trimethylpent-2-ene
B 2,2,4-trimethylpent-3-ene
C 2,4,4-trimethylpent-2-ene
D 2,4,4-trimethylpent-3-ene (2)

1.4 Which ONE of the following statements is CORRECT?

Alkenes …

A have the general formula C_nH_{2n+2}.
B are unsaturated hydrocarbons.
C readily undergo substitution reactions.
D have one triple bond between two carbon atoms. (2)

1.5 The following equation represents the cracking of a hydrocarbon at high temperature and pressure:

$$C_{11}H_{24} \longrightarrow 2C_2H_4 + \mathbf{Y} + C_4H_{10}$$

Which ONE of the following is the IUPAC name of product **Y**?

A Prop-1-ene.
B Propane.
C Ethene.
D Ethane. (2)

1.6 When 2-chlorobutane is strongly heated in the presence of concentrated sodium hydroxide, the major product formed is …

A but-1-ene.
B but-2-ene.
C butan-1-ol.
D butan-2-ol. (2)

1.7 Which ONE of the following compounds is an aldehyde?

A Pentanal
B Pentan-2-ol

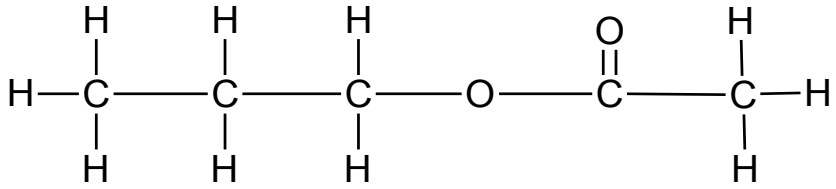
C Pentan-2-one
D Ethyl propanoate (2)

Consider the reaction represented by the equation below:

$$CH_3CHCH_2 + H_2 \longrightarrow CH_3CH_2CH_3$$

This reaction is an example of …
A hydration.
B dehydration.
C substitution.
D hydrogenation. (2)

1.8 Consider the structural formula of a compound below.



1.9 Which ONE of the following pairs of reactants can be used to prepare this compound in the laboratory?
A Propanoic acid and ethanol
B Propanoic acid and methanol
C Ethanoic acid and propan-1-ol
D Methanoic acid and propan-1-ol (2)

1.10. Which ONE of the following compounds has dipole-dipole forces between its molecules?
A Ethanal
B Ethane
C Ethene
D Ethyne (2)

1.11. Which ONE of the following is a product formed during the hydrolysis of bromoethane?
A Water
B Ethene
C Ethanol
D Bromine (2)

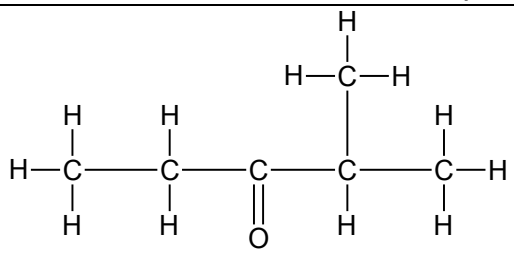
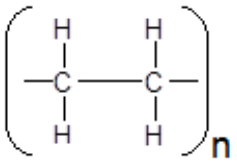
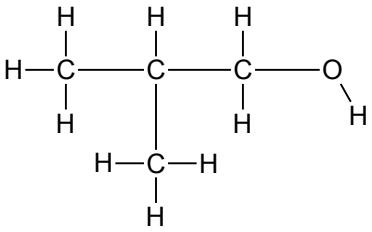
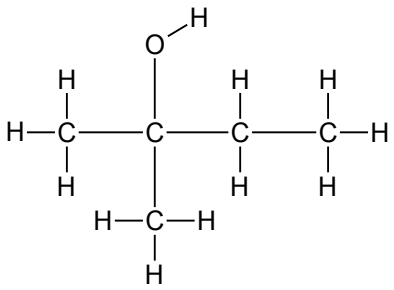
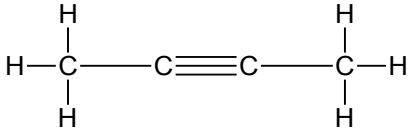
1.12. Which ONE of the following is the EMPIRICAL FORMULA of 1,2-dichloroethane?
A $CHC\ell$
B $CH_2C\ell$
C $CHC\ell_2$
D $C_2H_4C\ell_2$ (2)

1.13. Which ONE of the following pairs of compounds are FUNCTIONAL isomers?

A Methanol and methanal
B Butane and 2-methylpropane
C Propan-1-ol and pronan-2-ol
D Propanoic acid and methyl ethanoate (2)

QUESTION 2

The letters **A** to **G** in the table below represent seven organic compounds.

A		B	
C		D	
E	Butane	F	
G	Ethyl propanoate		

2.1. Write down the:

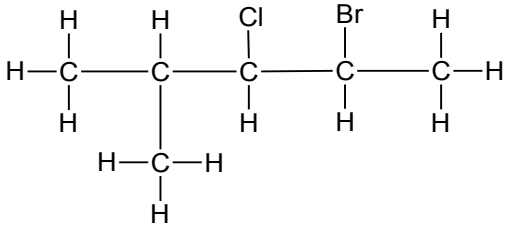
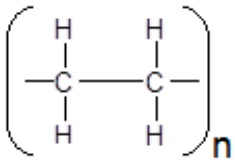
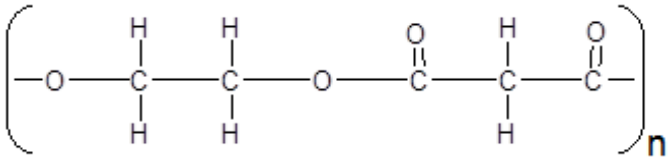
2.1.1. Name of the homologous series to which compound **F** belongs. (1)

2.1.2. Name of the functional group of compound **D**. (1)

2.1.3. Letter that represents a primary alcohol. (1)
2.1.4. IUPAC name of compound **A**. (2)
2.1.5. Structural formula of the monomer of compound **B**. (2)
2.1.6. Balanced equation, using molecular formulae, for the combustion of compound **E** in excess oxygen. (3)
2.2. Briefly explain why compounds **C** and **D** are POSITIONAL ISOMERS. (2)
2.3. Compound **G** is prepared using an alcohol as one of the reactants. Write down the balanced equation for the reaction using structural formulae for all the organic reagents. (7)

QUESTION 3

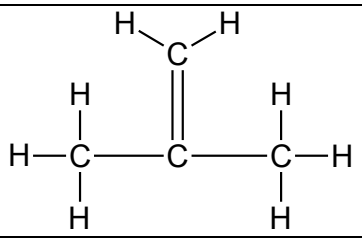
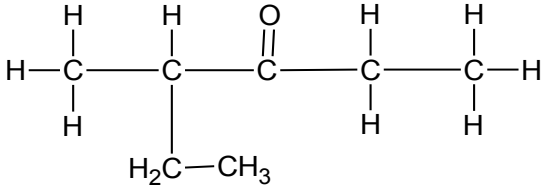
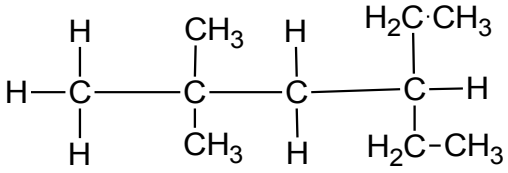
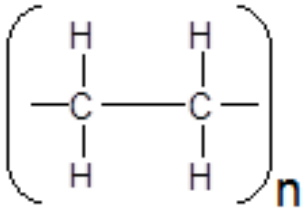
Consider the organic compounds represented by the letters A to F in the table below.

A	2,2,4-trimethylhexane	B	$CH_3CH_2CH_2CH_2CHO$
C		D	
E		F	Pentan-2-one

3.1. Write down the LETTER that represents the following:
3.1.1. An aldehyde. (1)
3.1.2. A condensation polymer (1)
3.1.3. A compound which has a carbonyl group bonded to two carbon atoms as its functional group. (1)
3.2. Write down the IUPAC name of:
3.2.1. Compound **C** (3)
3.2.2. The monomer of compound **D** (1)
3.3. Write down the structural formula of:
3.3.1. Compound **A** (2)
3.3.2. Compound **F** (2)
3.4. The table contains compounds which are functional isomers.
3.4.1. Define the term *functional isomer*. (2)
3.4.2. Write down the LETTERS that represent two compounds that are functional isomers. (1)

QUESTION 4

The letters **A** to **F** in the table below represent six organic compounds.

A		B	2-methylbutanoic acid
C		D	
E	But-2-ene	F	

4.1. Write down the:

4.1.1. NAME of the functional group of compound **B** (1)

4.1.2. Homologous series to which compound **C** belongs. (1)

4.1.3. Type of polymerisation reaction that produces compound **F** (1)

4.2. Write down the IUPAC name of:

4.2.1. The monomer used to prepare compound **F** (1)

4.2.2. Compound **C** (2)

4.2.3. Compound **D** (2)

4.3. Write down the NAME or FORMULA of each product formed during the complete combustion of compound **D.** (2)

4.4. Write down the structural formula of:

4.4.1. Compound **B** (2)

4.4.2. A CHAIN ISOMER of compound **A** (2)

4.5. A laboratory assistant uses bromine water to distinguish between compounds **D** and **E**. She adds bromine water to a sample of each in two different test tubes. She observes that the one compound decolourises the bromine water immediately, whilst the other one reacts after placing the test tube in direct sunlight.

Write down the:

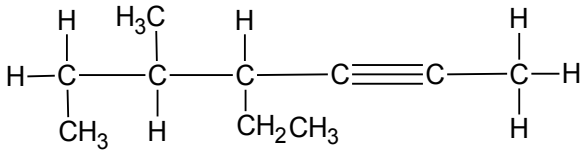
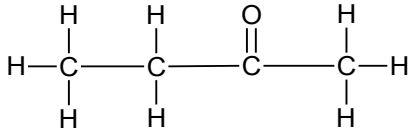
4.5.1. Letter (**D** or **E**) of the compound that will immediately decolourise the bromine water. (1)

4.5.2. Name of the type of reaction that takes place in the test tube containing compound **D** (1)

4.5.3. Structural formula of the organic product formed in the test tube containing compound **E** (2)

QUESTION 5

The letters **A** to **D** in the table below represents four organic compounds.

A		B	
C	CH_3CH_2CHO	D	Butane

Use the information in the table to answer the questions that follow.

5.1. Write down the:

5.1.1. Letter that represents a ketone. (1)

5.1.2. Structural formula of the functional group of compound **C**. (1)

5.1.3. General formula of the homologous series to which compound **A** belongs. (1)

5.1.4. IUPAC name of compound **A**. (3)

5.1.5. IUPAC name of compound **B**. (2)

5.2. Compound **D** is a gas used in cigarette lighters.

5.2.1. To which homologous series does compound **D** belong? (1)

5.2.2. Write down the STRUCTURAL FORMULA and IUPAC NAME of a structural isomer of compound **D**. (4)

5.3. Compound **D** reacts with bromine (Br_2) to form 2-bromobutane.

Write down the name of the:

5.3.1. Homologous series to which 2-bromobutane belongs. (1)

5.3.2. Type of the reaction that takes place. (1)

Questions 6 - 11 involve Properties of Organic Compounds & Intermolecular Forces.

QUESTION 6

The table below shows the results obtained from experiments to determine the boiling point of some alkanes and alcohols of comparable molecular masses.

Compound	**Relative molecular mass**	**Boiling point (ºC)**
CH_3CH_3	30	-89
CH_3OH	32	65
$CH_3CH_2CH_3$	44	-42
CH_3CH_2OH	46	78
$CH_3CH_2CH_2CH_3$	58	0
$CH_3CH_2CH_2OH$	60	97
$CH_3CH_2CH_2CH_2CH_3$	72	36
$CH_3CH_2CH_2CH_2OH$	74	117

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

6.2 Consider the boiling points of the four alkanes in the above table.

6.2.1 Describe the trend in their boiling points. (1)
6.2.2 Fully explain the trend in QUESTION 6.2.1. (3)
6.2.3 The boiling point of each alcohol is much higher than that of the alkane of comparable relative molecular mass. Explain this observation by referring to the type and strength of the intermolecular forces in alkanes and alcohols (2)

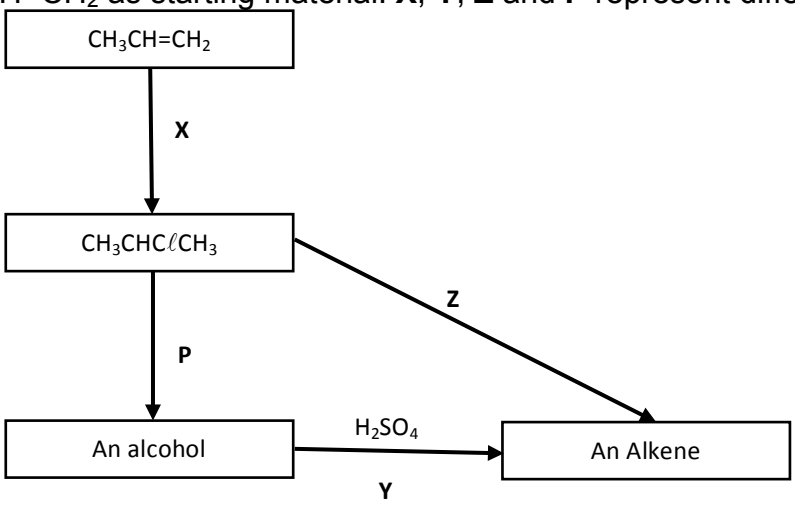
QUESTION 7

7.1 Give a reason why alkanes are *saturated* hydrocarbons. (1)
7.2 Write down the structural formula of:
7.2.1 The functional group of alcohols. (1)
7.2.2 A tertiary alcohol that is a structural isomer of butan-1-ol. (2)
7.3 Learners investigate factors that influence the boiling points of alkanes and alcohols. In one of the investigations they determine boiling points of the first three alkanes.
7.3.1 Write down an investigative question for this investigation. (2)
7.3.2 Fully explain why the boiling point increases from methane to propane. (3)
7.4 The learners find that the boiling point of propan-1-ol is higher than that of propane.Explain this observation by referring to the TYPE of INTERMOLECULAR FORCES present in each of these compounds. (3)

Questions 8 to 16 involve Types of Organic Reactions.

QUESTION 8

The flow diagram below shows the preparation of the organic compounds using $CH_3CH=CH_2$ as starting material. **X**, **Y**, **Z** and **P** represent different organic reactions.

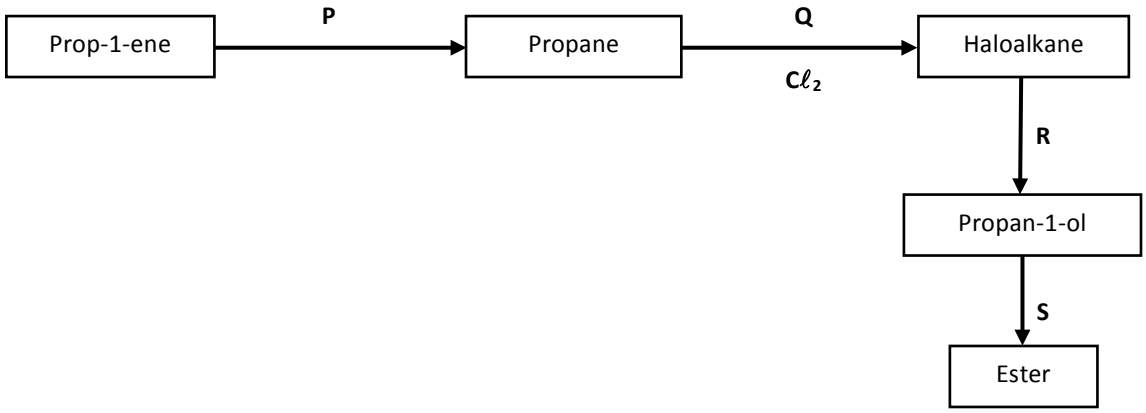


8.1 To which homologous series does $CH_3CH=CH_2$ belong? (1)
8.2 Write down the:
8.2.1 Type of reaction of which **X** is an example. (1)

8.2.2 Structural formula and IUPAC name of the alcohol produced during reaction **P**. (3)
8.2.3 The type of reaction of which **Y** is an example. (1)
8.2.4 Function of the acid in reaction **Y**. (1)
8.3 For reaction **Z**, write down:
8.3.1 The NAME of the inorganic reagent needed. (1)
8.3.2 TWO reaction conditions needed. (2)

QUESTION 9

The diagram below shows the preparation of an ester using prop-1-ene as a starting reagent. **P**, **Q**, **R** and **S** represent different organic reactions.



9.1 Write down the type of reaction represented by:
9.1.1 Q (1)
9.1.2 R (1)
9.2 For reaction **P** write down the:
9.2.1 Type of addition reaction (1)
9.2.2 Balanced equation using structural formulae (3)
9.3 Write down the structural formula of the haloalkane formed in reaction **Q**. (2)
9.4 In reaction **S** propan-1-ol reacts with ethanoic acid to form the ester. For this reaction write down the:
9.4.1 Name of the reaction that takes place (1)
9.4.2 FORMULA or NAME of the catalyst needed (1)
9.4.3 Structural formula of the ester formed (2)
9.4.4 IUPAC name of the ester formed (2)

CHEMICAL CHANGE

- Is the change that involves the formation of a new substance e.g combustion of petrol, rusting of iron.

Energy changes in reactions related to bond energy changes

• Define *heat of reaction* (ΔH) as the energy absorbed or released in a chemical reaction.

• Define *exothermic reactions* as reactions that release energy.

• Define *endothermic reactions* as reactions that absorb energy.

• Classify (with reason) reactions as exothermic or endothermic.

Exothermic and endothermic reactions

• State that ΔH > 0 for endothermic reactions, i.e. reactions in which energy is released.

• State that ΔH < 0 for exothermic reactions, i.e. reactions in which energy is absorbed.

Activation energy

• Define *activation energy* as the minimum energy needed for a reaction to take place.

• Define an *activated complex* as the unstable transition state from reactants to products.

• Draw or interpret fully labelled sketch graphs (potential energy versus course of reaction graphs) of catalysed and uncatalysed endothermic and exothermic reactions.

- **HEAT OF REACTION/ENTHALPY CHANGE**

-is the energy absorbed or released in a chemical reaction

-Symbol is ΔH

- Unit is kJ or kJ/mol

- **BOND ENERGY**

- Is the amount of energy required to break a bond in a molecule

ENERGY CHANGES THAT TAKE PLACE DURING CHEMICAL REACTIONS

- **TYPES OF CHEMICAL REACTIONS:**

1. Exothermic reaction
2. Endothermic reaction

Exothermic reaction

-is the reaction that releases energy

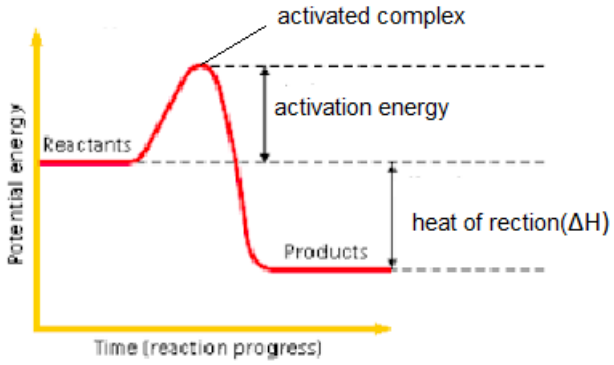
Endothermic reaction

-is the reaction that absorb energy

Exothermic reactions

-reactions in which energy is released

$\Delta H<0$, ΔH is negative

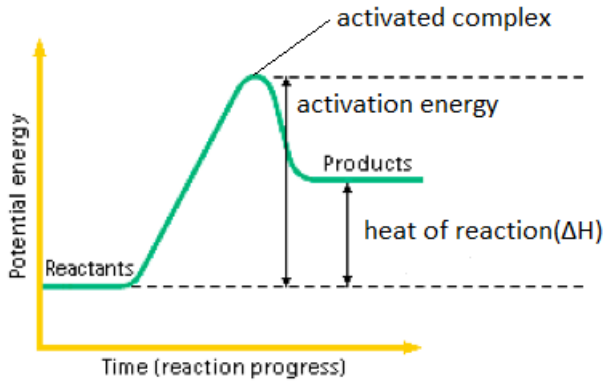


- **Are spontaneous reactions-** do not need a continuous supply of energy.

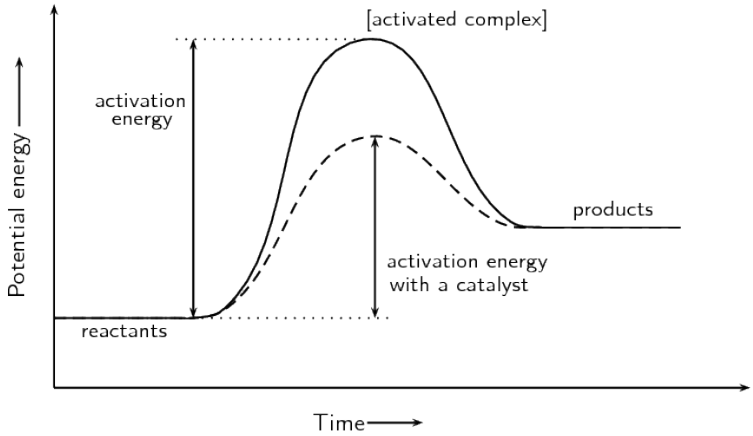
- Activation energy is the minimum energy needed for a reaction to take place
- Activated complex is the unstable transition state from reactants to products or is the temporary unstable state that is formed during the course of a chemical reaction.
- Enthalpy(H) is the amount of energy of reactants or products
- Enthalpy cannot be measured
- Enthalpy change (ΔH) can be calculated using: $\Delta H = H_{products} - H_{reactants}$

ENDOTHERMIC REACTIONS

- Reactions which energy is absorbed and are non-spontaneous
- $\Delta H>0$, ΔH is positive



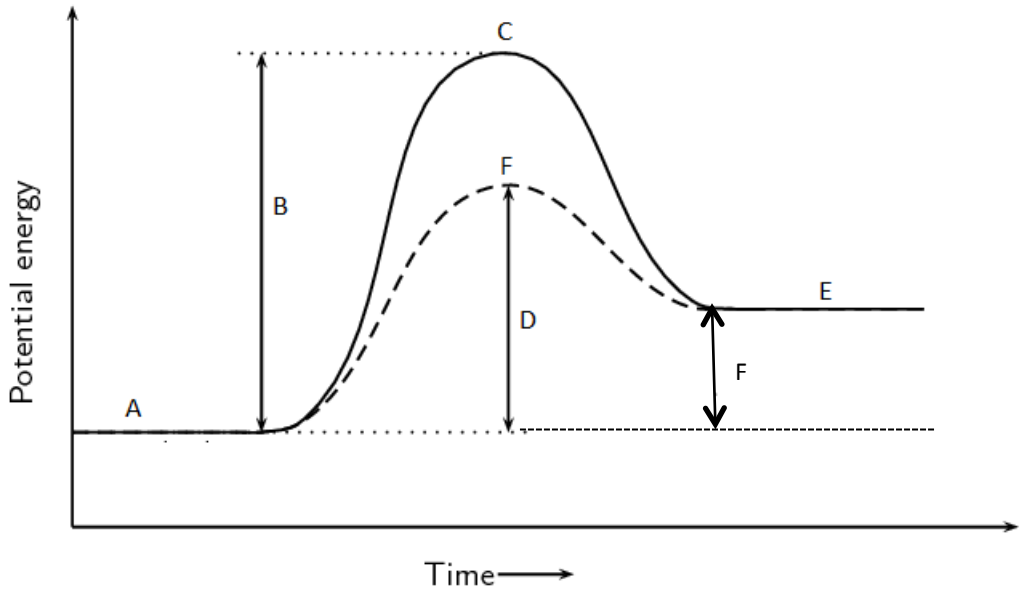
-addition of a catalyst will lower the activation energy



Comparing exothermic and endothermic reactions:

Exothermic reaction	Endothermic reaction
ΔH < 0 negative	ΔH > 0 positive
E_p of the reactants decreases as products form	E_p of the reactants increases as products form
Net energy is given out (liberated)	Net energy is taken in (gained)
The reaction flask becomes hot	The reaction flask becomes cold

Class activity



1.1 label parts A to F (6)

1.2 Is the forward reaction an exothermic or endothermic reaction? (1)

1.3 Calculate heat of the reaction for the forward reaction and reverse reaction (3)

1.4 is the reverse reaction exothermic or an endothermic reaction? (1)

1.5 What is the activation energy for the forward reaction and reverse reaction? (2)

1.6 Is the forward reaction spontaneous or non-spontaneous reaction? (2)

1.7 A catalyst is added. How does this affect the activation energy for the forward reaction?

(Write down only **INCREASES , DECREASES or STAYS THE SAME**)

Rates of reaction and factors affecting rate

• Define *reaction rate* as the change in concentration of reactants or products per unit time.

• Calculate reaction rate from given data.

$$\text{Rate} = \frac{\Delta c}{\Delta t} \text{ (Unit: mol·dm}^{-3}\text{·s}^{-1}\text{)}$$

Questions may also include calculations of rate in terms of change in mass/volume/ number of moles per time.

• List the factors that affect the rate of chemical reactions, i.e. nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.

• Explain in terms of the collision theory how the various factors affect the rate of chemical reactions. The collision theory is a model that explains reaction rate as the result of particles colliding with a certain minimum energy.

Measuring rates of reaction

• Answer questions and interpret data (tables or graphs) on different experimental techniques for measuring the rate of a given reaction.

Mechanism of reaction and of catalysis

• Define the term *positive catalyst* as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.

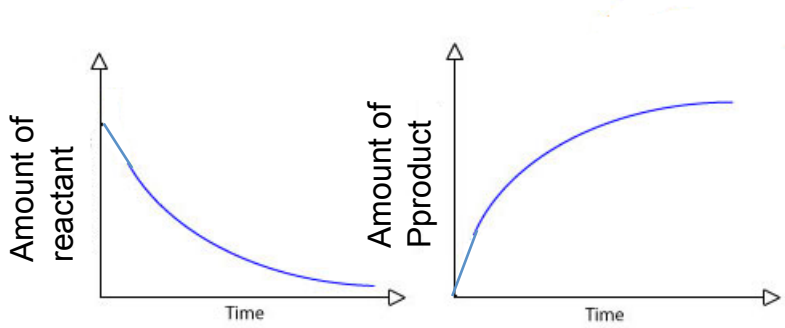
Interpret graphs of distribution of molecular energies (number of particles against their kinetic energy or Maxwell-Boltzmann curves) to explain how a catalyst, temperature and concentration affect rate.

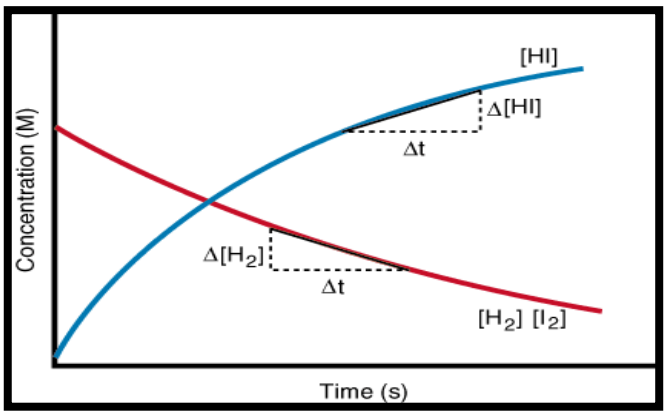
• Explain that a catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net/total activation energy.

- **RATE OF A CHEMICAL REACTION (REACTION RATE)**

- Is the change in concentration of reactants or products per unit time

- Can be calculated using: Rate $= \frac{\Delta c}{\Delta t}$





$H_2 + I_2 \rightarrow 2HI$

The gradient of either curve will give the average rate of reaction for the time interval Δt.

Measuring the rate of a reaction:

For the products:

$$\text{Average rate} = \frac{\text{change in amount of product}}{\text{time taken}}$$

For the reactants:

$$\text{Average rate} = \frac{\text{change in amount of reactant}}{\text{time taken}}$$

Example

Use experimental data to determine the rate of a chemical reaction.

Calculate the rate of reaction if it takes 18 seconds to produce 42 moles of carbon dioxide from a wood fire.

$$\text{Average rate} = \frac{\text{change in amount of product}}{\text{time taken}}$$

$$= \frac{42 \text{ mol}}{18\text{s}}$$

$$= 2{,}3 \text{ mol.s}^{-1}$$

COLLISION THEORY

- For a chemical reaction to take place particles must collide.

- Not all collisions will result in a reaction
- A collision that results in a reaction that produce one or more products is called **EFEECTIVE COLLISION**
- **Requirements for effective collisions:**

1. Correct orientation of particles
2. Sufficient kinetic energy of the particles

THE RATE OF REACTION IS DETERMINED BY:

-the number of collisions per second or frequency of the collisions

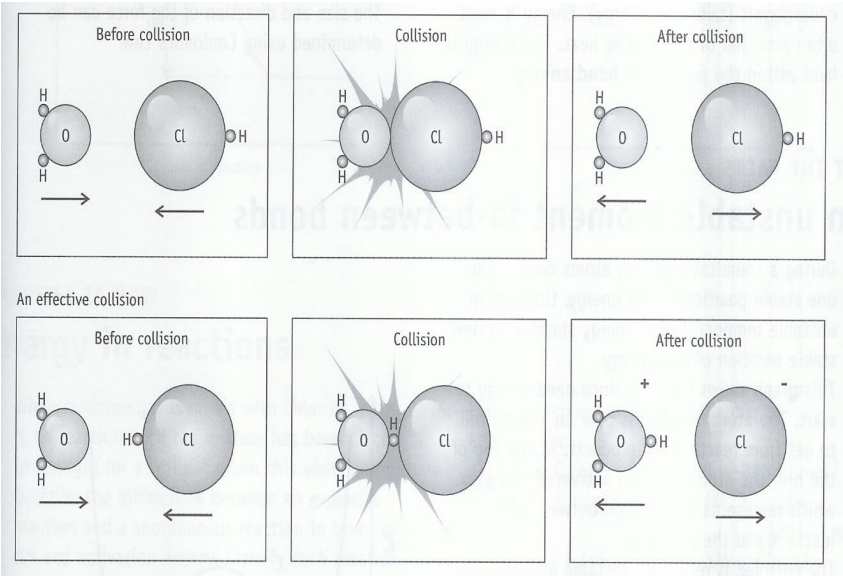
-the energy of the colliding particles

-the orientation of the colliding particles

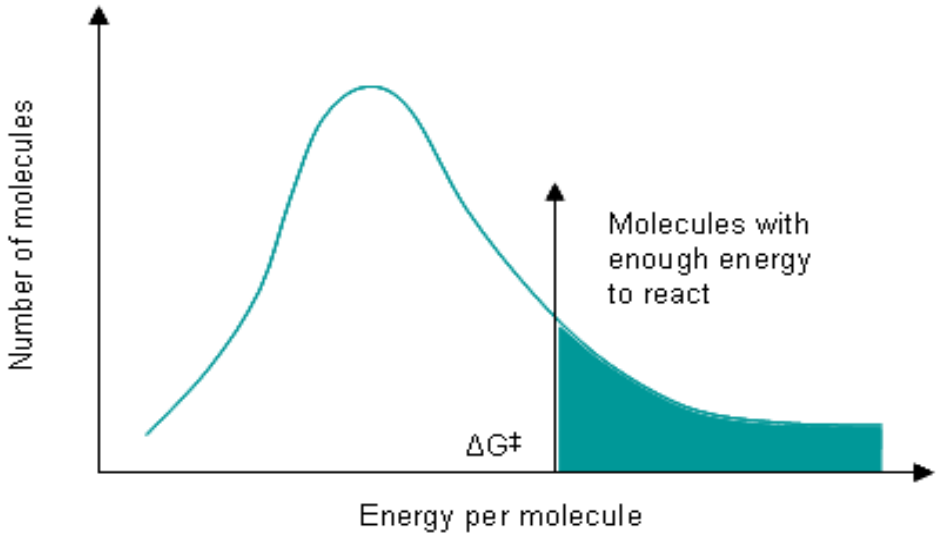
The Collision Theory

- reacting atoms, molecules or ions must collide with each other.
- the particles must have sufficient energy and must be oriented correctly.
- bonds in the original molecules must break and new bonds must form.
- electrons must re-arranged in order to form new bonds.

Amount of energy and orientation of colliding particles leads to some collisions being effective and others not.



Particles with sufficient energy



This Boltzmann curve shows that there is only a small fraction of molecules that have enough energy for the reaction.

FACTORS THAT AFFECT THE RATE OF A CHEMICAL REACTION

There are FIVE factors:

1. The nature of the reactants
2. Surface area
3. Temperature
4. Concentration
5. Catalyst

The nature of the reactants

- Some chemical compounds are more reactive than others.
- For example group 1 elements, their reactivity increases as you move down the group
- Sodium and potassium are reactive metals than heavy metals like copper and zinc
- Gold and silver are very unreactive metal
- The strength of the bond and activation energy required to break the bonds determines the reactivity of a substance.

- Simple substances with weak bonds and lower activation energy react faster than complex molecules.

Surface area

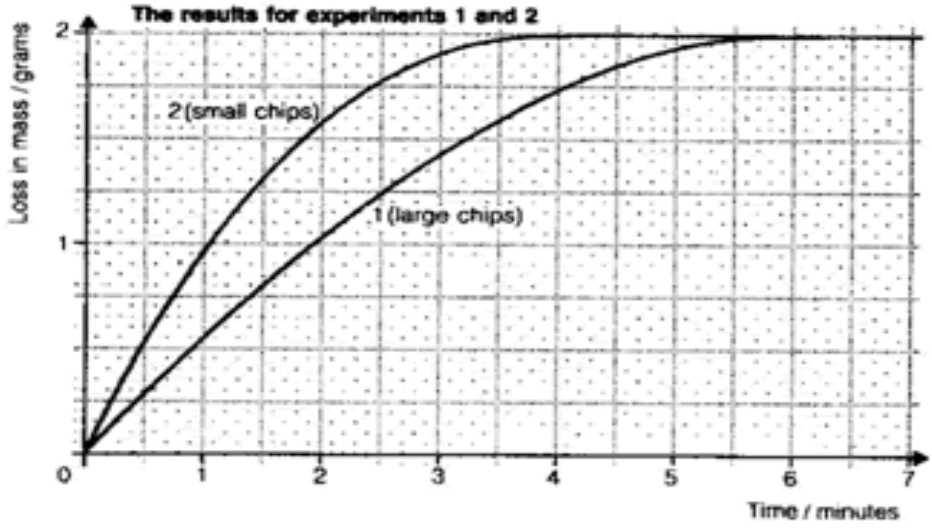
- Applies on solids only
- When surface area increases the rate of the reaction also increases or vice versa.
- Surface area is greater when a solid is in powder form and is lesser when a solid is in lump form.

According to collision theory:

- When a solid is in powder form
- As the surface area increases, there are more particles available for reacting.
- Thus there will be more collisions per second, and thus a

greater number of effective collisions per second and thus the reaction rate will increase.

The greater the exposed surface area of the particles of a solid (the finer the particles) the greater the chance of collisions with the particles on the surface and so the greater the rate of reaction



TEMPERATURE

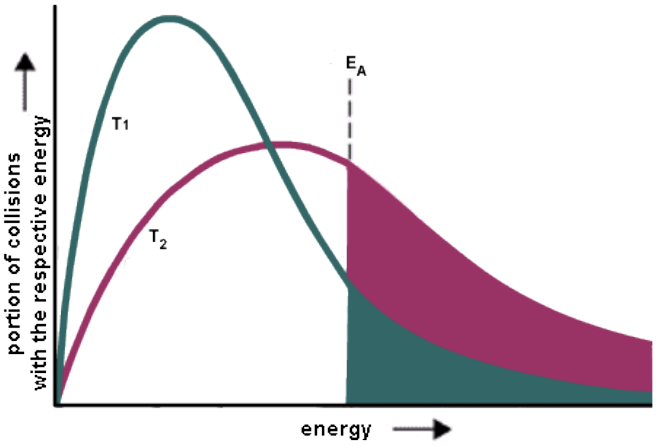
- When the temperature increases the rate of the reaction increases or vice versa.
- According to collision theory:

If the temperature of the reaction mixture is increased

- The speed of the particles increases

- The average kinetic energy of the particles increases
- more particles have sufficient energy
- There are more collisions taking place resulting in more effective collisions per unit time
- Thus the rate of the reaction increases

The effect of increasing the temperature of the reaction mixture



More molecules with sufficient energy to react at the higher temperature

CONCENTRATION

- An increase in concentration of a solution(pressure in gases) increases the rate of a reaction or vice versa.
- According to collision theory:

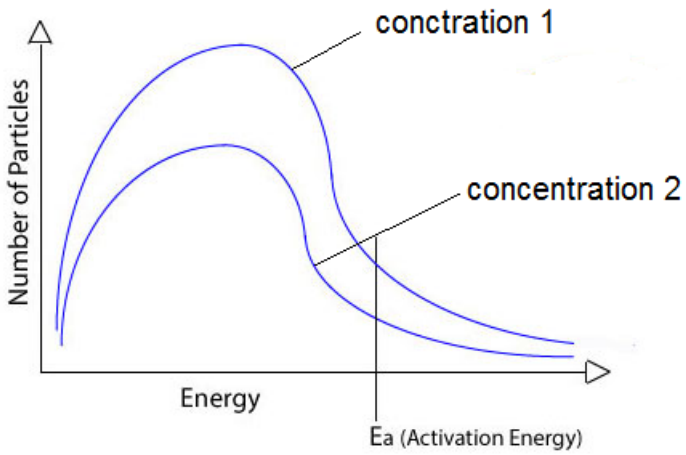
When concentration is increased

-more collisions occur due to more particles per unit volume in the container

-more particles have sufficient energy

- There are more effective collisions per unit time
- Thus the rate of the reaction increases.

The effect of increasing concentration on the reaction mixture.



In solution:

Concentration 1 is greater than concentration 2

-more particles collide per unit volume.

CATALYST

- Is a substance that speeds up the rate of a chemical reaction without itself being used up.
- Catalyst can be a solid or a gas or a liquid

-homogeneous catalysis: reactants and catalyst are in the same phase

-heterogeneous catalysis: reactants and catalyst are in the different phases

-less activation energy is required to form activated complex

-provides an alternative path with a lower activation energy

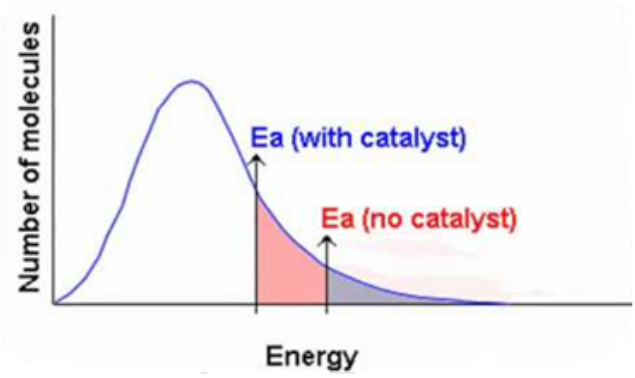
-products are formed quickly

- ***positive catalyst*** as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.
- **According to collision theory:**

When a suitable catalyst is used

-The catalyst provides an alternative pathway/route for the reaction

- with a lower activation energy
- More molecules/particles have enough energy
- and more effective collisions occur
- increasing the rate of reaction.
- Effect of a catalyst on reaction rate:



- A catalyst always lowers the activation energy
- And so more molecules have sufficient energy
- To make effective collisions.

QUESTION 1 (DBE NOV 2008)

1.1 The collision theory can be used to explain how different factors affect the rate of a chemical reaction.

1.1.1 Name TWO conditions that determine whether a collision between two molecules, A and B, will lead to a chemical

reaction.

(2)

1.1.2 In terms of the collision theory, explain why the rate of a chemical reaction increases with increasing temperature.

1.2 The reaction between nitrogen dioxide and carbon monoxide is represented below.

$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g) \qquad \Delta H = -226 \text{ kJ}$$

The activation energy for the reaction, Ea, is 132 kJ.

1.2.1 Sketch a potential energy versus reaction coordinate graph for this reaction.

Label the axes an indicate the following on your graph:

ΔH = -226 kJ

Ea = 132 kJ

(4)

1.2.2 Use a broken line on your graph to show the effect a catalyst would have on the potential energy as the reaction

proceeds.

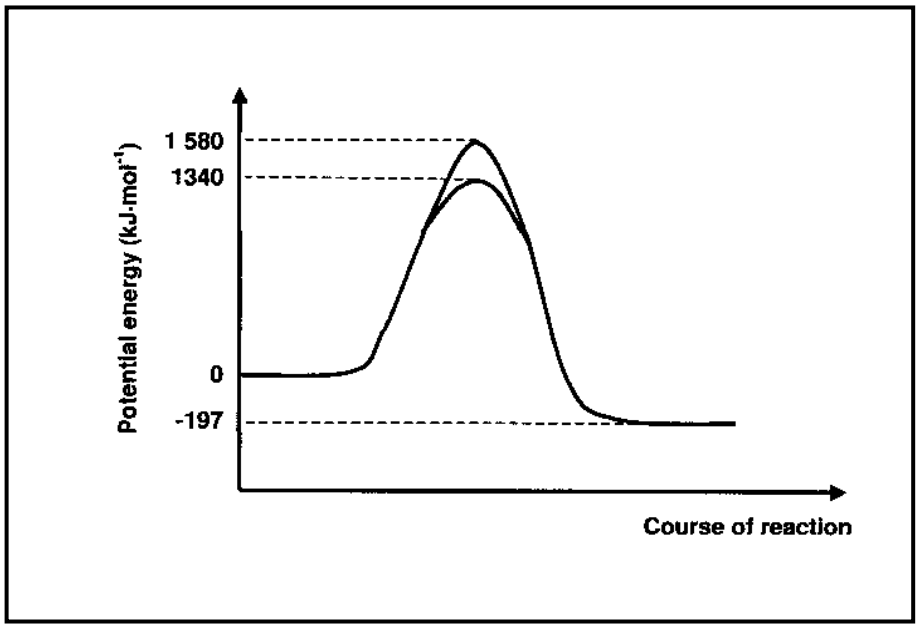
(1)

QUESTION 2(KZN JUNE 2012)

The contact process is used to prepare sulphuric acid in the high concentrations needed for industrial purposes. The heart of this process involves the oxidation of sulphur dioxide in the presence of a vanadium(V) oxide catalyst:

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

Consider the following graph (not drawn to scale) that represents the change in chemical potential energy for the above reaction:



Use the reaction and the graph, where applicable, to answer the questions that follow.

2.1 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Prove your answer by writing down the value of ΔH for this reaction. (2)

2.2 Write down the activation energy for the forward reaction in the absence of the vanadium(V) oxide catalyst. (1)

2.3 If we assume that 1580 $kJ \cdot mol^{-1}$ is involved to break the bonds in the $SO_2(g)$ and $O_2(g)$ molecules, how much energy is released when the new bonds in the $SO_3(g)$ molecules form?

(2)

2.4 Determine the activation energy for the reverse reaction in the presence of the vanadium(V) oxide catalyst.

(2)

2.5 In the contact process, the catalysed reaction reaches equilibrium in a

closed container. Chemical engineers devise ways to shift the above equilibrium to the right, so that a higher yield of $SO_3(g)$ can be obtained.

2.5.1 Describe the role that vanadium(V) oxide plays in this chemical reaction. (2)

2.5.2 What effect does the addition of vanadium(V) oxide have on the amount of $SO_3(g)$ at equilibrium? Only answer INCREASES, DECREASES or NO EFFECT (1)

QUESTION 3 (DBE NOV 2013)

A hydrogen peroxide solution dissociates slowly at room temperature according to the following equation:

$$2H_2O_2(aq) \rightarrow 2H_2O(\ell) + O_2(g)$$

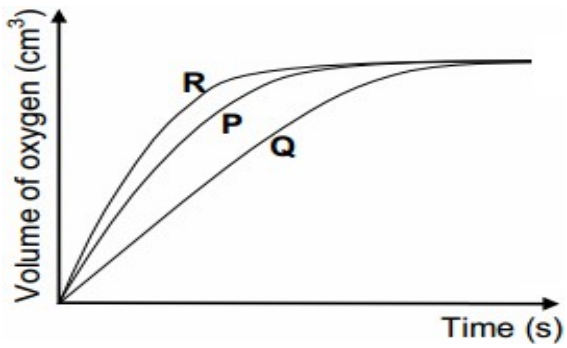
During an investigation, learners compare the effectiveness of three different catalysts on the rate of decomposition of hydrogen peroxide. They place EQUAL AMOUNTS of sufficient hydrogen peroxide into three separate containers. They then add EQUAL AMOUNTS of the three catalysts, **P**, **Q** and **R**, to the hydrogen peroxide in the three containers respectively and measure the rate at which oxygen gas is produced.

3.1 For this investigation, write down the:

3.1.1 Independent variable (1)

3.1.2 Dependent variable (1)

The results obtained are shown in the graph below.



3.2 Which catalyst is the most effective? Give a reason for the answer. (2)

3.3 Fully explain, by referring to the collision theory, how a catalyst increases the rate of a reaction. (3)

In another experiment, the learners obtain the following results for the decomposition of hydrogen peroxide:

TIME (s)	H_2O_2 CONCENTRATION ($mol \cdot dm^{-3}$)
0	0,0200
200	0,0160
400	0,0131
600	0,0106
800	0,0086

3.4 Calculate the AVERAGE rate of decomposition (in $mol.dm^{-3}.s^{-1}$) of $H_2O_2(aq)$ in the first 400s.
(3)

3.5 Will the rate of decomposition at 600s be GREATER THAN, LESS THAN or EQUAL TO the rate calculated in QUESTION 3.4?
Give a reason for the answer.
(2)

3.6 Calculate the mass of oxygen produced in the first 600s if 50 cm^3 of hydrogen peroxide decomposes in this time interval.
(5)

QUESTION 4(DBE FEB/MARCH 2012)

A group of learners use the reaction between zinc and sulphuric acid to investigate one of the factors that affects reaction rate. The equation below represents the reaction that takes place.

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

They add 6,5 g of zinc granules to excess DILUTE sulphuric acid and measure the mass of zinc used per unit time.

The learners then repeat the experiment using excess CONCENTRATED sulphuric acid.

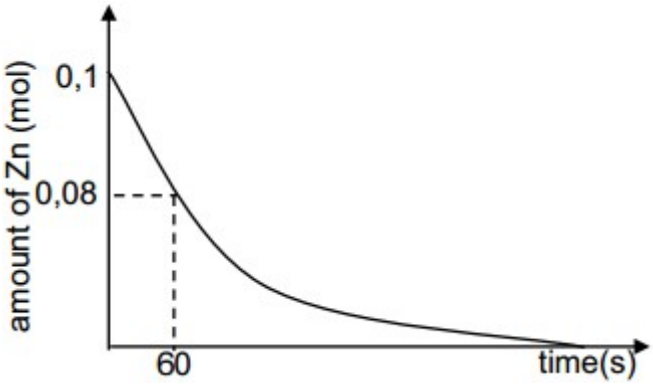
4.1 Define the term reaction rate.
(2)

4.2 Give a reason why the acid must be in excess.
(1)

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

4.4 Give a reason why the learners must use the same amount of ZINC GRANULES in both experiments.
(1)

The results obtained for the reaction using DILUTE sulphuric acid are represented in the graph below.



4.5 Using the graph, calculate the mass of zinc used from t = 0s to t = 60s. (4)

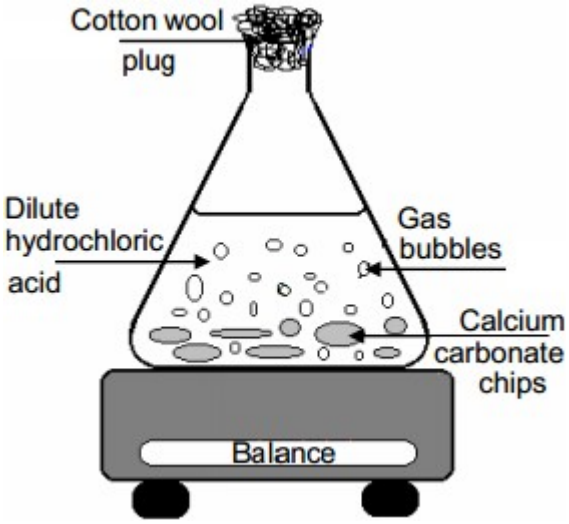
4.6 Calculate the average rate of the reaction (in gram per second) during the first 60s. (2)

4.7 Copy the above graph into your ANSWER BOOK. ON THE SAME SET OF AXES, use a dotted line to show the curve that will be obtained when concentrated sulphuric acid is used. Label that curve P (no numerical values are required). (2)

QUESTION 5 (DBE NOV 2012)

Calcium carbonate chips are added to an excess dilute hydrochloric acid solution in a flask placed on a balance as illustrated below. The cotton wool plug in the mouth of the flask prevents spillage of reactants and products, but simultaneously allows the formed gas to escape. The balance equation for the reaction that takes place is:

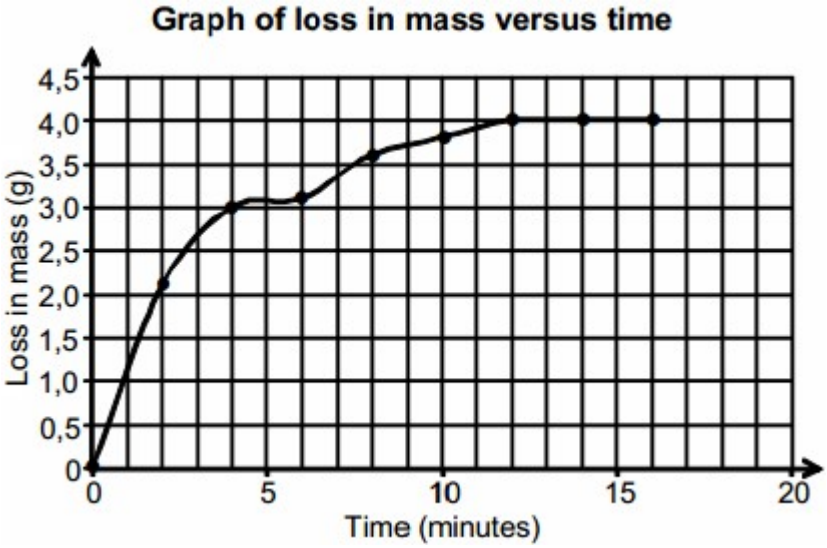
$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + CO_2(g) + H_2O(\ell)$$



5.1 Write down the NAME of the gas that escapes through the cotton wool plug while the reaction takes place. (1)

The loss in mass of the flask and its contents is recorded in intervals of 2 minutes. The results

obtained are shown in the graph below.



5.2 From the graph, write down the following:
5.2.1 The coordinates of the point that represents results that were measured incorrectly
(1)

5.2.2 How long (in minutes) the reaction lasts
(1)

5.2.3 How long (in minutes) it takes 75% (three quarters) of the reaction to occur
(1)

5.3 The experiment is now repeated using hydrochloric acid of a higher concentration. It is found that the rate of the reaction INCREASES. Use the collision theory to explain this observation.
(2)
5.4 How would a higher concentration of hydrochloric acid affect the following:
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

QUESTION 6 (KZN JUNE 2011)

There are many antacid tablets available on the market today to help relieve the

pain of indigestion, which is caused by an increase in the acidity level in the stomach.

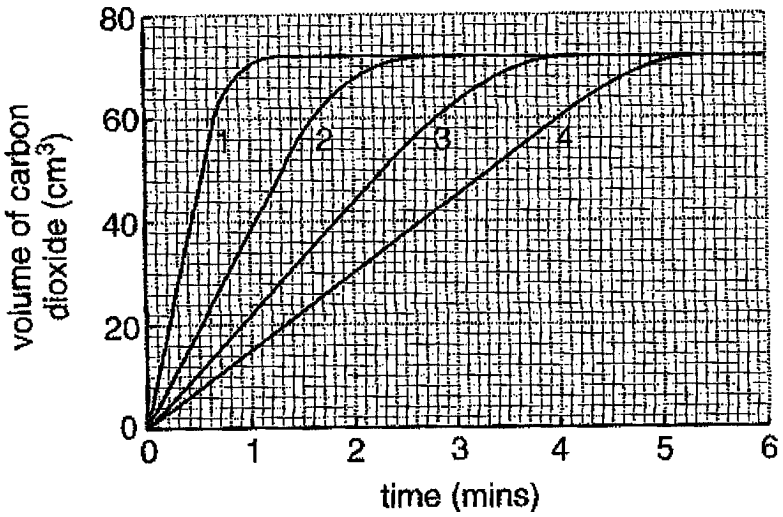
Pain relief relies on the neutralisation reaction between the antacid and the hydrochloric

acid in the stomach. The active ingredient in the antacid is carbonate ion which reacts

with the hydrochloric acid in the stomach according to the reaction:

$$CO_3^{2-}(aq) + 2HC\ell(aq) \rightleftharpoons 2C\ell^-_{(aq)} + H_2O_{(\ell)} + CO_{2(g).}$$

Shranda and Nichole investigated the reaction of a leading brand antacid. They used antacid in the form of small lumps of marbles. They conducted four experiments. In each experiment the temperature of the acid was changed each time. The rate at which this reaction takes place was studied by measuring the amount of carbon dioxide gas produced. The graphs below show the results of four experiments (1 to 4).



6.1 Give a possible hypothesis for this experiment.
(2)

6.2 What is the independent variable in this situation?
(1)

6.3 What is the dependent variable in this situation?
(1)

6.4 Give THREE controlled variables.
(3)

6.5 Apart from altering the temperature, suggest two ways in which the reaction of calcium carbonate and hydrochloric acid could be speeded up.
(2)

6.6 Which of the graphs 1 to 4, shows the results of the experiment in which the acid had the highest temperature? Explain fully.
(2)

6.7 Explain, using the collision theory, why the reaction rate changes during each

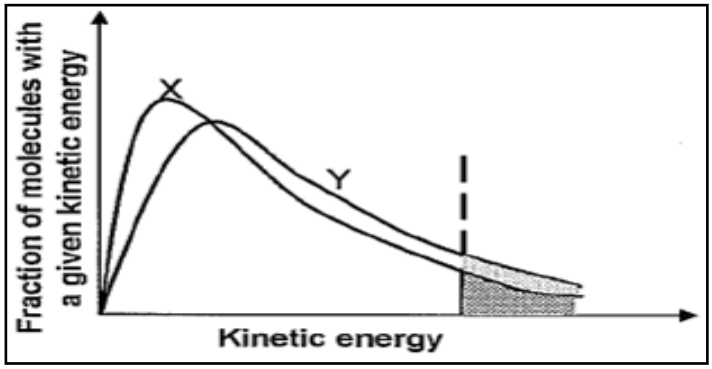
experiment.
(2)

QUESTION 7 (KZN JUNE 2013)

Kayla investigates a way to increase the rate at which hydrogen gas is produced in the reaction between zinc and hydrochloric acid.

7.1 By changing one reaction condition she obtains the graph below, in which:

- Curve X denotes the initial condition
- Curve Y denotes the changed condition that produced a higher reaction rate

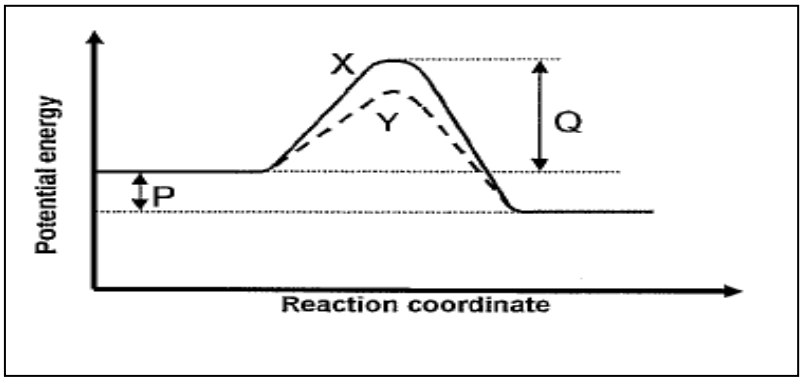


7.1.1 Which reaction condition did the learner change?
(1)

7.1.2 Apply the collision theory and explain why the changed condition results in a higher reaction rate.
(3)

7.2 Kayla then changes another condition in which the effect is represented by the graph below. Once again:

- Curve X denotes the initial condition
- Curve Y denotes the changed



7.2.1 Which reaction condition did the Kayla change?
(1)

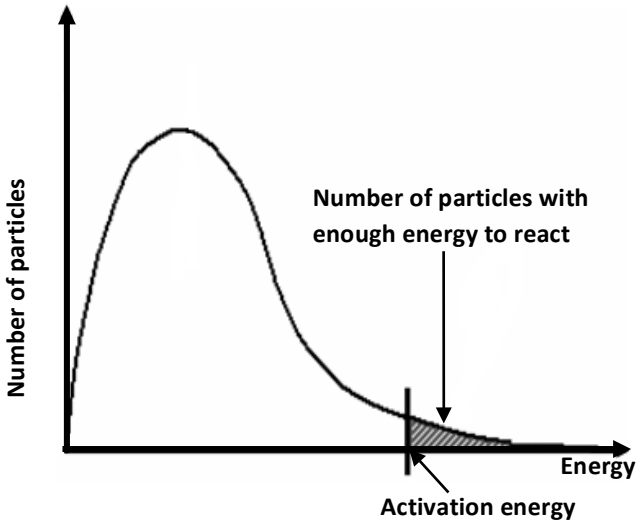
7.2.2 What is the name of the energy value denoted by the following:

(a) P
(1)

(b) Q
(1)

A catalyst speeds up the rate of a reaction. This behaviour of a catalyst can be explained in terms of the activation energy and the collision theory.

7.3 The diagram below shows the Maxwell-Boltzmann distribution curve for a certain reaction.



7.3.1 Explain in terms of the collision theory and activation energy, how a catalyst influences the rate of a reaction.
(4)

7.3.2 Redraw the above distribution curve into the answer book and show the new activation energy when a catalyst is added to the reaction mixture on the diagram.
(2)

QUESTION 8 (DBE FEB/MARCH 2011)

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

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

EXCESS HYDROCHLORIC ACID is used and the calcium carbonate is COMPLETELY COVEF investigations.

8.1 INVESTIGATION A:

The learners conduct two experiments using the conditions as shown in the table below.

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

8.1.1 Which factor influencing reaction rate is investigated?

8.1.2 Write down an INVESTIGATIVE QUESTION for this investigation.

8.1.3 The learners now repeat **Experiment 1**, but use 4 g of calcium carbonate in excess g. They find that the rate of the reaction INCREASES.

Give a reason why the rate increases.

8.2 INVESTIGATION B:

The learners conduct two experiments using the conditions as shown in the table below.

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

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

8.2.2 Write down a hypothesis for this investigation.

8.2.3 Is it fair to compare results obtained in **Experiment 3** with that in **Experiment** reason for the answer.

8.2.4 The reactions in **Experiments 3** and **4** both run to completion. How will the yie **Experiment 3** compare to that in **Experiment 4**? Write down only LARGER TH THAN or EQUAL TO and give a reason for the answer.

8.3 INVESTIGATION C:

The learners conduct two experiments using the conditions as shown in the table below.

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

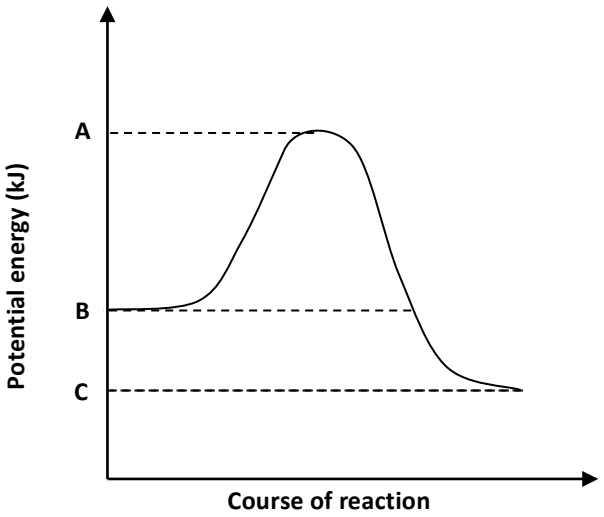
Experiment 6	4	powder	0,2	35

8.3.1 How does the average kinetic energy of the particles in the reaction in **Experi** compare to that in **Experiment 6**? Write down only HIGHER THAN, LOWER T EQUAL TO.

8.3.2 On the same set of axes, draw sketch graphs of the number of molecules vers kinetic energy (Maxwell-Boltzmann distribution curves) for each of **Experiment Experiment 6**.

- Label the axes.
- Clearly label each graph as **Experiment 5** or **Experiment 6**.

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



8.4.1 Is this reaction endothermic or exothermic? Give a reason for the answer.

8.4.2 Use the relevant energy values, **A**, **B** and **C**, to write down an expression for e following:

(a) The energy of the activated complex (1)

(b) ΔH for the forward reaction (1)

[20]

CHEMICAL EQUILIBRIUM

Definitions

Open system – reactants or products can escape from reaction vessel
(An open system continuously interacts with its environment)

Closed system – reactants or products can escape from reaction vessel
(A closed system is isolated from its surroundings)
Macroscopic changes – measurable or visible changes, eg. changes in colour,temperature, pressure, volume, concentration
Yield – the amount of product formed during a chemical reaction
Endothermic reaction – a reaction which absorbs more energy than is released
Exothermic reaction – a reaction which releases more energy than is absorbed
Reversible reaction – reaction that does not go to completion and occurs in both the the forward and reverse directions (products can be converted back to reactants)
Dynamic chemical equilibrium – the rate of the forward reaction equals the rate of reverse reaction and they occur simultaneously
Homogeneous equilibrium – all the substances in the system are in the same phase
Heterogeneous equilibrium – substances of different phases occur in the system
Equilibrium constant – ratio of the concentration of products to the concentration of reactants

FACTORS AFFECTING EQUILIBRIUM

- concentration
- temperature
- pressure (in the case of gases)

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

NB: *Adding a catalyst has NO EFFECT on the equilibrium position, a catalyst only increases the rate of both the forward and the reverse reactions equally.
*If a catalyst is added initially, then the equilibrium position is reached much quicker.
*The addition of an inert gas does not alter the equilibrium position.

Examples:

1. Equilibrium mixtures of solutions (**temperature and concentration** play a role)

Equation: $CoC\ell_4^{2-}(aq) + 6H_2O \rightleftharpoons Co(H_2O)_6^{2+} + 4C\ell^-$ $\quad \Delta H < 0$

Disturbance	Effect on equilibrium	Colour change
1. Temperature		
○ increase	○ favours endothermic (reverse) reaction	○ turns blue
○ decrease	○ favours exothermic (forward) reaction	○ turns pink

2. Concentration		
○ $[H_2O]$ is increased by adding H_2O	○ favours forward reaction (which uses up water)	○ turns pink
○ $[C\ell]$ is increased by adding $HC\ell/NaC\ell$ (with common $C\ell^-$ ion)	○ favours reverse reaction (which will decrease $C\ell^-$)	○ turns blue
○ $[C\ell^-]$ is decreased by adding Ag^+ ($Ag^+ + C\ell^- \rightarrow AgC\ell_{(s)}$)	○ favours forward reaction (which produces more $C\ell^-$)	○ turns pink
○ $[H_2O]$ is decreased by adding a dehydrating agent, eg. H_2SO_4	○ favours reverse reaction (which will decrease $C\ell^-$)	○ turns blue

2. Gasesous equilibrium mixtures (**temperature and pressure** play a role)

Equation: $NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H < 0$

	Disturbance	Effect on equilibrium	Colour change
1. Temperature	○ increase	○ favours endothermic (reverse) reaction	○ colourless to brown
	○ decrease	○ favours exothermic (forward) reaction	○ brown to colourless
2. Pressure	○ increase	○ favours forward reaction (less moles of gas molecules)	○ brown to colourless
	○ decrease	○ favours reverse reaction (more moles of gas molecules)	○ colourless to brown

THE EQUILIBRIUM CONSTANT

It indicates the relationship between the product and reactant concentrations at equilibrium, and is a constant at a specific temperature.

Important:

- The K_c value indicates to what extend reactants have changed into products by the time equilibrium is reached.
- This is of particular importance in the evaluation of the efficiency of industrial processes:
  - ✓ A high K_c value ($K_c > 1$) indicates that a lot product has been formed (the equilibrium lies to the right)
  - ✓ A low K_c value ($K_c < 1$) indicates that more reactants than products are present (the equilibrium lies to the left)
  - ✓ $K_c = 1$ indicates equal concentrations of reactants and products
- It is a number only, without units
- The K_c value changes ONLY if the TEMPERATURE changes
- The K_c value is only calculated using the concentrations of the gases and the aqueous substances in the equation, because these concentrations remain constant

Calculating the equilibrium constant

- Set up a table
- Use the balanced equation to determine the mole ratio of the substances in the equation
- Fill in all the information given in the question in the block where the information belongs
- Calculate whatever you can in the table, keeping in mind that the mole ratio ONLY applies in the 'used/formed' row of the table
- Once the number of moles at equilibrium is known, the concentration at equilibrium can then be calculated
- Once the concentration of each substance at equilibrium has been filled in, the equilibrium constant can then be calculated

Examples

1. 1 mol of A and 2 mol of B react in a 2 dm^3 container. If at equilibrium 0,75 mol of C has formed, calculate the value of K_c.

Solution

A (g) + 2B (g) ⇌ C (g)

Mole ratio	1	2	1
Start	1 mol	2 mol	0 mol
Used/Formed	n = 0,75 mol	n = 2 x 0,75 = 1,5 mol	n = 0,75 mol
Equilibrium	n = 1 – 0,75 = 0,25 mol	n = 2 – 0,75 = 1,5 mol	n = 0,75 mol
Concentration	c = n/V = 0,25/2 = 0,125 $mol.dm^{-3}$	c = n/V = 0,5/2 = 0,25 $mol.dm^{-3}$	c = n/V = 0,75/2 = 0,375 $mol.dm^{-3}$

Table “cleaned up

A (g) + 2B (g) ⇌ C (g)

Mole ratio	1	2	1
Start	1	2	0
Used/Formed	- 0,75	- 1,5	+ 0,75
Equilibrium	0,25	1,5	0,75
Concentration	0,125	0,25	0,375

$K_c = [C]/[A][B]^2 = (0,375)/(0,125)(0,25)^2 = 48$

2. 0,5 mol H_2 and 0,5 mol O_2 are placed in a container and allowed to react according to the chemical reaction below. At equilibrium, 9,6 g O_2 remains. Calculate the value of K_c if the volume of the container is 200 cm^3.

Solution

$2H_2$ (g) + O_2 (g) ⇌ $2H_2O$ (g)

Mole ratio	2	1	2
Start	0,5 mol	0,5 mol	0 mol
Used/Formed	n = 0,2 x 2 = 0,4 mol	n = 0,5 – 0,3 = 0,2 mol	n = 0,4 mol
Equilibrium	n = 0,5 – 0,4 = 0,1 mol	n = m/M = 9,6/32 = 0,3 mol	0,4 mol
Concentration	c = n/V = 0,1/0,2 = 0,5 $mol.dm^{-3}$	c = n/V = 0,3/0,2 = 1,5 $mol.dm^{-3}$	c = n/V = 0,4/0,2 = 2 $mol.dm^{-3}$

$2H_2$ (g) + O_2 (g) ⇌ $2H_2O$ (g)

Mole ratio	2	1	2
Start	0,5	0,5	0
Used/Formed	-0,4	-0,2	+0,4
Equilibrium	0,1	0,3	0,4
Concentration	0,5	1,5	2

$K_c = [H_2O]/[H_2][O_2] = (2)^2/(0,5)^2(1,5) = 10,67$

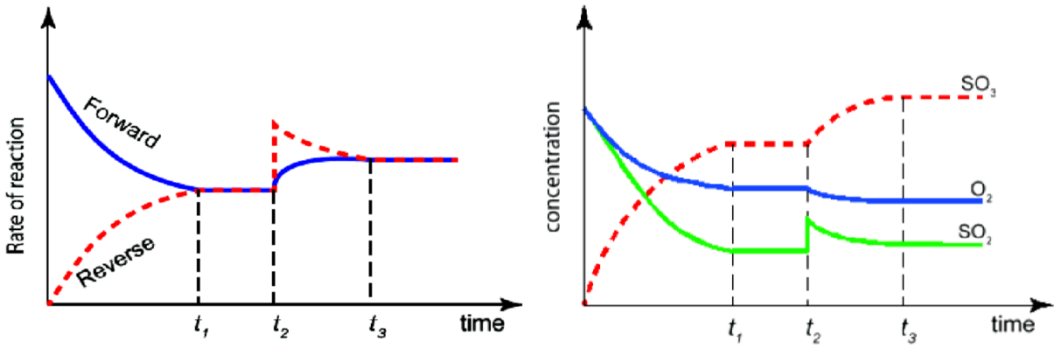
Graphs for Equilibrium

Changing the concentration of reactants or products

Increasing concentration of a reactant will speed up the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. Forward reaction will be favoured to re-establish the equilibrium.

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

At time t_2 , the concentration of SO_2 is increased.

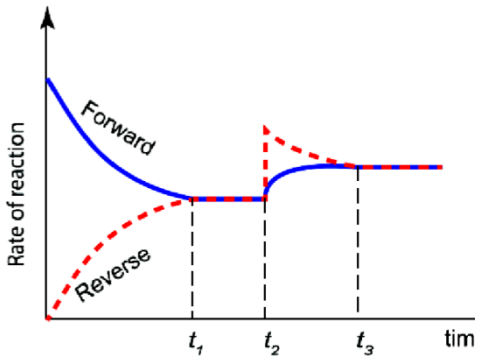


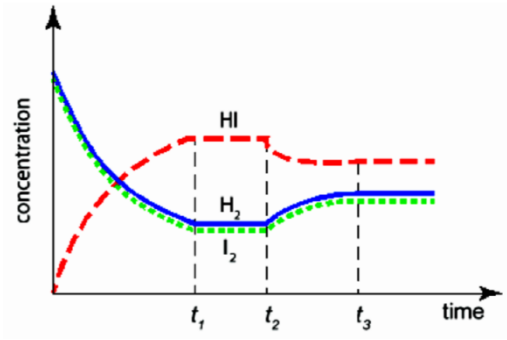
Changing the temperature

Increasing temperature increases the rates of both reactions but the rate of the endothermic reaction increases more than the rate of the exothermic reaction. An increase in a temperature will favour the endothermic reaction to re-establish of a reactant will speed up the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. The forward reaction will be favoured to re-establish the new equilibrium.

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

At time t_2 , the temperature of the container is increased.





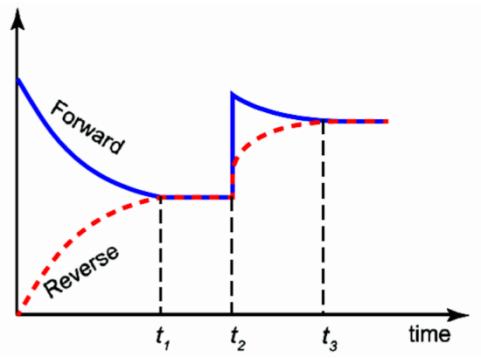
Changing the pressure

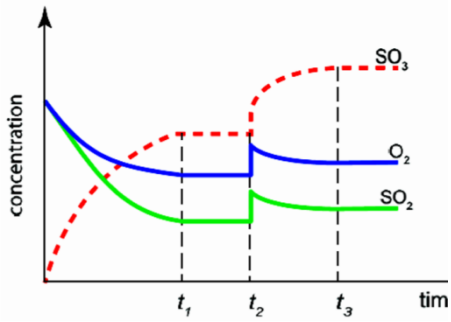
Changing the volume of the gases will change the pressure in system. **But this change will also change the concentration of both reactants and products.**

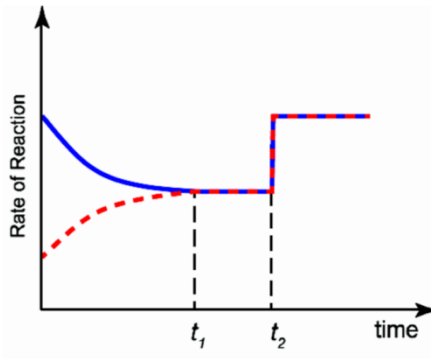
If the pressure is increased by decreasing the volume of the container, concentration of both reactants and products are increased. The reaction with the fewer mole sides will be favoured to re-establish the new equilibrium. Pressure is only for gases.

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

In this example when the pressure is increased, the rates of both reactions will increase but forward reaction will increase more than the reverse reaction.







Use of a catalyst

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

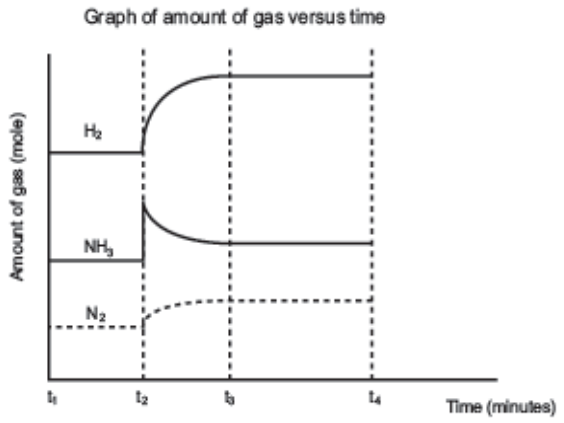
Activities

QUESTION 1

1.1 The following equation represents a reversible reaction that has reached equilibrium at 470°C in a closed container:

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

A change was then made to the system at t_2 . A graph showing the effect of this change is drawn below.
(The graph is not drawn to scale.)



1.1.1 What is implied by the horizontal lines between t_1 and t_2? (1)

1.1.2 State the change that was made to the system at time t_2. (1)

1.1.3 Using Le Chatelier's principle explain why the concentrations of H_2 and N_2 gases changed as shown in the graph at t_2. (3)

1,5 mol of $N_2(g)$ and 2 mol $H_2(g)$ were injected into a 0,5 dm^3 closed reaction vessel and allowed to reach equilibrium at 470°C. When equilibrium was reached it was found that 1 mol of $NH_3(g)$ was present.

1.1.4 Calculate the equilibrium constant (Kc) at 470°C.
Show ALL your calculations. (8)

1.1.5 The temperature is now increased to 800°C.

a) How will the value of Kc be affected if the temperature is increased to 800°C?
Write down only INCREASES or DECREASES or REMAINS THE SAME. (1)

b) Explain, with reference to Le Chatelier's principle, your answer to

question 1.1.5a). (5)

1.2 A rigid container holds a mixture of graphite pellets,water vapour, carbon monoxide and hydrogen gas at equilibrium.

$$C(s)\ H_2O(g) \rightleftharpoons CO(g)\ H_2\ (g) \qquad \Delta H = +131\ kJ$$

State whether the number of moles of CO(g) in the container will **increase, decrease, or remain the same** after each of the following disturbances is applied to the original mixture. For each case, assume that all other variables remain constant except for the given disturbance.

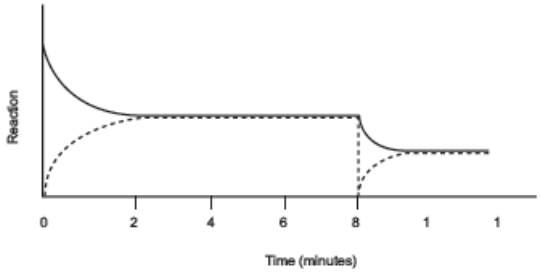
1.2.1 The volume of the container is decreased at constant temperature. (2)
1.2.2 The graphite pellets are pulverized (crushed). (2)

QUESTION 2

The gas XA_3 is introduced into an empty flask which is then sealed. The XA_3 gas decomposes and sets up equilibrium at
300ºC, as represented by the following balanced chemical equation.

$$2XA_3\ (g) \rightleftharpoons 2XA_2\ (g) + A_2\ (g)$$

The graph below shows the change in reaction rate over 12 minutes:



2.1 Write down the balanced equation which is represented by the broken line. (2)
2.2 After 8 minutes the pressure is decreased.

2.2.1 State *Le Chatelier's Principle.* (2)
2.2.2 Apply Le Chatelier's principle to the reaction in order to EXPLAIN the changes shown on the graph between 8 and 10 minutes. (3)

2.3 Write down an expression for the equilibrium constant (K_c) for this reaction. (2)
2.4 Initially 5 mol of $XA_3(g)$ was sealed in a 2 dm^3 flask. At equilibrium the reaction mixture contained exactly 1,5 mol of $A_2(g)$ at 300ºC. Calculate the value of the equilibrium

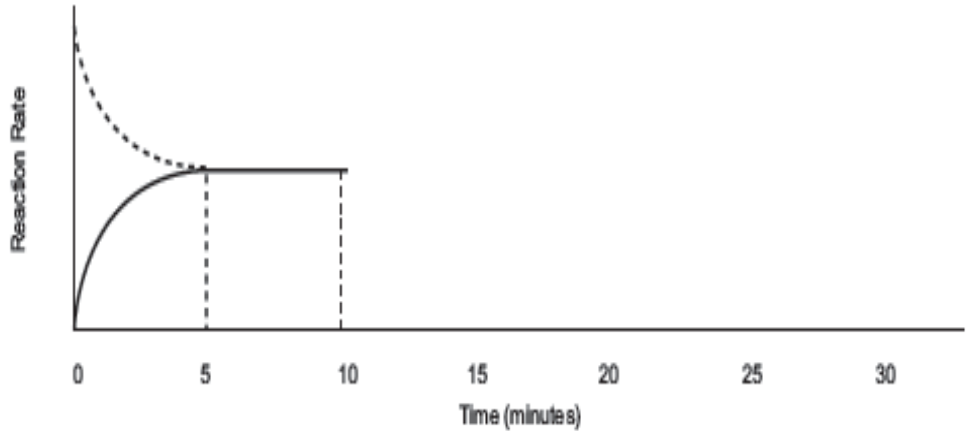
constant (K_c) at this temperature. (6)

QUESTION 3

Nitrogen monoxide is an atmospheric pollutant, formed inside car engines by the reaction between nitrogen and oxygen:

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H = + 66kJ.mol^{-1}$$

Consider the graph below of reaction rate versus time for the reaction shown above.
4 mol of NO were added to a 0,5 dm^3 container and sealed at 25ºC. The equilibrium constant for this reaction at 25ºC is $4,8 \times 10^{-4}$.



3.1 Which reaction (forward or reverse) is represented by the solid line? Give a reason for your answer. (2)

3.2 What does the magnitude of the equilibrium constant indicate for this reaction? (2)

3.3 At what time did the system reach equilibrium? (1)

3.4 How will the value of the equilibrium constant at 8 minutes compare with its value at 17 minutes? Write down only *greater than, less than or equal to.* (2)

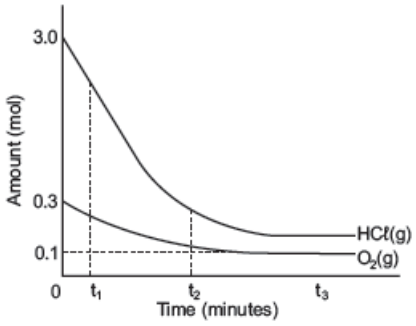
3.5 Explain, with reference to the rates of the forward and reverse reactions, how the yield of NO would be affected by a decrease in temperature. (4)

3.6 Write the expression for the equilibrium constant for this reaction. (2)
3.7 Calculate the concentration of N_2 at 6 minutes. (5)

QUESTION 4

The reaction between hydrogen chloride and oxygen reaches equilibrium in a closed container according to the following balanced equation:

$$4HC\ell(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2C\ell_2(g) \qquad \Delta H = -113kJ$$



4.1 The graph above, not drawn to scale, shows how the amounts of reactants present in the container change with time at a

specific temperature. The volume of the container is 5 dm^3.

4.1.1 How does the rate of the forward reaction at time t_1 compare to that at time t_2? Write down GREATER THAN, SMALLER THAN or EQUAL TO. Use the graphs to give a reason for the answer. (2)
4.1.2 How does the rate of the forward and the reverse reactions compare at time t_3? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)
4.1.3 Calculate the number of moles of $HC\ell$ at equilibrium. (4)
4.1.4 Calculate the number of moles of H_2O and Cl_2 at equilibrium. (3)
4.1.5 Write down an expression for the equilibrium constant (K_c) for this reaction. (4)
4.1.6 Calculate the equilibrium constant (K_c) for this reaction at this temperature. (5)

4.2 The temperature is NOW increased. How will this change affect the value of the equilibrium constant? Write down INCREASES, DECREASES or REMAINS THE SAME. Explain your answer. (4)

4.3 How will each of the following changes affect the equilibrium concentration of $C\ell_2$ (g) ? Write down INCREASES, DECREASES or REMAINS THE SAME.

4.3.1 Water vapour is added into the container. (2)

4.3.2 A catalyst is added. (2)
4.3.3 The volume of the container is increased. (2)

QUESTION 5

7 moles of nitrogen gas (N_2) and 2 moles of oxygen gas (O_2) are placed in an empty container of volume 2 dm^3 . The container is sealed and the following equilibrium is established:

$$N_2\,(g) + O_2\,(g) \rightleftharpoons 2NO(g)$$

The K_c value for this reaction at 25ºC is $4{,}8 \times 10^{-31}$.

5.1 What information does this value of K_c indicate with regards to the amount of NO(g) in the equilibrium mixture at 25ºC? (2)

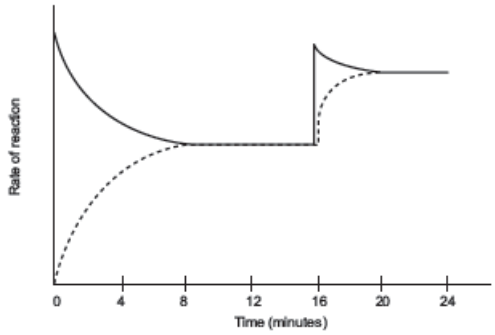
The container is heated and the system reaches a new equilibrium at 2 500ºC. At this temperature it is found that there are 0,4 moles of NO(g) present.

5.2 How much N_2 reacted? (1)
5.3 How much O_2 is there at equilibrium? (1)
5.4 Determine the concentration of NO at equilibrium. (3)
5.5 Determine the K_c value at this temperature. (4)
5.6 Making use of Le Chatelier's principle, explain why the forward reaction is endothermic. (4)

QUESTION 6

Exactly 12,0 mol SO_3 (g) is sealed in an empty 2,0 dm^3 container.The following reaction reaches equilibrium at 700 K after 8 minutes.

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



The temperature is increased to 800 K at the 16th minute.The graph below shows the changes in the rate of the reaction over 24 minutes from the time that the 12,0 mol of SO_3 was introduced into the container.

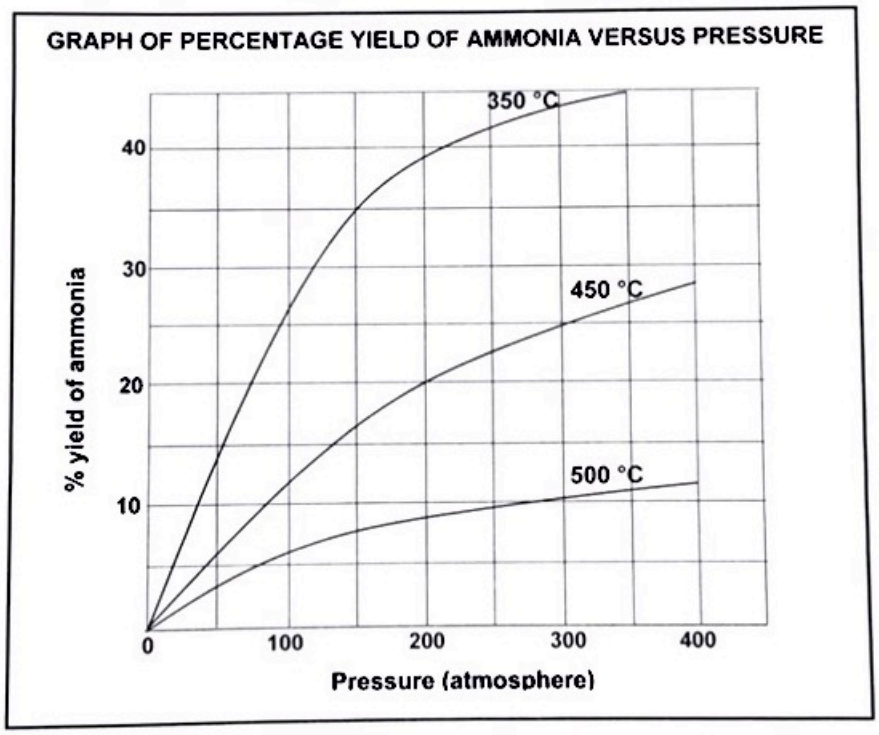
6.1 Write down the balanced equation for the reaction that is represented by the broken line.(2)
6.2 What is the reason for the decrease in the reaction rate represented by the solid line between t = 0 minutes and t = 8 minutes? (2)
6.3 Explain how we can determine that the value of K_c at the 24th minute is than larger the value of K_c at the 12th minute?
(2)
6.4 What does the horizontal part of the graph between the 20th minute and the 24th minute indicate about the reaction?
(1)
6.5 Extend the graph on the answer sheet if the volume of the container is increased slightly after 24 minutes.
(2)

QUESTION 7

The balanced equation below represents the reaction used in the Haber process to produce ammonia.

$$N_2(g) + 3H_2(g) \quad 2NH_2(g) \qquad \Delta H < 0$$

In industry the product is removed as quickly as it forms.
7.1 Write down the meaning of the double arrow used in the equation above. (1)
7.2 Give ONE reason why ammonia is removed from the reaction vessel as quickly as it forms. (1)
The graph below shows the percentage yield of ammonia at different temperatures and pressures.



7.3 Write down the percentage yield of ammonia at a temperature of 450°C and a pressure of 200 atmospheres. (1)

7.4 Refer to Le Chatelier's principle to explain EACH of the following deductions made from the graph:

7.4.1 For a given pressure, the yield of ammonia at 500°C is much lower than that at 350°C. (3)

7.4.2 For a given temperature, the yield of ammonia at 350 atmospheres is much lower than that at 150 atmospheres. (2)

7.5 A technician prepares $NH_3(g)$ by reacting 6 moles of $H_2(g)$ and 6 moles of (g).

7.5.1 Calculate the maximum number of moles of $NH_3(g)$ that can be obtained in this reaction. (2)

7.5.2 The above reaction now takes place in a 500 cm^3 container at a temperature of 350°C and a pressure of 150 atmospheres. The system is allowed to reach equilibrium.

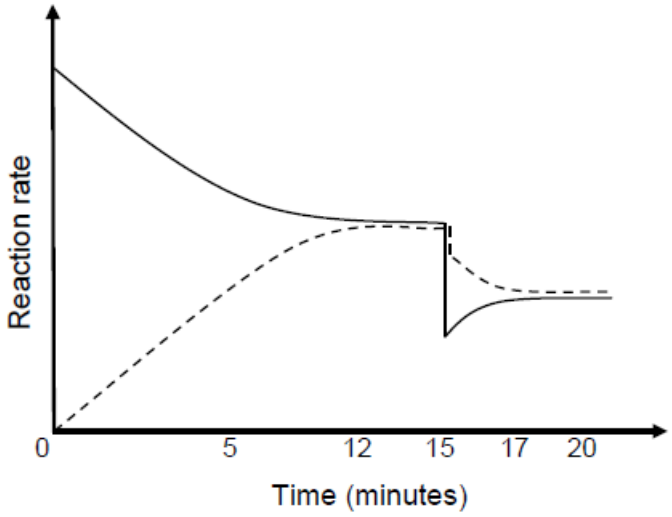
Use the graph above and calculate the equilibrium constant, K_c, for this reaction under these conditions.(7)

QUESTION 8

Pure hydrogen iodide, sealed in a 2 dm^3 container at 721 K, decomposes according to the following balanced equation:

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \qquad \Delta H = + 26\ kJ \cdot mol^{-1}$$

The graph below shows how reaction rate changes with time for this reversible reaction.



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

8.2 How does the concentration of the reactant change between the 12th and the 15th minute? Write down only INCREASES, DECREASES or NO CHANGE. (1)

8.3 The rates of both the forward and the reverse reactions suddenly change at t = 15 minutes.

8.3.1 Give a reason for the sudden change in reaction rate. (1)

8.3.2 Fully explain how you arrived at the answer to QUESTION 8.3.1. (3)

The equilibrium constant (K_c) for the forward reaction is 0,02 at 721 K.

8.4 At equilibrium it is found that 0,04 mol HI(g) is present in the container. Calculate the concentration of H_2(g) at equilibrium.

(6)

8.5 Calculate the equilibrium constant for the reverse reaction. (1)

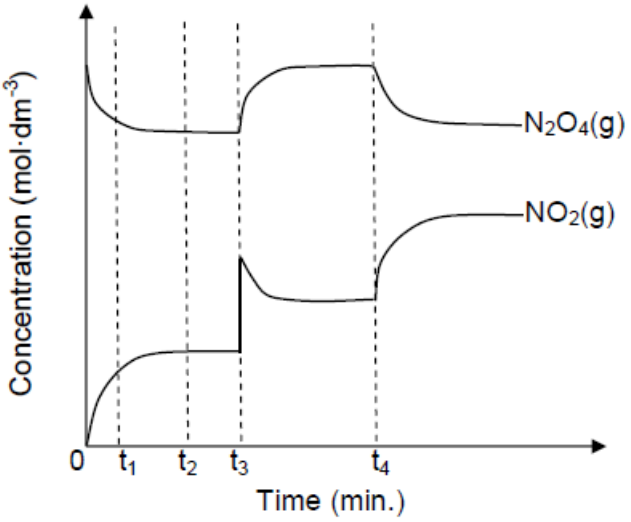
8.6 The temperature is now increased to 800 K. How will the value of the equilibrium constant (K_c) for the forward reaction change? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

QUESTION 9

A sample of N_2O_4 gas is sealed in a container and heated. The N_2O_4 gas decomposes to NO_2 gas and the reactionreaches equilibrium according to the following balanced equation:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H > 0$$

The graph below shows how the concentrations of the two gases change as a result of changes made to the reaction conditions.



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

9.2 How does the rate of the forward reaction compare to that of the reverse reaction at each of the following times? Only write down HIGHER THAN, LOWER THAN or EQUAL TO.

9.2.1 t_1 (1)

9.2.2 t_2 (1)

9.3 What change was made to the reaction conditions at each of the following times? In both instances, the equilibrium constant for the reaction did not change.

9.3.1 t_3 (1)

9.3.2 t_4 (1)

9.4 How will an increase in temperature influence the yield of $NO_2(g)$?

Write down INCREASES, DECREASES or REMAINS THE SAME. Use Le Chatelier's principle to explain the answer.

(3)

9.5 Initially 0,92 mol N_2O_4 gas is sealed in a 2 dm^3 container and heated to 100 °C. At equilibrium it is found that 20,7% of the N_2O_4 gas has decomposed to NO_2 gas. Calculate the equilibrium constant (K_c) for this reaction at 100 °C. (7)

ACIDS AND BASES

Acid	(**Arrhenius theory**): is a substance that produces hydrogen ions (H^+) / hydronium ions (H_3O^+) when it dissolves in water (**Brønsted-Lowry theory**): is a proton (H^+ ion) donor.
Strong acid	Ionises completely in water to form a high concentration of H_3O^+ ions. Examples of strong acids are hydrochloric acid ($HC\ell$), sulphuric acid (H_2SO_4) and nitric acid (HNO_3).
Weak acid	Ionises incompletely in water to form a low concentration of H_3O^+ ions. Examples of weak acids are ethanoic acid (CH_3COOH) and oxalic acid $(COOH)_2$.
Concentrated acid	Concentrated acids contain a large amount (number of moles) of acid in proportion to the volume of water.
Diluted acid	Dilute acids contain a small amount (number of moles) of acid in proportion to the volume of water.
Base	(**Arrhenius theory**): is a substance that produces hydroxide ions (OH^-) when it dissolves in water. (**Brønsted-Lowry theory**): is a proton (H^+ ion) acceptor.
Strong base	Dissociates (breaks up) completely in water to form a high concentration of OH^- ions. Examples of strong bases are sodium hydroxide (NaOH) and potassium hydroxide (KOH).
Weak base	Dissociates/ionises incompletely in water to form a low concentration of OH^- ions. Examples of weak bases are ammonia (NH_3), calcium carbonate ($CaCO_3$), potassium carbonate (K_2CO_3) , and sodium hydrogen carbonate ($NaHCO_3$).
Concentrated base	Concentrated bases contain a large amount (number of moles) of base in proportion to the volume of water.
Diluted base	Dilute bases contain a small amount (number of moles) of base in proportion to the volume of water.
Equivalence point	is the point at which the acid / base has completely reacted with the base/acid.
End point	is the point where the indicator changes colour.
Ionisation	a process that takes place when a covalent compound reacts with water to form new ions OR Breaking up of a molecule into charged components (ions). In acid-base reactions this usually means dissolving in water.

1. Properties of acids and bases

	ACIDS	BASES
PROPERTIES	• Have a sour taste; • Influence the colour of indictors; • Are electrolytes in solution; • Increase the H^+-ion concentration in a solution; • Decrease the OH^--ion concentration in a solution; • Decrease the pH of a solution.	• Have a bitter taste and feel soapy; • Influence the colour of indictors; • Are electrolytes in solution; • Decrease the H^+-ion (or H_3O^+-ion) concentration in a solution; • Increase the OH^--ion concentration in a solution; • Increase the pH of a solution.

ACID-BASE THEORIES	ARRHENIUS	
	• An acid releases H^+/ H_3O^+ -ions/ in aqueous solutions. • $HC\ell \rightarrow H^+ + C\ell^-$ • $HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$	• A base releases OH^- -ions in aqueous solutions. • $NaOH \rightarrow Na^+ + OH^-$
	BRØNSTED-LOWRY	
	• An acid is a **proton donor**. • $HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$ • $NH_4^+ + H_2O \rightarrow H_3O^+ + NH_3$	• A base is a **proton acceptor**. • $OH^- + H^+ \rightarrow H_2O$ • $NH_3 + H_2O \rightarrow OH^- + NH_4^+$
REACTIONS WITH WATER	• **Ionise** in water to produce hydronium ions E.g. $HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$	• Ionic bases like NaOH **dissociate** in water to form hydroxyl ions. $NaOH(s) \rightarrow Na^+(aq) + C\ell^-(aq)$ • Ammonia (NH_3) ionises in water to form hydroxyl ions $NH_3 + H_2O \rightarrow OH^- + NH_4^+$

Activity 1

1. An Arrhenius acid is a substance that

A. Accept a proton B. Donates a proton

C. Produces H^+ in an aqueous solution D. Produces OH^- in an aqueous solution (2)

2. Which of the following is an example of the strong base

A. $CaCO_3$ B. KOH

C. K_2CO D. $NaHCO_3$ (2)

3. An aqueous solution that contains more hydronium ions than hydroxyl ions is a(an)

A. Acidic solution B. Neutral solution

C. Basic solution D. Standardised solution (2)

4. A solution that has a large amount of dissolved substances in proportion to the volume of water

A. Strong solution B. Weak solution

C. Concentrated solution D. Diluted solution (2)

Activity 2

1. Which of the following is the property of an acid

A. Decreases H_3O^+ ion concentration in solution

B. Decreases OH^- ion concentration in solution

C. Increases OH^- ion concentration in solution

D. Increases the pH of a solution (2)

2. Common acids

	ACID	FORMULA	STRONG / WEAK		EXAMPLES & USES
STRONGEST INCREASING STRENGTH WEAKEST	Hydrochloric acid	$HC\ell$	Strong	Ionises almost completely in water	• Stomach acid (to digest food) Used • in swimming pools to control the pH (acidity) of the water; • to clean metals for soldering.
	Sulphuric acid	H_2SO_4	Strong		Used • to produce fertilisers; • to produce phosphoric acid; • as dehydrating agent; • as car battery acid and • in gold extraction.
	Nitric acid	HNO_3	Strong		Used • to produce fertilisers and • to produce explosives.
	Oxalic acid	$(COOH)_2$	Weak	Ionises partially in water	Used • to remove rust and stains and • as bleach.
	Phosphoric acid	H_3PO_4	Weak		Used • to add taste to gaseous cold drinks; • in dental cement and • to produce fertilisers like superphosphates.
	Ethanoic acid	CH_3COOH	Weak		Vinegar • Used • to flavour food; • to produce plastics; • to neutralise hair relaxers and • to treat jellyfish stings.
	Carbonic acid	H_2CO_3	Weak		Used • to make gaseous cold drinks.

- Strong acid : $HC\ell$; H_2SO_4; HNO_3
- Weak acid : CH_3COOH; $(COOH)_2$
- Strong base : NaOH; KOH; $Mg(OH)_2$
- Weak base : NH_3; $NaHCO_3$; $CaCO_3$

3. Common bases

STRONGEST

INCREASING STRENGTH

WEAKEST

BASE	FORMULA	STRONG / WEAK		EXAMPLES & USES
Sodium hydroxide (Caustic soda)	NaOH	Strong	Dissociates completely in water	Used • in the production of soap and • as drain cleaner and • to relax the curl in human hair.
Potassium hydroxide (Caustic potash)	KOH	Strong		Used • in the production of soap; • in the production of biodiesels and • as electrolytes in cells.
Magnesium hydroxide	$Mg(OH)_2$	Strong		Used • in antacids (Milk of Magnesia); • in laxatives and • to neutralise acidic waste water.
Calcium hydroxide (Slaked lime)	$Ca(OH)_2$	Strong		Used • to clarify water by removing particles from the water; • to neutralise acidic water so that water pipes are not damaged and • to neutralise acidic soil.
Sodium carbonate (Washing soda)	Na_2CO_3	Weak	Dissociates / Ionises partially in water	Used • to manufacture glass and • to soften water or laundry.
Calcium carbonate (Limestone)	$CaCO_3$	Weak		Found in marble and sea shells. Used • in the production of cement; • in chalk to write with; • as an antacid.
Ammonia	NH_3	Weak		Used • to produce nitric acid; • to produce fertilizers and • in cleaning materials.
Sodium bicarbonate (Baking soda)	$NaHCO_3$	Weak		Used • in baking to let dough rise

4. Mono - and polyprotic acids

Acids can be classified according to the number of protons (H^+) that they can donate.

NB: **Monoprotic** acids have only one proton (H^+) to donate.

Polyprotic acids can donate two or three protons.

The protons are donated in steps as shown in the examples in the table below.

Monoprotic acids Can only donate only one proton (H^+)	Polyprotic acids Can donate more than one proton (H^+)	
	Diprotic acids	Triprotic acids
	Can donate 2 protons (H^+).	Can donate 3 protons (H+).
$HC\ell$, HNO_3, CH_3COOH	H_2SO_4, H_2CO_3	H_3PO_4
E.g. $HC\ell \rightarrow H^+ + C\ell^-$	E.g. $H_2SO_4 \rightarrow H^+ + HSO_4^-$ $HSO_4^- \rightarrow H^+ + SO_4^{2-}$	E.g. $H_3PO_4 \rightarrow H^+ + H_2PO_4^-$ $H_2PO_4^- \rightarrow H^+ + HPO_4^{2-}$ $HPO_4^{2-} \rightarrow H^+ + PO_4^{3-}$

5. Conjugate acid-base pairs

5.1 Acid-base reactions

HINT!

- "Conjugate" is from Latin, it means literally "yoked together" or to be a couple.
- Acid-base reactions take place simultaneously. The acid donates a proton to the base, while the base accepts the proton from the acid.

5.2 Conjugate acids and bases

CONJUGATE ACIDS
• When an acid donates a proton (H^+), a conjugate base is produced. • The acid and its conjugate base are called a conjugate acid-base pair.
acid $\rightleftharpoons$ H^+ + *conjugate base*
Examples: $HC\ell \rightleftharpoons H^+ + C\ell^-$ acid — *conjugate base* $H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$ acid — *conjugate base*

CONJUGATE BASES
• When a base receives a proton (H^+), a *conjugate acid* is produced. • The base and its conjugate acid are called a conjugate acid-base pair.
base + H^+ $\rightleftharpoons$ ***conjugate acid***
Examples: $OH^- + H^+ \rightleftharpoons H_2O$ base — *conjugate acid* $HSO_4^- + H^+ \rightleftharpoons H_2SO_4$ base — *conjugate acid*

Activity 3

1. In the reaction: $H_2SO_{4(aq)} + H_2O_{(\ell)} \leftrightarrow HSO_4^-{}_{(aq)} + H_3O^+_{(aq),}$ the Brønsted-Lowry bases are:

A H_2O and H_3O^+

B H_2SO_4 and H_3O^+

C HSO_4^- and H_3O^+

D H_2O and HSO_4^- (2)

Steps to follow when identifying conjugates

1. Find the **acid** on the **left hand side** of the arrow. Label it $acid_1$.
2. Find the **conjugate base** of this acid on the **right hand side** of the arrow. Label it $base_1$.
3. Draw a **bracket** to show that these two form an **acid-base conjugate pair**.
4. Find the **base** on the **left hand side** of the arrow. Label it $base_2$.
5. Find the **conjugate acid** of this base on the **right hand side** of the arrow. Label it $acid_2$.
6. Draw a b**racket** to show that these two form an **acid-base conjugate pair**.

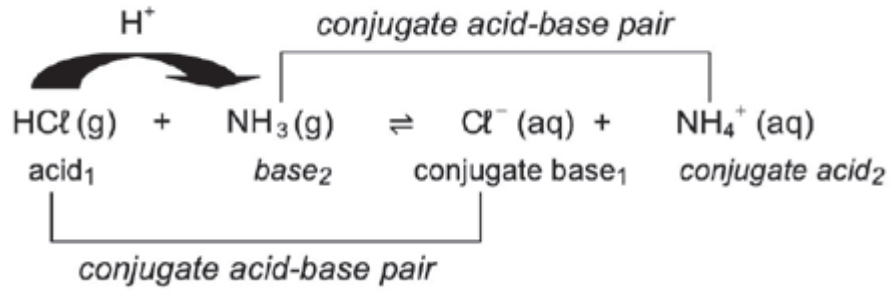
Worked example 1

For each of the following reactions, indicate the acid-base conjugate pairs.

1. $HC\ell_{(g)} + NH_{3(g)} \leftrightarrow C\ell^-_{(aq)} + NH_4^+{}_{(aq)}$
2. $H_2SO_{4(g)} + H_2O_{(\ell)} \leftrightarrow HSO_4^-{}_{(aq)} + H_3O^+_{(aq)}$
3. $H_3PO_{4(g)} + OH^-_{(aq)} \leftrightarrow H_2PO_4^-{}_{(aq)} + H_2O_{(\ell)}$

Solutions

1.



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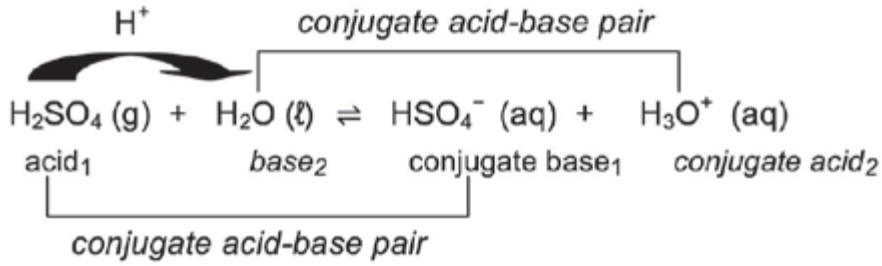
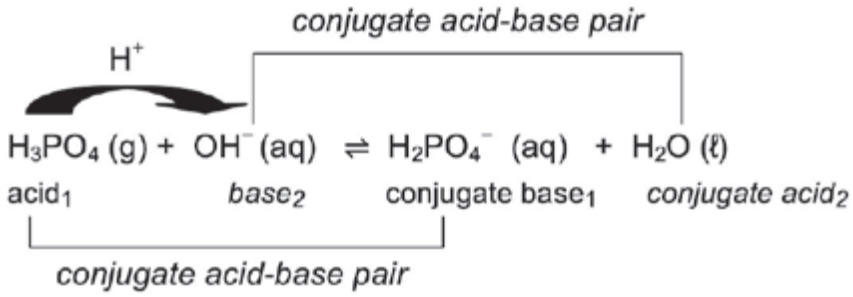


3.



Activity 4

Find the conjugate bases and conjugate acids.

HINT!

- To find the **conjugate base** of an acid, **remove one H^+ (proton)** from the acid.
- To find the **conjugate acid** of a base, **add one H^+ (proton)** to the base.

Acid	Conjugate base
$HC\ell$	
HNO_3	
H_2SO_4	
$\mathbf{HSO_4^-}$	
H_3PO_4	
$\mathbf{H_2PO_4^-}$	
$\mathbf{HPO_4^{2-}}$	
H_2CO_3	
$\mathbf{HCO_3^-}$	
CH_3COOH	
$(COOH)_2$	
$\mathbf{H_2O}$	
NH_4^+	
H_3O^+	

Base	Conjugate acid
$C\ell^-$	
NO_3^-	
$\mathbf{HSO_4^-}$	
SO_4^{2-}	
$\mathbf{H_2PO_4^-}$	
HPO_4^{2-}	
PO_4^{3-}	
$\mathbf{HCO_3^-}$	
CO_3^{2-}	
SO_4^{2-}	
$\mathbf{HSO_4^-}$	
OH^-	
NH_3	
$\mathbf{H_2O}$	

6. Ampholyte (amphiprotic) substance

An ampholyte:

- acts as a **base** in the presence of an **acid** and
- acts as an **acid** in the presence of **a base**.

Example:

Water (H_2O) is an ampholyte:

Water as an acid
$\mathbf{H_2O(\ell)}$ + $NH_3(g)$ ⇌ $\mathbf{OH^-(aq)}$ + $NH_4^+(aq)$
$acid_1$ $base_2$ conjugate $base_1$ *conjugate* $acid_2$

Water as a base
$HC\ell(g)$ + $\mathbf{H_2O\ (g)}$ ⇌ $C\ell^-(aq)$ + $\mathbf{H_3O^+(aq)}$
$acid_1$ $base_2$ conjugate $base_1$ *conjugate* $acid_2$

Show that hydrogen sulphate ion (HSO_4^-) is anampholyte. Activity 5

The hydrogen sulphate ion (HSO_4^-) donates a proton when it acts as an acid	The hydrogen sulphate ion (HSO_4^-) accepts a proton when it acts as a base
$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$	$HSO_4^-(aq) + H^+(aq) \rightleftharpoons H_2SO_4(aq)$
acid — conjugate base	base — conjugate acid

In the acid-base equilibrium formed by adding HSO_4^- and OH^- the acids are:

A HSO_4^- and H_2SO_4 B HSO_4^- and H_2O

C SO_4^{2-} and H_2SO^- D SO_4^{2-} and H_2O (2)

Which of the following is amphiprotic in water?

A SO_2 C HSO_3^-

B SO_3^{2-} D H_2SO_3 (2)

7. Salt hydrolysis

A salt is formed in the reaction between an acid and a base.

When an ionic salt dissolves in water, the ions in the salt dissociate. These ions react with the water and new ions form.

NB: **Hydrolysis** occurs when a salt (a compound made of a metal + nonmetal portion) reacts with water. Hydrolysis, more generally, is the splitting of any compound by reacting it with water.

In this chapter, we only deal with the hydrolysis of salts. (Salt is not just what you have on your table; that is just one type of salt, specifically NaCℓ. Any metal combined with any nonmetal is a salt).

Worked example 2

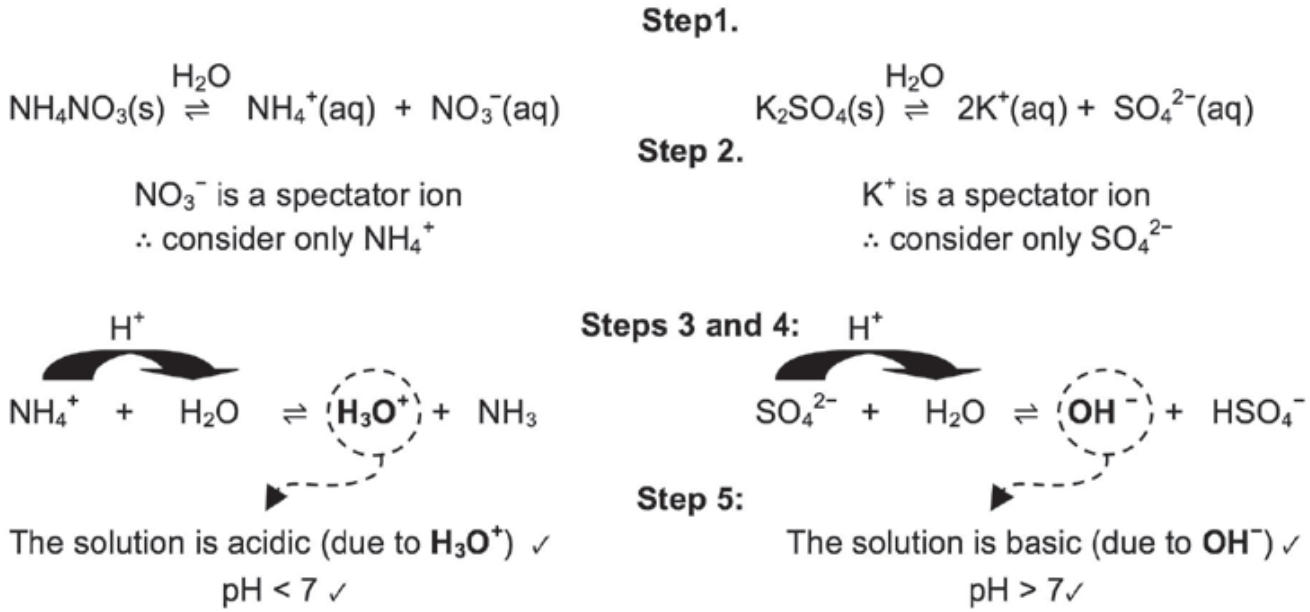
To determine whether the solutions of each of the following salts are:

1. acidic or basic, and the pH of each solution is above or below 7?

1.1 $NH_4NO_{3(aq)}$ (2)

1.2 $K_2SO_{4(aq)}$ (2)

Solutions



In summary:

Remember that acids and bases react with each other to form new compounds:

acid + base → salt + water

We can determine whether the salt solution is basic or acidic by comparing the strengths of the reacting acids and bases.

- A salt formed between a strong acid and a weak base is an **acidic salt**, for example $NH_4C\ell$.
- When a salt reacts with water to form **hydronium ions** (H_3O^+), the solution is acidic (pH < 7).
- A salt formed between a weak acid and a strong base is a **basic salt**, for example $NaCH_3COO$.
- When a salt reacts with water to form **hydroxyl ions** (OH^-), the solution is basic (pH > 7).
- **Neutral salt** is formed when a strong acid and a strong base are neutralized in the reaction.

To determine the approximate pH of salts in salt hydrolysis:

H_2O forms H_3O^+	H_2O forms OH^-
• H_2O acts as a base; • it receives a proton (H^+) and • H_3O^+ ions form so • the solution is acidic and • pH < 7	• H_2O acts as an acid; • it donates a proton (H^+) and • OH^- ions form so • the solution is basic and • pH > 7
Hydrolysis reaction: ion + H_2O ⇌ H_3O^+ + molecule / ion	Hydrolysis reaction: ion + H_2O ⇌ OH^- + molecule / ion

REMEMBER:

- When water reacts with a salt to form hydronium ions **(H_3O^+)**, the solution is acidic (pH < 7).
- When a salt reacts with water to form hydroxyl ions **(OH^-)**, the solution is basic (pH > 7).
- The ions that don't react are called **spectator ions**.

❖ Positive spectator ions: cations from Groups I and II e.g. K^+ and Mg^{2+}

❖ Negative spectator ions e.g. SO_4^{2-}; $C\ell^-$; NO_3^-.

Salt of		Nature of solution	pH in an aqueous solution	Example
Acid	Base			
Strong	Strong	Neutral	pH = 7	$NaC\ell(aq)$ ($HC\ell$ + NaOH)
Weak	Weak	Neutral	pH = 7	$CH_3COONH_4(aq)$ (CH_3COOH + NH_3)
Strong	Weak	Acidic	pH < 7	$NH_4C\ell(aq)$ ($HC\ell$ + NH_3)
Weak	Strong	Basic	pH > 7	$CH_3COONa(aq)$ (CH_3COOH + NaOH)

Worked example 3

Determine whether each of the following salt solutions are acidic, basic or neutral.

1. $Na_2SO_{4(aq)}$

2. $NH_4NO_{3(aq)}$

Solutions

1. Acid + Base

H_2SO_4 + NaOH

Strong + Strong

= neutral solution

2. Acid + Base

HNO_3 + NH_3

Strong + Weak

= acidic solution

8. Acid-base indicators

Indicators:

- can be used to determine whether a solution is acidic or basic;
- are weak acids that are in equilibrium with their conjugate bases (or vice versa) and
- have complex structures and formulae which will simply be represented as HIn (**H** followed by **In** for "indicator").

Indicator in equilibrium

$HIn \rightleftharpoons H^+ + In^-$

colour 1 *colour 2*

Indicator in acid

- The high $[H^+]$ of the acid will disturb the indicator equilibrium.
- According to Le Châtelier's Principle, the reverse reaction, which lowers the $[H^+]$, will be favoured.
- More HIn is produced and the indicator will exhibit colour **1**.

Indicator in base

- The low $[H^+]$ of the base will disturb the indicator equilibrium.
- According to Le Châtelier's principle the forward reaction, which increases the $[H^+]$, will be favoured.
- More In^- is produced and the indicator will exhibit (show) colour **2**.

Worked example 4

Bromothymol blue is an acid-base indicator. The colours it exhibits (shows) can be represented as follows:

$$\underset{\text{blue}}{HIn} \leftrightarrow H^+ + \underset{\text{yellow}}{In^-}$$

A test tube contains a solution to which a drop of bromothymol blue has been added. The solution appears blue.

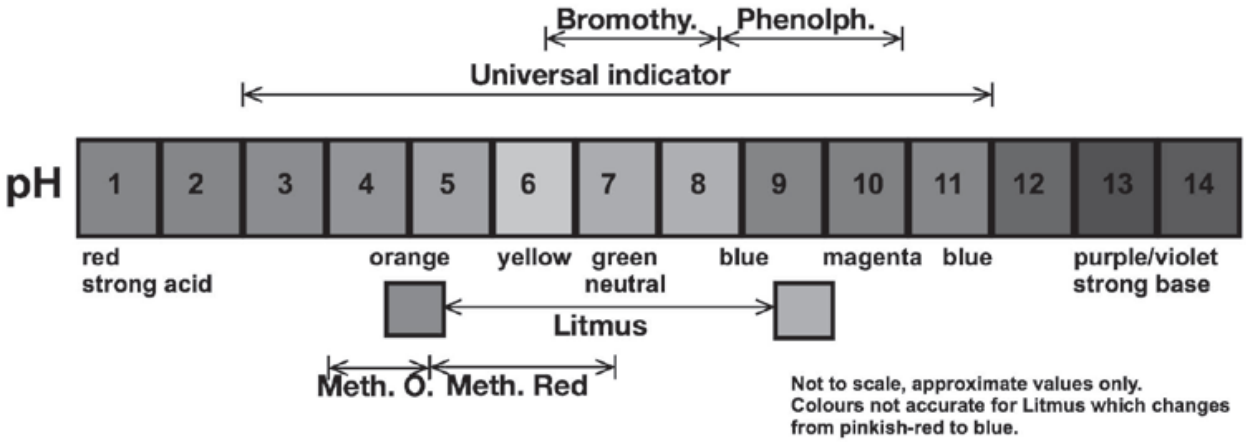
1. What will you observe if a few drops of concentrated hydrochloric acid are added to the test tube?
2. Explain your answer.

Solutions

1. The colour of the solution changes from blue to yellow.
2. Adding hydrochloric acid increases the concentration of the H^+ ions in solution. According to Le Châtelier's Principle the reverse reaction that opposes this change and decreases the $[H^+]$, will be favoured. Therefore the [HIn] increases and the colour changes to blue.

The most common indicators that are used in laboratories are:

INDICATOR	pH RANGE	COLOUR CHANGE
methyl orange	3,1 – 4,4	red to orange to yellow
methyl red	4,2 – 6,2	red to yellow
litmus	4,5 – 8,3	red to blue
bromothymol blue	6,0 – 7,8	yellow to blue
phenolphthalein	8.3 – 10	pink-purple (magenta) in range, colourless outside range
universal	3-11	red (3 and below); 3-6 orange/yellow; 7 green; 8-11 blue; 11 and above, violet.



Choose the most suitable indicator for a particular titration. If you do not have Universal Indicator available, you should follow these steps:

Step by step – universal indicator

Step 1: Identify the strength of the acid and the base (pH range maximum and minimum)

Step 2: Draw a bracket to show the strength of the identified acid and base (shown as a line with arrowheads above)

Step 3: Note or mark the mid point (centre) of the bracket (or line as shown above)

Step 4: Use the indicator table to choose the indicator that shows the range of pH around the mid point (centre) of that bracket/line.

RESULT: You now have selected the appropriate indicator to use.

Worked example 5

Which one of the indicators given below will be the most suitable to be used in the titration of ethanoic acid against sodium hydroxide?

	INDICATOR	pH COLOUR CHANGE RANGE
A	bromothymol blue	6,0 – 7,8
B	phenolphthalein	8,3 – 10
C	methyl orange	3,1 – 4,4
D	methyl red	4,2 - 6,2

Solution

Consult the table at Sections (3) and (4) above.

We see Ethanoic Acid has a pH of about 2,4 (1M solution), and NaOH has a pH of about 14.

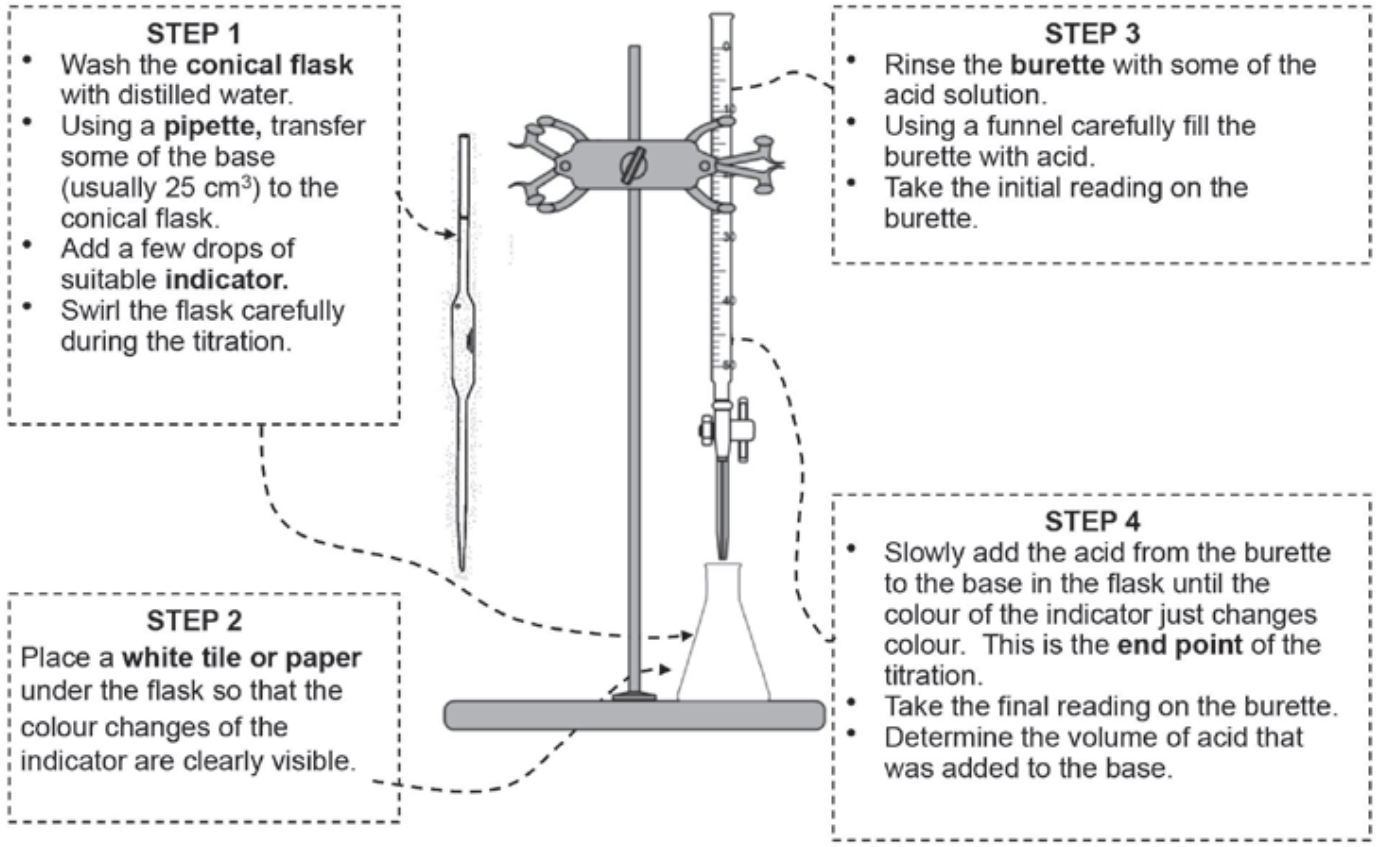
The mid-point between 2,4 and 14 is about 5,8, so any indicator which changes from indicating acid to base around 5,8 would do.

Answer: D; methyl red.

9. Acid-base titrations (volumetric analysis)

Titrations are used to experimentally determine the concentration of an unknown acid or base. When the titration results are used to determine the concentration of the unknown solution it is called a **volumetric analysis**.

a) Method and apparatus for an acid-base titration



10. Preparing a standard solution

A standard solution *has a known concentration which remains constant for a period of time.*

Standard solutions are often used in laboratories and it is important to know how to prepare a standard solution.

CONCENTRATION ($c = \frac{n}{V}$)

CONCENTRATED SOLUTION

Greater number of moles of substance per unit volume.

$$c = \frac{n_{solute}}{V_1}$$

$+ H_2O(\ell)$

$$n_{diluted} = n_{concentrated}$$

DILUTE SOLUTION

Smaller number of moles of substance per unit volume.

$$c = \frac{n_{solute}}{V_1 + V_{water\ added}} = \frac{n_{solute}}{V_2}$$

Worked example 6

Aim: To prepare a 200 cm^3 NaOH standard solution with a concentration of 0,5 $mol \cdot dm^{-3}$.

Step 1: Calculate the mass of NaOH pellets required. M(NaOH) = 40 + 16 + 1 = 40 $g \cdot mol^{-1}$

Step 2: Use an electronic scale (balance) to measure off ± 4,4 g NaOH.

Step 3: Note the exact mass of NaOH on the scale.

Step 4: Transfer the NaOH pellets to a volumetric flask. Add ± 100 cm^3 of distilled water to the flask and seal it with a stopper. Shake the flask carefully until all the solute (NaOH) has dissolved.

Step 5: Slowly fill the flask to the calibration mark on the neck of the flask.

Step 6: Now calculate the exact concentration of the prepared solution – use the mass that was noted on the scale in Step 3.

$$n = \frac{m}{M}$$
$$= \frac{4,1}{40}$$
$$= 0,103 \text{ mol}$$

and

$$c = \frac{n}{V}$$
$$= \frac{0,103}{0,3}$$
$$= 0,52 \text{ mol} \cdot dm^{-3}$$

a standard $NaOH_{(aq)}$ solution of concentration 0,52 $mol \cdot dm^{-3}$ has been prepared.

11. Dilution of solutions

We sometimes need to dilute a solution so that we can use it in a laboratory. We do this by taking a small amount of the solution and adding distilled water to it.

When diluting a solution, we need to know:

- the exact amount of distilled water that needs to added as well as

- the exact concentration of the dilute solution.

In symbols:

$$c_1 V_1 = c_2 V_2$$

- c_1 - concentration 1 ($mol.dm^{-3}$)
- V_1 - volume 1 (dm^{-3})
- c_2 - concentration 2 ($mol.dm^{-3}$)
- V_2 - volume 2 (dm^{-3})

Remember:
*When a solution is diluted,the number of moles of substance remains constant. Only the volume of the solution changes (hence **n** is omitted in this equation.)*

WORKED EXAMPLE 7

Solution 1 has a concentration of 0,2 $mol \cdot dm^{-3}$. Exactly 150 cm^3 of solution A is transferred to a beaker 2 and 250 cm^3 of distilled water is added to the beaker. Calculate the concentration of the diluted solution.

$$c_1V_1 = c_2V_2$$

$$(0,2)(0,15) = c_2(0,4)$$

$$c_2 = \frac{(0,2)(0,15)}{0,4}$$

$$= 0,075 \ mol \cdot dm^{-3}$$

The volume of the final solution (V_2) is:

$$V_2 = V_1 + V_{water}$$

$$= 150 + 250$$

$$= 400 \ cm^3$$

$400 \ cm^3 = 400 \div 1000 = 0,4 \ dm^3$

12. Acid-base titration calculations

$\frac{n_a}{n_b} = \frac{c_aV_a}{c_bV_b}$	$c = \frac{n}{V}$ $c = \frac{m}{MV}$	n : mol (mol) c : concentration ($mol.dm^{-3}$) V : volume (dm^{-3})

	$n = \frac{m}{M}$	a : acid b : base
REMEMBER: • To convert volume from cm^3 to dm^3 (by dividing by 1000).		

Worked example 8

During a titration 20 cm^3 diluted H_2SO_4 precisely neutralises 25 cm^3 of a NaOH solution. If the concentration of the H_2SO_4 solution is 0,5 $mol \cdot dm^{-3}$, calculate the concentration of the NaOH.

SOLUTION

First write down the balanced reaction.

$1\ H_2SO_{4(aq)} + 2\ NaOH_{(aq)} \rightarrow Na_2SO_{4(aq)} + H2O_{(\ell)}$

Find the mol ratio of acid : base: $H_2SO_4 : NaOH = 1 : 2$

$$\frac{na}{nb} = \frac{caVa}{cbVb}$$

$$\frac{1}{2} = \frac{(0,5)(20)}{cb\ (25)}$$

1. $c_b\ (25) = (0,5)(20)(2) = 0,8\ mol \cdot dm^{-3}$

Worked example 9

TITRATION CALCULATIONS

Eight grams (8,0 g) of sodium hydroxide are dissolved in 350 cm^3 of distilled water. 15 cm^3 of this solution neutralises 20 cm^3 of a sulphuric acid solution. The balanced equation for this reaction is:

$$2NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(\ell)}$$

Calculate the concentration of the sulphuric acid solution.

Solution

STEP 1

$c = \frac{m}{MV}$ **OR** $n = \frac{m}{M}$

$c = \frac{8}{(40 \times 0,35)}$ $n = \frac{8}{40} = 0,2$ mol NaOH

$c = 0,57$ mol·dm^{-3} $c = \frac{n}{V}$

$c = \frac{0,2}{0,35}$

$c = 0,5$ mol·dm^{-3}

Solution

STEP 1

$c = \frac{m}{MV}$ **OR** $n = \frac{m}{M}$

$c = \frac{8}{(40 \times 0,35)}$ $n = \frac{8}{40} = 0,2$ mol NaOH

$c = 0,57$ mol·dm^{-3} $c = \frac{n}{V}$

$c = \frac{0,2}{0,35}$

$c = 0,5$ mol·dm^{-3}

STEP 2

$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$

From the balanced equation **2** n(NaOH) : 1 n(H_2SO_4)

$\frac{1}{2} = \frac{(c_a \times 0,02)}{(0,57 \times 0,025)}$

$c_a = 0,36$ mol·dm^{-3}

Worked example 10

The titration of oxalic acid with sodium hydroxide

Part 1:

Aim: To prepare a 250 cm^3 of oxalic acid standard solution with a concentration of 0,08 mol·dm^{-3}

Solutions

Step 1

- Measure between 2,5 and 2,7 g of pure oxalic acid hydrate crystals $(COOH)_2 \cdot 2H_2O$ into the glass beaker and weigh again.
- Add 30-60 cm^3 of distilled water to the glass beaker and dissolve the crystals.
- Transfer the solution into a clean 250 cm^3 volumetric flask.
- Rinse the beaker with 15-20 cm^3 of distilled water and pour this solution into the volumetric flask and repeat. This will ensure that all of the oxalic acid is transferred into the volumetric flask.
- Fill the volumetric flask to within about 2 cm of the mark and allow it to sit for a minute. This will allow any water clinging to the edges of the neck to drain into the flask. Using an eyedropper, fill the flask to the calibrated mark with water.
- Stopper (close) the flask and mix the solution by repeated inversion (turning upside-down) and swirling. This requires about 30 inversions and takes close to 1 minute.

Step 2

- Calculate the exact concentration of the oxalic acid solution using the mass of acid used and the volume of the volumetric flask and record the concentration of your solution on the bottle.
- If you have used the following

Mass oxalic acid crystals 2,6 g

Final volume solution 250,0 cm3

- Using the above information to calculate the number of moles and concentration of oxalic acid crystals.

Part 2:

Procedure to perform (to do) a titration of sodium hydroxide with oxalic acid.

Aim: use a standard solution of oxalic acid to determine the concentration of sodium hydroxide

$$H_2C_2O_{4(aq)} + 2\,NaOH_{(aq)} \rightarrow 2\,H_2O_{(\ell)} + Na_2C_2O_{4(aq)}$$

Solutions

- Measure exact 25,00 cm^3 of the oxalic acid standard solution (c = 0,084 $mol \cdot dm^{-3}$) into a flask and add few drops of phenolphthalein.

- In this titration the oxalic acid solution is acidic and therefore phenolphthalein will be **colourless**.
- The sodium hydroxide solution will be added drop wise (drop by drop) from a burette into the flask containing the oxalic acid and indicator.
- As the sodium hydroxide is added to the flask it will react with the oxalic acid and be neutralized.
- At the point where all of the oxalic acid is reacted, the next drop of sodium hydroxide will make the entire solution basic and it will turn pink. At this point you have completed the titration.

Results (If the following data and results were obtained after at least three trials)

- Volume oxalic acid solution 25,00 cm^3
- Volume sodium hydroxide to titrate 19,43 cm^3

Mole of sodium hydroxide reacted:

$$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$

First write down the balanced reaction.

$1\ H_2C_2O_{4(aq)} + 2\ NaOH_{(aq)} \rightarrow 2\ H_2O_{(\ell)} + Na_2C_2O_{4(aq)}$

Find the mol ratio of acid : base ... ratio of $H_2C_2O_4$: NaOH = 1 : 2

$$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$

$$\frac{1}{2} = \frac{(0{,}084)(25)}{c_b\ (25)}$$

1. $c_b\ (19) = (0{,}084)(25)(2) = 0,\ 0{,}216\ mol \cdot dm^{-3}$

Part 3:

In order to determine the concentration of acetic acid in the vinegar solution you will titrate it with the standardized sodium hydroxide solution. The equation for this reaction is

$$1\ CH_3COOH_{(aq)} + 1\ NaOH_{(aq)} \rightarrow H_2O_{(\ell)} + CH_3COONa_{(aq)}$$

The following data was obtained during titration

- Volume vinegar solution 25,00 cm^3

- Volume sodium hydroxide titrated 22,84 cm^3

Calculations for determining concentration of acetic acid in vinegar

First write down the balanced reaction.

$$1\ CH_3COOH_{(aq)} + 1\ NaOH_{(aq)} \rightarrow H_2O_{(\ell)} + CH_3COONa_{(aq)}$$

Find the mol ratio of acid : base ... $CH_3COOH : NaOH = 1 : 1$

From a balanced equation 2 n(NaOH) : 1 $n(H_2SO_4)$

$$\frac{n_a}{n_b} = \frac{c_aV_a}{c_bV_b}$$

$$\frac{1}{1} = \frac{(c_a)(25)}{(0,216)\ (22,84)}$$

1. $(0,216)\ (22,84) = c_a\ (25)$

$$c_a = 0,197\ mol{\cdot}dm^{-3}$$

In order to get the best precision possible, you should repeat each titration until you get 3 trials that are within 1% of each other.

13. The Equilibrium Constant (Kc) - (The Law of Mass Action)

- The concentrations of all the compounds (solutions and gases) in a closed system in dynamic chemical equilibrium are related by a mathematical equation.
- The numerical value of this equation is called the **equilibrium constant (Kc)**.

Solids and pure liquids are omitted from the Kc expression as their concentration is [1], as multiplying by 1 has no effect.

In the hypothetical equation below the equilibrium expression for this reaction is:

$$2P + 3R \text{ É } 2S + 4T$$

$$Kc = \frac{[S]^2 \times [T]^4}{[P]^2 \times [R]^3}$$

- This is the correct way of writing the Kc expression
- The coefficients are the moles of each reactant and product in the balanced equation

- The product of the concentration of **reactants** (not to be added, but multiplied!!), raised to the power of the number of moles is the **numerator**
- The product of the concentration of **products** (not to be added, but multiplied!!), raised to the power of the number of moles is the **denominator**
- The concentrations used in the Law of Mass Action is the **[reactant]$_{equilibrium}$** and **[product]$_{equilibrium}$** (NOT initial concentrations!! i.e. the concentrations of reactants and products at equilibrium)

HINT!

K_c : equilibrium constant (no unit)

[substance] : concentration of reactant or product (in mol·dm–3)

mol : number of moles of each compound in the balanced reaction equation

14. K_a and K_b values

Since the ionisation of a weak acid is an equilibrium, a chemical equation and an equilibrium constant expression can be written as follows.

Remember that square brackets [ ] means "concentration", or moles per dm^3.

$$HA + H_2O \text{ É } H_3O^+ + A^-$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

The equilibrium constant for the ionisation of an acid is called the **acid ionisation constant** *(K_a)*.

A similar expression can be written for bases:

$$A + H_2O \text{ É } HA^+ + OH^-$$

$$K_b = \frac{[OH^-][HA^+]}{[A^+]}$$

The equilibrium constant for the ionisation of a base is called the **base ionisation constant** *(K_b)*

ACIDS	BASES
Ionisation of acid (HA): $HA + H_2O \rightleftharpoons H_3O^+ + A^-$	Ionisation of base (B): $B + H_2O \rightleftharpoons OH^- + BH^+$ (aq)
$K_a = \frac{[H_3O^+][A^-]}{[HA]}$	$K_b = \frac{[OH^-][BH^+]}{[B]}$ (NB: here we substituted in values from the line above!)
Strong acid ⟶ high K_a-value (>1) Weak acid ⟶ low K_a-value (<1)	Strong base ⟶ high K_b-value (>1) Weak base ⟶ low K_b-value (<1)

Examples:

$HC\ell(g) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + C\ell^-(aq)$	$NH_3(g) + H_2O(\ell) \rightleftharpoons OH^-(aq) + NH4^+(aq)$
	Dissociation of base: $NaOH\ (s) \xrightarrow{H_2O(\ell)} Na^+\ (aq) + OH^-\ (aq)$ $K_b = [Na^+][OH^-]$

- An acid or base's strength refers to its degree of ionisation.
- A strong acid will completely ionise in water while a weak acid will only partially ionise.
- Since there are different degrees of ionisation, there are different levels of weakness. Fortunately, there is a simple quantitative way of expressing this.

Activity 6

Do you think a strong acid will have larger or smaller Ka value? **Explain your answer.** (3)

Activity 7

Choose the strongest base in the list below by comparing their Kb values.

	Base	K_b
A	Ammonia, NH_3	$1{,}8 \times 10^{-5}$
B	Hydroxylamine, $HONH_2$	$9{,}1 \times 10^{-9}$
C	Ethylamine, $C_2H_5NH_2$	$4{,}3 \times 10^{-4}$

(2)

15. The relationship between K_a and K_b for a substance

We know that the strength of a conjugate base is inversely proportional to the strength of the conjugate acid; i.e. weak acids produce strong conjugate bases, and vice versa.

ACID	CONJUGATE BASE
$HA(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + A^-(aq)$	$A^-(aq) + H_2O(\ell) \rightleftharpoons HA(aq) + OH^-(aq)$
$K_a = \frac{[H_3O^+][A^-]}{[HA]}$	$K_b = \frac{[OH^-][HA^+]}{[A^-]}$
Then follows:	
$K_aK_b = \frac{[H_3O^+][A^-]}{[HA]} \times \frac{[HA][OH^-]}{[A^-]} = [H_3O^+][OH^-]$	
But:	
$[H_3O^+][OH^-] = K_w = 1 \times 10^{-14}$	

16. Auto-ionisation of water

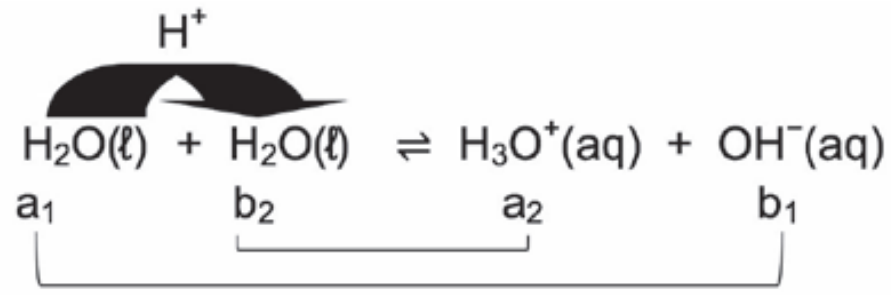
Water is an ampholyte and can react as an acid (donates a H^+) or a base (accepts a H^+).

Two water molecules can undergo **autoprotolysis or auto-ionisation**. One water molecule can act as an acid and donate a H^+ to the other water molecule, the base.

An acid : H_2O É $H^+ + OH^-$

A base : $H_2O + H^+$ É H_3O^+

- Water is a weak acid and a weak base.
- Low % auto-ionisation occurs.
- Pure water is a weak electrical conductor.



17. Equilibrium constant for water (K_w)

From the acid-base reaction for water the equilibrium expression for water can be written.

$$H_2O_{(\ell)} + H_2O_{(\ell)} \text{ É } H_3O^+_{(aq)} + OH^-_{(aq)}$$

$$K_c = [H_3O^+]\,[OH^-]$$

$$K_w = [H_3O^+]\,[OH^-]$$

- Kw : equilibrium constant for water
- At 25°C: $K_w = 1 \times 10^{-14}$

- Water has a low percentage of ionisation with a low concentration of products. The K_w - value will be low.
- Due to the symbol H^+ often being used instead of H_3O^+, the ionization constant (ion product) for water can also be written as:

$$K_w = [H^+]\,[OH^-]$$

Therefore:Ion product for water: $K_w = [H_3O^+][OH^-] = [H^+][OH^-] = 1 \times 10^{-14}$ at 25 °C

18. The pH scale

pH of a solution is the negative logarithm of the hydronium ion concentration in a solution.

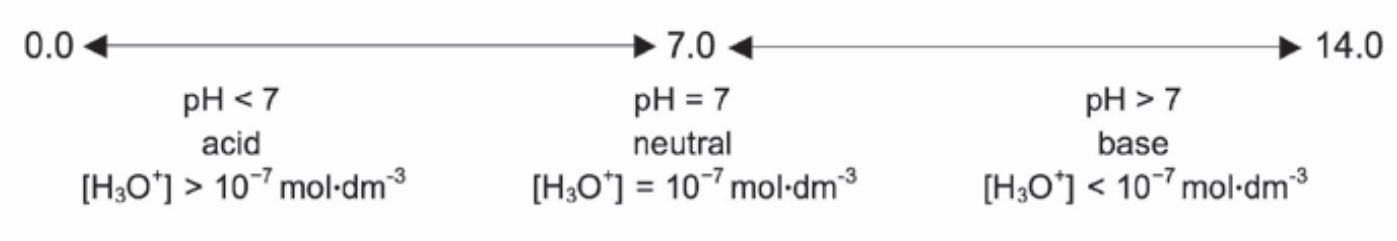
$$pH = \log [H_3O^+]$$

We know $K_w = [H_3O^+]\,[OH^-] = [H^+]\,[OH^-] = 1 \times 10^{-14}$

therefore

$[H_3O^+] = [OH^-] = 10^{-7}$ or $[H^+] = [OH^-] = 10^{-7}$

Acid solution	Neutral solution	Base solution
$[H_3O^+] > [OH^-]$ OR $[H^+] > [OH^-]$	$[H_3O^+] = [OH^-]$ OR $[H^+] = [OH^-]$	$[H_3O^+] < [OH^-]$ OR $[H^+] < [OH^-]$
$[H_3O^+] > 10^{-7}$ mol·dm^{-3}	$[H_3O^+] = 10^{-7}$ mol·dm^{-3}	$[H_3O^+] < 10^{-7}$ mol·dm^{-3}



Worked example 11

Determine whether the following solutions are acidic, basic or neutral:

A solution with	
$[H_3O^+] = 10^{-3}$ mol·dm^{-3}	1. A solution with $[H_3O^+] = 10^{-3}$ mol·dm^{-3} 10^{-3} mol·dm^{-3} > 10^{-7} mol·dm^{-3} ∴ Solution is acidic
$[H_3O^+] = 10^{-12}$ mol·dm^{-3}	2. A solution with $[H_3O^+] = 10^{-12}$ mol·dm^{-3} 10^{-12} mol·dm^{-3} < 10^{-7} mol·dm^{-3} ∴ Solution is basic
$[OH^-] = 10^{-7}$ mol·dm^{-3}	3. A solution with $[OH^-] = 10^{-7}$ mol·dm^{-3} $[H_3O^+][OH^-] = 10^{-14}$ ∴ $[H_3O^+]\,(10^{-7}) = 10^{-14}$ ∴ $[H_3O^+] = 10^{-14} \div 10^{-7} = 10^{-7}$ ∴ Solution is neutral
$[OH^-] = 10^{-4}$ mol·dm^{-3}	4. A solution with $[OH^-] = 10^{-4}$ mol·dm^{-3} $[H_3O^+][OH^-] = 10^{-14}$ ∴ $[H_3O^+]\,(10^{-4}) = 10^{-14}$ ∴ $[H_3O^+] = 10^{-14} \div 10^{-4} = 10^{-10}$ 10^{-10} mol·dm^{-3} < 10^{-7} mol·dm^{-3} ∴ Solution is basic

19. pH Calculations for strong acids and bases

To calculate the pH of a strong acid or base, these steps should be followed:

Acid	Step	Base
0,1 mol·dm^{-3} of HCℓ solution	For example:	0,5 mol·dm^{-3} of NaOH solution
Write down the ionisation reaction for the acid. $HC\ell + H_2O \rightleftharpoons 1\,H_3O^+ + C\ell^-$	1	Write down the dissociation reaction for the base. $1NaOH(s) \rightleftharpoons Na^+(aq)^+OH^-(aq)$
Find the mol ratio of acid to hydronium ions 1 mol HCℓ : 1 mol H_3O^+	2	Find the mol ratio of base to hydroxyl ions 1 mol NaOH : 1 mol OH^-
Determine the $[H_3O^+]$ $[HC\ell] = 0,1$ mol·dm^{-3} $\therefore [H_3O^+] = 0,1$ mol·dm^{-3}	3	Determine the $[OH^-]$ $[NaOH] = 0,5$ mol·dm^{-3} $\therefore [OH^-] = 1\,(0,5) = 0,5$ mol·dm^{-3}
No step 4 for acids	4	Determine the $[H_3O^+]$ $[H_3O^+][OH^-] = 10^{-14}$ $\therefore [H_3O^+]\,(0,5) = 10^{-14}$ $\therefore [H_3O^+] = 10^{-14} \div 0,5 = 2 \times 10^{-14}$
Calculate the pH $pH = -\log [H_3O^+]$ $= -\log 0,1$ $= 1$	5	Calculate the pH $pH = -\log [H_3O^+]$ $= -\log (2 \times 10^{-14})$ $= 13,7$

Worked example 12

Calculate the pH of a H_2SO_4 solution of concentration 0,6 mol·dm^{-3}.

Solutions

Step 1: $1\ H_2SO_{4(g)} + 2\ H_2O_{(\ell)} \leftrightarrow 2\ H_3O^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

Step 2: 1 mol $HC\ell$: 2 mol H_3O^+

Step 3: $[H_2SO_4] = 0,6$ mol·dm^{-3} ∴ $[H_3O+] = 2(0,6) = 1,2$ mol·dm^{-3}

Step 4: $pH = -\log [H_3O^+]$

$= -\log 1,2$

$= 0,08$

20. Summary: Strong and weak acids and bases

Acids ionise in water to form ions:

Examples:

$$HC\ell_{(g)} + H_2O_{(\ell)} \leftrightarrow H_3O^+_{(aq)} + C\ell^-_{(aq)}$$

$$CH_3COOH_{(g)} + H_2O_{(\ell)} \leftrightarrow H_3O^+(aq) + CH_3COO^-(aq)$$

STRONG AND WEAK ACIDS	
Strong acids	**Weak acids**
• High % ionisation • Donate many protons (H^+) • High $[H_3O^+]$ or $[H^+]$ • Low pH • Good electric conductors • High reaction rates	• Low % ionisation • Donate few protons (H^+) • Low $[H_3O^+]$ or $[H^+]$ • Relatively low pH • Poor electric conductors • Low reaction rates
Examples: $HC\ell$ (hydrochloric acid) H_2SO_4 (sulphuric acid) HNO_3 (nitric acid)	*Examples:* CH_3COOH (acetic acid) $(COOH)_2$ (oxalic acid) $C_6H_8O_7$ (citric acid) H_2CO_3 (carbonic acid)
Strong acid ⇌ weak conjugate base + H^+ $HC\ell \rightleftharpoons C\ell^- + H^+$	Weak acid ⇌ strong conjugate base + H^+ $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

Bases like:

- NaOH are ionic and dissociate in water while

- NH_3 consists of covalent molecules which ionise in water forming NH_4^+.

STRONG AND WEAK BASES	
Strong bases	**Weak bases**
• High % dissociation • Accept many protons (H^+) • High [OH^-] • Very high pH	• Low % dissociation or ionisation • Accept few protons (H^+) • Low [OH^-] • Relatively high pH
NaOH Sodium hydroxide KOH Potassium hydroxide	NH_3 Ammonia $CaCO_3$ Calcium carbonate
strong base + $H^+ \rightleftharpoons$ weak conjugate acid $OH^- + H^+ \rightleftharpoons H2O$	weak base + $H^+ \rightleftharpoons$ strong conjugate acid $NH_3 + H^+ \rightleftharpoons NH_4^+$

In general:

pH 1 - 2 : strong acid pH 12 - 14 : strong base

pH 3 - 6 : weak acid pH 8 - 11 : weak base

pH 7 : neutral

21. Summary:

Concentrated and dilute acids and bases

Concentration of an acid or a base is an indication of the number of moles of solute per unit volume. Both strong and weak acids and bases can be either concentrated or diluted.

Examples:

1 $mol \cdot dm^{-3}$ $HC\ell_{(aq)}$: concentrated solution of a strong acid

0,01 $mol \cdot dm^{-3}$ $HC\ell_{(aq)}$: diluted solution of a strong acid

1 $mol \cdot dm^{-3}$ $CH_3COOH_{(aq)}$: concentrated solution of a weak acid

0,01 $mol \cdot dm^{-3}$ $CH_3COOH_{(aq)}$: diluted solution of a weak acid

1 $mol \cdot dm^{-3}$ $NaOH_{(aq)}$: concentrated solution of a strong base

0,01 $mol \cdot dm^{-3}$ $NaOH_{(aq)}$: diluted solution of a strong base

1 mol·dm^{-3} $NH_{3(aq)}$: concentrated solution of a weak base

0,01 mol·dm^{-3} $NH_{3(aq)}$: diluted solution of a weak base

Structured Activities

QUESTION 1

1.1 Write down:

1.1.1 The meaning of the term diprotic acid. (2)

1.1.2 The formula of a diprotic acid. (1)

1.2. Magnesium hydroxide ($Mg(OH)_2$) is often used as medicine to relieve an upset stomach. The pH of the $HC\ell_{(aq)}$ in a person's stomach is 1.

1.2.1 Calculate the concentration of the hydrochloric acid in the person's stomach. (3)

1.2.2 Will the pH in the stomach INCREASE, DECREASE or STAY THE SAME after taking in a dose of $Mg(OH)_2$? (2)

1.3 A person takes in a dose of $Mg(OH)_2$. Write down the balanced equation for the reaction that takes place in the stomach. (3)

QUESTION 2 (NORTH-WEST (SEPTEMBER) 2015)

2.1 Define an acid in terms of the Brønsted-Lowry theory. (2)

2.2 Consider the reaction below:

$$HF + H_2O \text{ É } H_3O^+ + F^-$$

2.2.1 Identify the reactant which acts as a Brønsted-Lowry base. (1)

2.2.2 Write down the formula of the conjugate acid the base identified in QUESTION 2.2.1 above. (1)

2.3 Sulphuric acid (H_2SO_4) is a strong acid.

2.3.1 Explain why sulphuric acid is considered a strong acid. (2)

2.3.2 Calculate the pH of a 0,025 mol.dm^{-3} sulphuric acid solution (4)

2.4 A certain solution **X**, has a pH of 12,8.

2.4.1 Which of the ions, OH^- or H^+ is in excess? (1)

2.4.2 Acetic acid (CH_3COOH) is added to solution **X**. Is the pH of the solution going to **INCREASE**, **DECREASE** or **REMAIN THE SAME**? (1)

2.5 A learner accidentally spills 15 cm^3 of 0,4 $mol.dm^{-3}$ sulphuric acid solution in the laboratory. He adds 25 cm^3 of 0,2 $mol.dm^{-3}$ of sodium hydroxide to the spilled sulphuric acid in an attempt to neutralize it.

The equation for the reaction is given below:

$$H_2SO_4 + 2NaOH \rightarrow NaSO_4 + 2H_2O$$

Show by calculation that the addition of the sodium hydroxide solution will not neutralize the sulphuric acid spill. (6)

QUESTION 3 (MPUMALANGA (SEPTEMBER) 2015)

3.1 A bottle in a laboratory contains dilute sulphuric acid of unknown concentration. Learners with to determine the concentration of the sulphuric acid solution. To do this they tritrate the sulphuric acid against a standard potassium hydroxide solution.

The balanced equation for the reaction taking place is:

$$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$$

3.1.1 What is a standard solution? (1)

3.1.2 Calculate the mass of KOH which he must use to make 300 cm^3 of a 0,2 $mol.dm^{-3}$ KOH solution. (3)

3.1.3 Calculate the pH of the 0,2 $mol.dm^{-3}$ KOH solution. (5)

3.1.4 Which one of the indicators listed in the table below should he use in this titration? Explain your answer.

INDICATOR	pH
Methyl orange	2.9 – 4.0
Methyl red	4.4 – 6.0
Bromothymol blue	6.0 – 10.0
Phenolphthalein	8.3 – 10.0

(2)

3.1.5 During the titration the learners find that 15 cm^3 of the KOH solution neutralizes 20 cm^3 of the H_2SO_4 solution. Calculate the concentration of the H_2SO_4 solution. (4)

3.2 An impure sample of calcium oxalate, CaC_2O_4, with a mass of 0,803 g, is titrated with 15.70 cm^3 of a 0,101 $mol.dm^{-3}$ $KMnO_4$.

The net reaction is …

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Calculate the percentage purity of the CaC_2O_4 in the original sample (6)

QUESTION 4 (DBE - FEB/MARCH 2018)

4.1 The balanced equation below represents the first step in the ionization of sulphuric acid (H_2SO_4) in water:

$$H_2SO_4(\ell) + H_2O(\ell) \text{ É } H_3O^+(aq) + HSO_4^-(aq)$$

4.1.1 Write down the FORMULAE of the two bases in the equation above. (2)

4.1.2 Is sulphuric acid a STRONG or a WEAK acid? Give a reason for the answer. (2)

4.2 Learners use the reaction of a 0,15 $mol.dm^{-3}$ sulphuric acid solution with a sodium hydroxide solution in two different experiments. The balanced equation for the reaction is

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2NaSO_4(aq) + H_2O(\ell)$$

4.2.1 They use 24 cm^3 of $H_2SO_4(aq)$ in a titration to neutralize 26 cm^3 of NaOH(aq).

Calculate the concentration of the NaOH(aq). (5)

4.2.2 In another experiment 30 cm^3 of the $H_2SO_4(aq)$ is added to 20 cm^3 of a 0,28 $mol.dm^{-3}$ NaOH solution in a beaker.

Calculate the pH of the final solution (8)

QUESTION 5 (KZN JUNE 2015)

5.1 Sodium hydroxide is classified as a base according to the Arrhenius theory.

Write down the chemical formula of the ion responsible for the basic properties of sodium hydroxide. (1)

5.2 Sulphuric acid reacts with water in two steps as represented by the equations below:

Equation **I**: $H_2SO_4(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$

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

5.2.1 A learner suggests that $HSO_4^-(aq)$ is an ampholyte. Give a reason to support the learner's suggestion. (2)

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

5.3 0,27 g of an IMPURE sample of anhydrous oxalic acid ($H_2C_2O_4$), was dissolved in enough water to make a solution of volume 75,00 cm^3.

The entire oxalic acid solution was then titrated against a sodium hydroxide solution of concentration 0,08 $mol.dm^{-3}$. The titration required 50,12 cm^3 of the NaOH solution to reach end point.

The reaction is shown below:

$$H_2C_2O_4 + 2NaOH \rightarrow Na_2C_2O_4 + 2H_2O$$

5.3.1 Define end point of a titration. (1)

5.3.2 Will the pH of the solution at the end point be EQUAL TO 7, LESS THAN 7 or GREATER THAN 7? Explain, with reference to the reactions of salts. (3)

5.3.3 Calculate the mass of impurities in the given sample of anhydrous oxalic acid. (7)

5.4 A solution is prepared by dissolving 2,54 g magnesium hydroxide, $Mg(OH)_2$, in water to make a solution of volume 250,00 cm^3. Calculate the pH of this solution. (7)

QUESTION 6 (KZN SEPT 2015)

6.1 A solution of an unknown, diprotic acid has a concentration of 0,02 $mol.dm^{-3}$ and a pH of 3,5.

6.1.1 Explain what is meant by a *diprotic acid*. (1)

6.1.2 Calculate the concentration of the hydrogen ions in this solution. (2)

6.1.3 How does the strength of this unknown acid compare to that of sulphuric acid of the same concentration? Choose from, STRONGER THAN, WEAKER THAN or EQUAL TO. (1)

6.1.4 Explain the answer to QUESTION 6.1.3. (2)

6.2 A solution of vinegar can be neutralised by a solution of sodium hydroxide. The following reaction occurs:

$$CH_3COOH(aq) + NaOH(aq) \longrightarrow CH_3COONa(aq) + H_2O(\ell)$$

Phenolphthalein is colourless in an acidic medium and pink in an alkaline medium.

6.2.1 The sodium acetate formed during the neutralisation of vinegar by sodium hydroxide can undergo hydrolysis. What will the colour of phenolphthalein be in a solution of sodium acetate. (1)

6.2.2 Write a balanced equation to explain the answer to QUESTION 6.2.1. (3)

6.3 An unknown carbonate has the formula X_2CO_3. A grade 12 learner is requested to identify element X.
The learner adds 0,212 g of the carbonate into a conical flask containing 25 cm^3 of nitric acid solution of concentration 0,2 $mol.dm^{-3}$. The nitric acid is in excess. She notices that the carbonate reacts completely.

The balanced equation for the reaction reaction:

$$HNO_3(aq) + X_2CO_3(s) \longrightarrow XNO_3(aq) + CO_2(g) + H_2O(\ell)$$

She uses 10 cm^3 of a NaOH solution of concentration 0,1 $mol.dm^{-3}$ to exactly neutralise the excess nitric acid.

The balanced equation for the reaction reaction is:

$$HNO_3(aq) + NaOH(aq) \longrightarrow NaNO_3(aq) + H_2O(\ell)$$

6.3.1 Calculate the number of moles of $HNO_3(aq)$, that reacted with the unknown carbonate. (5)

6.3.2 Provide a name for X, by performing the relevant calculations. (5)

QUESTION 7 (KZN SEPT 2016)

7.1 Magnesium hydroxide ($Mg(OH)_2$) is often used to relieve an upset stomach.
The pH of the $HC\ell(aq)$ in a person's stomach is 1.

7.1.1 Calculate the concentration of the hydrochloric acid in the person's stomach. (3)

7.1.2 Will the pH in the stomach **INCREASE, DECREASE** or **STAY THE SAME** after taking a dose of $Mg(OH)_2$? (1)

7.1.3 A person takes a dose of $Mg(OH)_2$. Write down the balanced equation for the reaction that takes place in the stomach. (3)

7.2 Explain what is meant by a neutralization reaction. (2)

7.3 12 cm^3 of NaOH of concentration 0,1 $mol \cdot dm^{-3}$ and 48 cm^3 of $Ba(OH)_2$ of unknown concentration are mixed in a large flask, and the solution is homogenized. This solution is completely neutralized by 54 cm^3 of a 0,05 $mol \cdot dm^{-3}$ H_2SO_4 solution. Calculate the concentration of the $Ba(OH)_2$ solution. (8)

QUESTION 8 (DBE NOV 2017)

8.1 Ammonia ionises in water to form a basic solution according to the following balanced equation:

$$NH_{3(g)} + H_2O_{(\ell)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

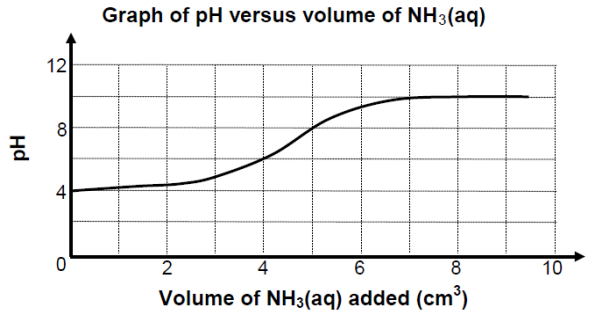
8.1.1 Is ammonia a WEAK or a STRONG base? Give a reason for the answer. (2)

8.1.2 Write down the conjugate acid of $NH_{3(g)}$. (1)

8.1.3 Identify ONE substance in this reaction that can behave as an ampholyte in some reactions. (1)

8.2 A learner adds distilled water to a soil sample and then filters the mixture. The pH of the filtered liquid is then measured.

He then gradually adds an ammonia solution, $NH_{3(aq)}$, to this liquid and measures the pH of the solution at regular intervals. The graph below shows the results obtained.



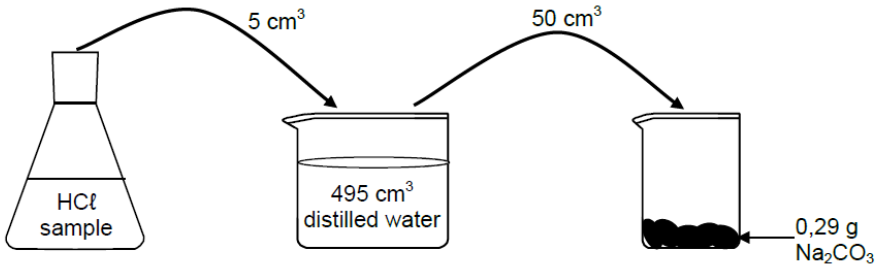
Graph of pH versus volume of $NH_{3(aq)}$

8.2.1 Is the soil sample ACIDIC or BASIC? Refer to the graph above and give a reason for the answer. (2)

8.2.2 Calculate the concentration of the hydroxide ions (OH^-) in the reaction mixture after the addition of 4 cm^3 of $NH_{3(aq)}$. (4)

8.3 A laboratory technician wants to determine the concentration of a hydrochloric acid (HCℓ) sample. He adds 5 cm^3 of the HCℓ sample to 495 cm^3 of distilled water to give 500 cm^3 of dilute hydrochloric acid, $HC\ell_{(aq)}$.

During a reaction 50 cm^3 of this dilute hydrochloric acid solution, $HC\ell_{(aq)}$, reacts completely with 0,29 g of sodium carbonate, $Na_2CO_{3(s)}$.



The balanced equation for the reaction is:

$Na_2CO_{3(s)} + 2HC\ell_{(aq)} \rightarrow 2NaC\ell_{(aq)} + CO_{2(g)} + H_2O_{(\ell)}$

Calculate the concentration of the hydrochloric acid sample. (7)

ELECTROCHEMICAL CELLS

Electrochemical cells are based on Redox reactions; therefore they can't be dealt with without considering the core of their existence.

REDOX REACTIONS

A redox reaction is defined as transfer of electrons. Therefore, any transfer of electrons must have two sides, one side must be losing electrons (**donating**), the other side must be gaining electron.

There are two types of electrodes (i) an ***anode*** that is being oxidized always shows a decrease in mass, (ii) a ***cathode*** undergoing reduction always shows an increase in mass.

Reduction reaction

Reduction reaction is defined as gaining of electrons, which consequentially leads to a decrease in the **oxidation number**. A substance that undergoes reduction facilitates the loss of electrons of another substance. Therefore it is called an **oxidizing agent**.

Oxidation reaction

Oxidation reaction is defined as the loss of electrons, which consequentially leads to an increase in the **oxidation number**. A substance that undergoes oxidation facilitates the gain of electrons by another substance. Therefore it is called a **reducing agent**.

Example:

Anode: $Zn \rightarrow Zn^{2+} + 2e^-$ (Oxidation half-reaction)

Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$ (Reduction half-reaction)

There are two type electrochemical cells

1. Galvanic / Voltaic cell
2. Electrolytic cell

Galvanic cell

Galvanic cells are electrochemical cells that convert chemical energy into electrical energy.

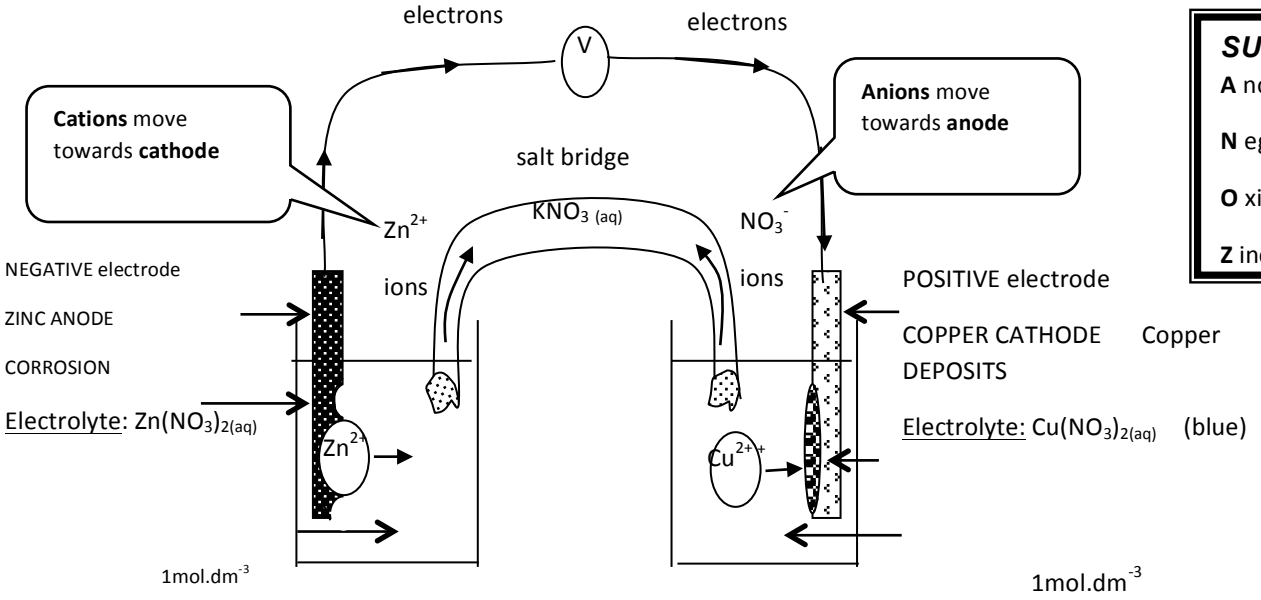
A salt bridge is used to:

(i) Complete the circuit,

(ii) Neutralize solutions by allowing the flow of ions in between solutions

Conducting wires are used to transport electrons that are being transferred. A voltmeter is used to measure the potential difference across the cell.

The diagram below shows a standard Galvanic Cell.



SUMMARY

A node

N egative

O xidation

Z inc

NOTE: The same observations would be made if zinc metal was placed in a solution of copper sulphate. The zinc is oxidised and corrodes, red brown deposits of copper would form, the blue solution would turn colourless and the solution would become hot (exothermic reaction).

STANDARD HYDROGEN ELECTRODE

The standard hydrogen electrode consists of;

- an inert platinum electrode to conduct electrons between the half cells
- a solution of H^+ ions of **concentration 1 mol.dm^{-3}** *eg. I mol.dm^{-3} HCl or 0,5mol.dm^{-3} H_2SO_4*

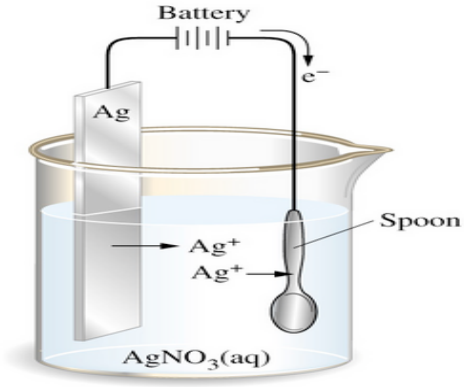
Electrolytic Cell

Electrolytic cell is an electrochemical cell in which electrical energy is converted into chemical energy.

Electro-plating

Electro-plating is the process whereby material that corrodes easily is coated with material that does not corrode easily. The the reason behind this is to mix useful properties of different substances to meet the needs of society.

The diagram below shows a simple electroplating cell



Anode: $Ag \rightarrow Ag^+ + e^-$ (silver metal is oxidised to Ag^+ ions ∴anode corrodes)

Cathode: $Ag^+ + e^- \rightarrow Ag$ (silver ions are reduced to silver metal which deposits on spoon)

NOTE: The concentration of the electrolyte remains the same during the electroplating process.

Electro-refining

Electro-refining is the process whereby metals are purified from their ores. An ore (impure metal) that is mined consists of other atoms bonded to a metal of interest. Then electro-refining is used to extract that metal from others.

THE CHLOR-ALKALI INDUSTRY

Chlorine is manufactured by the electrolysis of brine (saturated sodium chloride solution).

The overall reaction is:

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

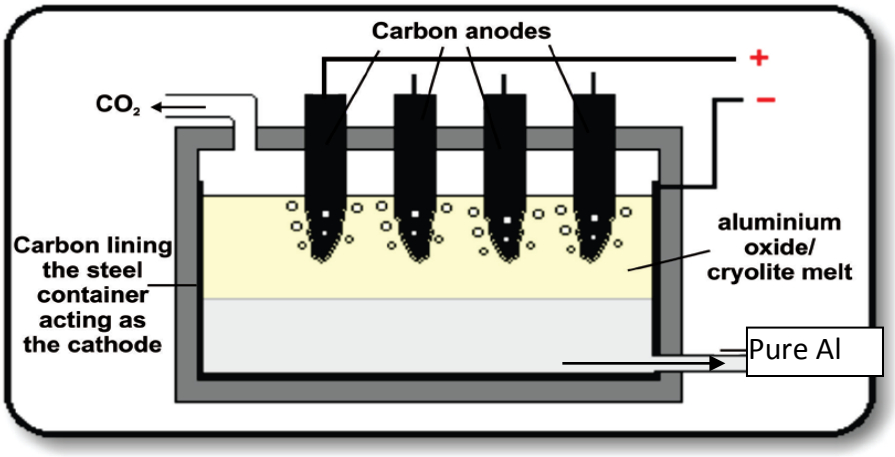
Aluminium Extraction

Aluminium is mined as an ore called Bauxite which is washed by NaOH to produce alumina (Al_2O_3) and mostly Fe_2O_3 which is known as read mud. Then aluminium has to be separated from oxygen during extraction. The aluminium extraction cell uses carbon electrodes (both anode and

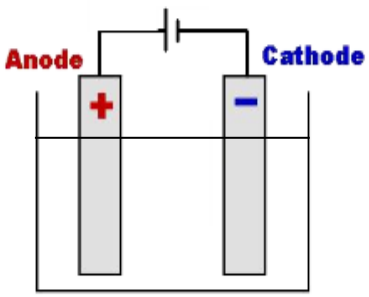
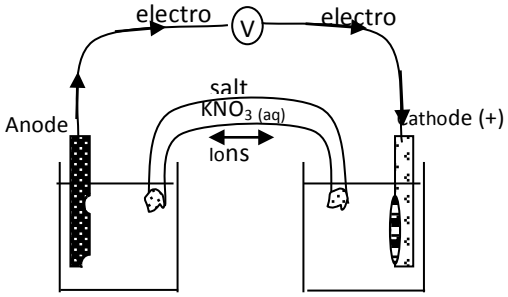
cathode). After alumina has been electrolyzed it produces Al^{3+} and O^{2-}. The Al^{3+} is attracted to the negative electrode which is the cathode and it undergoes reduction there. Whereas O^{2-} is attracted to the positive electrode which is the anode and it get oxidized there.
The reactions occurring in this cell are as follows:

Anode: $2O^{2-} \rightarrow O_2 + 4e^-$
Cathode: $Al^{3+} + 3e^- \rightarrow Al$
Nett: $4Al^{3+} + 6O^{2-} \rightarrow 4Al + 3O_2$

However the production of O_2 at the Carbon anode may lead to a side reaction which reduces the size of this electrode.
That side reaction $C + O_2 \rightarrow CO_2$. This CO_2 re-joins the environment. Therefore, after sometime the anode may need to be replaced.
The diagram below shows the simple representation of aluminium extraction cell.



SUMMARY OF ELECTROLYTIC CELL VS VOLTAIC (GALVANIC) CELL

	ELECTROLYTIC	VOLTAIC (GALVANIC)
Appearance of simple form of cell		
	• Must have a cell or battery in external circuit to supply electrical energy. • Consists of 2 electrodes in the SAME solution.	• No external source of electricity i.e. there will be no cell or battery shown in the external circuit. • It consists of two half cells containing different electrodes each of which is in a solution of its salt. The solutions in each half cell are DIFFERENT.

		• There must either be a salt bridge or some sort of porous membrane separating the two half cell to allow for the passage of ions between cells.
Energy conversion	Electrical to chemical	Chemical to electrical
Polarity of electrodes	Anode = positive Cathode = negative	Anode = negative Cathode = positive
Uses	• Extraction of aluminium; • purification of copper; • electroplating; • chlor-alkali process – electrolysis of brine to form chlorine, sodium hydroxide and hydrogen	Batteries • Primary – zinc-carbon; lithium; mercury (not rechargeable) • Secondary – lead-acid accumulator or car battery (rechargeable)

Multiple choice

1.1 Consider the following balanced equation of a chemical reaction:

$2NaC\ell + 2H_2O \rightarrow C\ell_2 + H_2 + 2NaOH$

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

The reaction takes place in a/an …

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

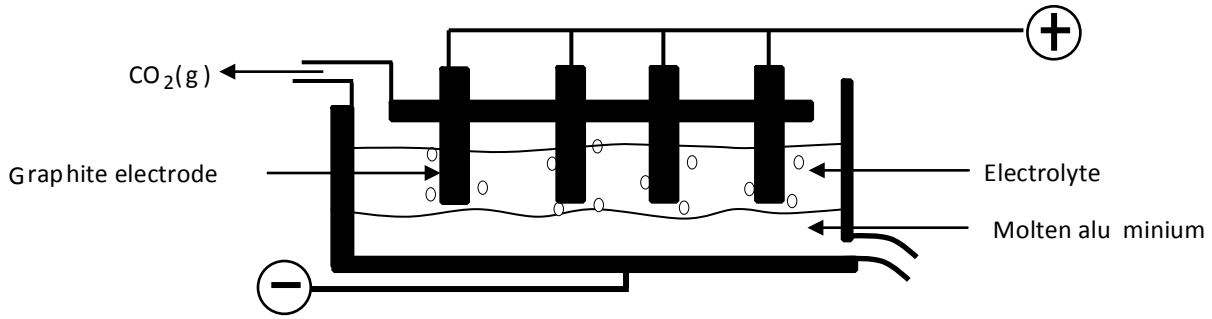
1.2 The following equation represents the reaction taking place in an electrochemical cell:

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

The flow of electrons through the external circuit of this cell is from

A Pb at the anode to Ni at the cathode.
B Pb at the cathode to Ni at the anode.
C Ni at the cathode to Pb at the anode.
D Ni at the anode to Pb at the cathode. (2)

1.3 A simplified diagram for the extraction of aluminium is shown below.



Consider the following statements regarding the process above:

I: The electrolyte is a mixture of cryolite and aluminium oxide.

II: $O_2(g)$ is produced at the anode.

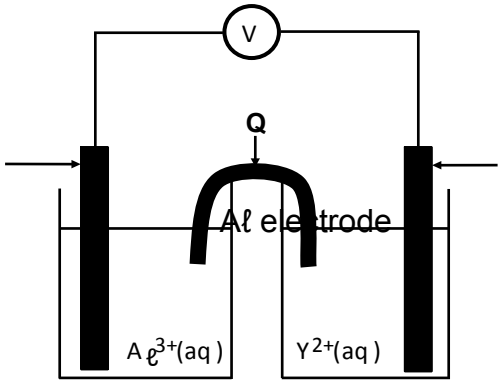
III: The half-reaction at the cathode is $A\ell^{3+}(aq) + 3e^- \rightarrow A\ell(s)$.

Which of the above statements are CORRECT?

A **I** and **II** only
B **II** and **III** only
C **I** and **III** only
D **I**,**II** and **III** (2)

QUESTION 2 DBE FEB-MARCH 2017

In the electrochemical cell shown below an aluminium electrode and another metal electrode, **Y**, are used.



electrode Y

2.1 Write down the:

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

2.1.2 Type of electrochemical cell represented above (1)

It is found that the mass of the aluminium electrode increases whilst the cell is functioning.

2.2 How will EACH of the following change while the cell is functioning? Choose from INCREASES, DECREASES or REMAINS THE SAME.

2.2.1 The concentration of $A\ell^{3+}(aq)$ (1)

2.2.2 The concentration of $Y^{2+}(aq)$ (1)

2.3 Write down the:

2.3.1 Half-reaction that takes place at electrode **Y** (2)

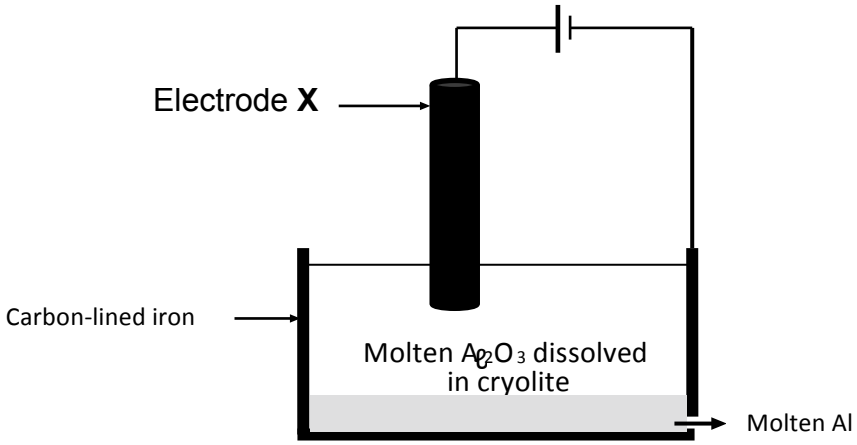
2.3.2 Cell notation of the cell (3)

2.4 The initial emf of this cell measured under standard conditions is 0,7 V.

Identify metal **Y** by means of a calculation. (5)

QUESTION 3 DBE FEB-MARCH 2017

The simplified diagram below shows an electrolytic cell used in the industrial extraction of aluminium (Aℓ) from aluminium oxide at temperatures as high as 1 000 °C. Electrode **X** is a carbon rod.



The cell reaction that takes place is as follows:

$2A\ell_2O_3(\ell) \rightarrow 4A\ell(\ell) + 3O_2(g)$

3.1 Write down the name of the ore used as a source of aluminium oxide. (1)

3.2 Which half-reaction (OXIDATION or REDUCTION) takes place at electrode **X**? (1)

3.3 What is the function of the cryolite? (1)

3.4 Write down the reduction half-reaction. (2)

3.5 Write down a balanced equation that shows why the carbon rod, **X**, must be

replaced regularly.

QUESTION 4 DBE FEB-MAR 2018

4.1 A group of learners use the redox reaction below to construct an electrochemical cell.

$$Sn^{2+}(aq) + 2Ag^{+}(aq) \rightarrow 2Ag(s) + Sn^{4+}(aq)$$

4.1.1 Define a *reducing agent* in terms of *electron transfer*. (2)

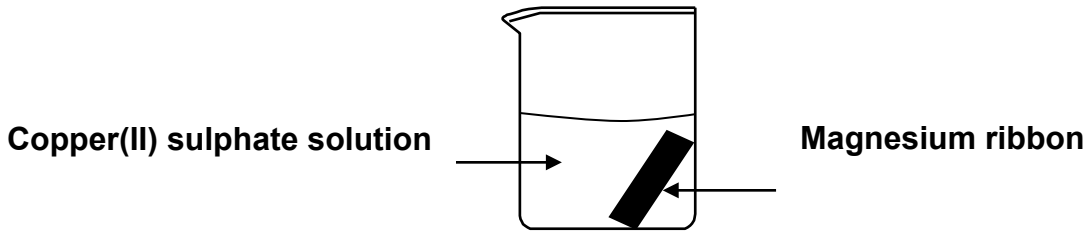
4.1.2 Name a substance that should be used as electrode in the anode half-cell. (1)

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

4.1.4 Write down the cell notation of the cell. (3)

4.1.5 Calculate the initial emf of this cell under standard conditions. (4)

4.2 In a separate experiment, the learners place magnesium ribbon in a beaker containing a blue solution of copper(II) sulphate. After a while the solution becomes colourless.

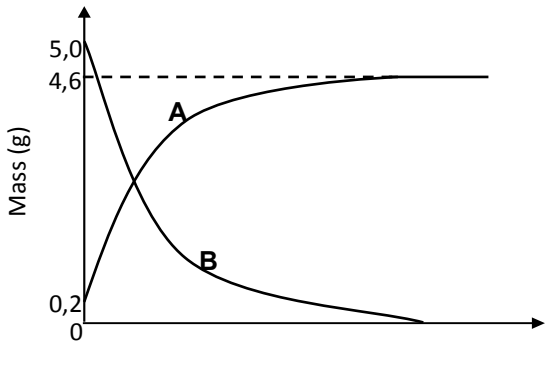


4.2.1 State ONE observable change in the beaker, besides a colour change of the solution, that the learners can make. (1)

4.2.2 Refer to the relative strengths of oxidising agents or reducing agents to explain why the solution becomes colourless. (3)

QUESTION 5 DBE FEB-MAR 2018

The graph below represents the changes in mass that occur at electrode **A** and electrode **B** in an electrolytic cell during the purification of copper.



5.1 Define *electrolysis*. (2)

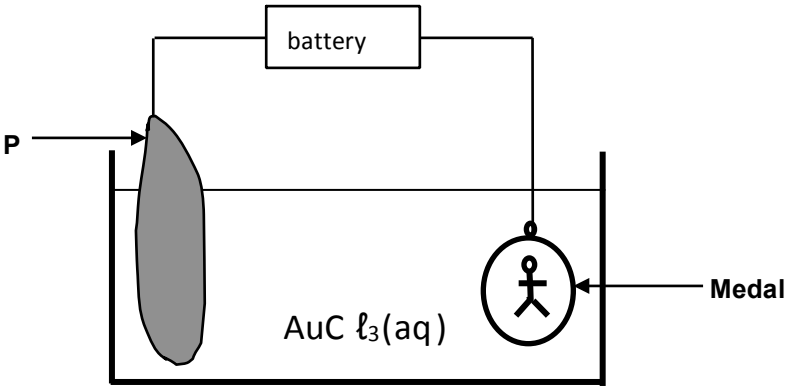
5.2 Which graph, **A** or **B**, represents the change in mass of the anode during electrolysis? (1)

5.3 Write down the equation of the half-reaction which takes place at the cathode of this cell.(2)

5.4 Use the information in the graph and calculate the percentage purity of the impure copper. (4)

QUESTION 6 DBE MAY-JUNE 2017

The simplified diagram below represents a cell used to electroplate an iron medal with a thin layer of gold.



6.1 Is this an ELECTROLYTIC or a GALVANIC cell? (1)

6.2 Which electrode, **P** or the **Medal**, is the anode? (1)

6.3 Write down the:

6.3.1 Half-reaction that takes place at electrode **P** (2)

6.3.2 Oxidation number of gold (Au) in the electrolyte (1)

6.3.3 Energy change that takes place in this cell (1)

6.3.4 Visible change that occurs on electrode **P** after the cell functions for a while (1)

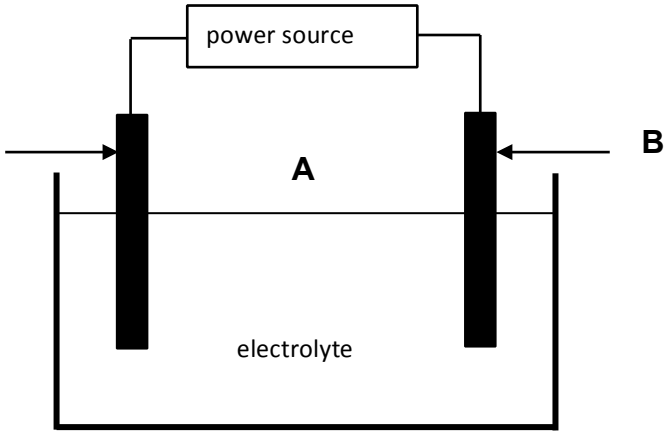
6.4 Besides improving appearance, state ONE other reason why the medal is electroplated. (1)

6.5 State ONE of the two possible changes that should be made to the cell above to

electroplate the medal with silver instead of gold. (1)

QUESTION 7 DBE NOV. 2018

The electrolytic cell below is set up to obtain pure copper from a piece of impure copper.



The impure copper contains other metals, such as platinum, iron, cobalt, silver and nickel.

The cell potential of the power source is adjusted so that only copper is deposited on electrode **B**.

7.1 Define an *electrolytic cell*. (2)

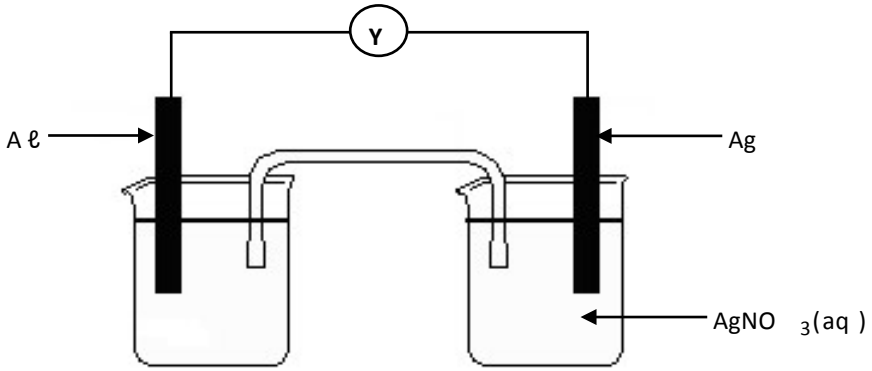
7.2 Write down the FORMULA of a suitable electrolyte for this cell. (1)

7.3 Which electrode (**A** or **B**) is the cathode? Write down the relevant half-reaction taking place at this electrode. (3)

7.4 Sludge forms below one of the electrodes while the cell above is in operation.
Which of the metals, PLATINUM, IRON, COBALT, SILVER or NICKEL, will be present in the sludge? (2)

QUESTION 8 DBE NOV 2017

8.1 Learners set up a galvanic cell and measure its emf under standard conditions.



8.1.1 Write down the name of component **Y**. (1)

8.1.2 Is Aℓ the ANODE or the CATHODE? (1)

8.1.3 Write down the overall (net) cell reaction that takes place in this cell when it is working. (3)

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

8.2 Consider the half-cells, **P**, **Q** and **R**, represented in the table below.

HALF-CELL		
P	**Q**	**R**
$Zn \mid Zn^{2+}(aq)$	$C\ell_2 \mid C\ell^-(aq)$	$Cu \mid Cu^{2+}(aq)$

Different combinations of the half-cells above are compared to determine the highest emf produced under standard conditions.

8.2.1 Write down the NAME of a suitable electrode for half-cell **Q**. (1)

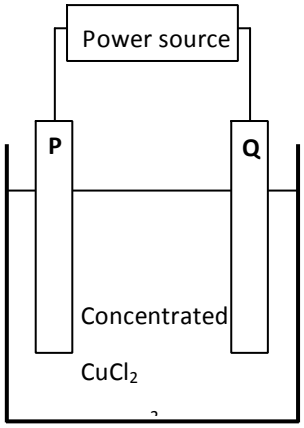
8.2.2 State the standard conditions under which the half-cells should operate to ensure a fair comparison. (2)

8.2.3 Write down the NAME or FORMULA of the strongest reducing agent in the half-cells above. (1)

8.2.4 Which combination of half-cells will produce the highest emf? Choose from **PR**, **PQ** or **QR**. (NO calculation is required.) (1)

QUESTION 9 DBE NOV 2017

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



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

9.2 When an electric current passes through the $CuC\ell_2(aq)$, the mass of electrode **P** increases. Is electrode **P** the CATHODE or the ANODE?

Write down the relevant half-reaction to support the answer. (3)

9.3 The impure copper contains zinc impurities which are oxidised to zinc ions.

Refer to the relative strengths of oxidising agents to explain why zinc ions will not influence the quality of the pure copper produced in this cell. (3)

9.4 Electrodes **P** and **Q** are now replaced by carbon electrodes.

9.4.1 What will be observed at electrode **Q**? (1)

9.4.2 How will the concentration of the electrolyte change as the reaction proceeds? Choose from INCREASES, DECREASES or REMAINS, THE SAME. (1)

CHEMICAL SYSTEMS
FERTILIZERS

Fertiliser is a substance that is used to make the soil fertile.

TYPES OF FERTILISERS	DESCRIPTION	EXAMPLES
Organic	Organic fertilisers are fertilisers that are manufactured by chemical processing of plants	• urea, ammonia, ammonium phosphate, ammonium nitrate, triple superphosphates, superphosphates and NPK fertilisers

Inorganic	Inorganic fertilisers are fertilisers that are derived mainly from plant remains and animal excretions	• plant compost, • animal manure • guano • bone meal

Why fertilisers are needed:

a) to produce more food

b) to fertilise soil faster than naturally.

c) to increase the rate of food production in a given space of land

d) Land available for agriculture decreases

Nutrients needed by plants

- There are 16 nutrients

NUTRIENTS	EXAMPLES	SOURCES OF NUTRIENTS
Mineral	Nitrogen (N)	organic sources: guano, manure inorganic sources: urea, ammonium nitrate, ammonia
	Phosphorous (P)	Organic sources: guano, bone meal Inorganic sources: superphophates, triple superphosphates, ammonium phosphate
	Potassium (K)	Organic sources: potash Inorganic sources: potassium chloride, potassium nitrate, potassium sulphate
Non-mineral	Carbon (C)	Carbon dioxide in the atmosphere
	Hydrogen (H)	Rain
	Oxygen (O)	Rain and atmosphere

NPK ratio is the proportion of nitrogen phosphorous and potassium in a fertiliser

FUNCTIONS OF NUTRIENTS

NUTRIENTS	FUNCTIONS
Nitrogen	1. Promote growth of the leaves 2. Stimulates growth of the plant
Phosphorus	1. Promote growth of roots and stems
Potassium	1. Improve quality of fruits and flowers

Interpretation of NPK ratio

N P K **3: 1: 2(30)** **50kg**

the N, P, K ratio above indicates that there is:

- 30 percentage fertiliser in the bag
- 3 parts of 6 parts is nitrogen
- 1 part of 6 parts is phosphorus
- 2 parts of 6 parts is potassium

Exercise 1 (Feb – March 2018)

A 10kg bag of NPK fertilizer is labelled 6 : 1 : 5 (22)

1.1 What is the meaning of NPK? (1)

1.2 What is the meaning of (22) on the label? (1)

1.3 Calculate the mass of potassium in the bag (4)

Solutions to Exercise 1

1.1 The ratio of Nitrogen (N), phosphorus (P) and potassium (K) in a certain fertilizer. (1)

1.2 Percentage fertilizer in the bag (1)

1.3

$$\%K = \frac{5}{12} \checkmark \times 22\% \checkmark$$
$$= 9{,}17\%$$
$$\therefore m(N) = \frac{9{,}17}{100} \times 10\,kg \checkmark$$
$$= 0{,}92\,kg \checkmark$$

(4)

INDUSTRIAL PROCESSES

There are THREE industrial processes of manufacturing fertilisers:

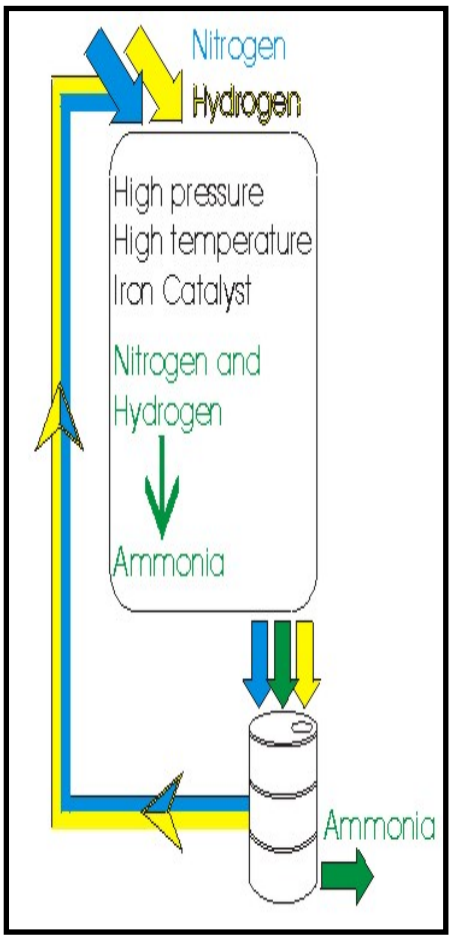
- Haber process
- Contact process
- Ostwald process
-

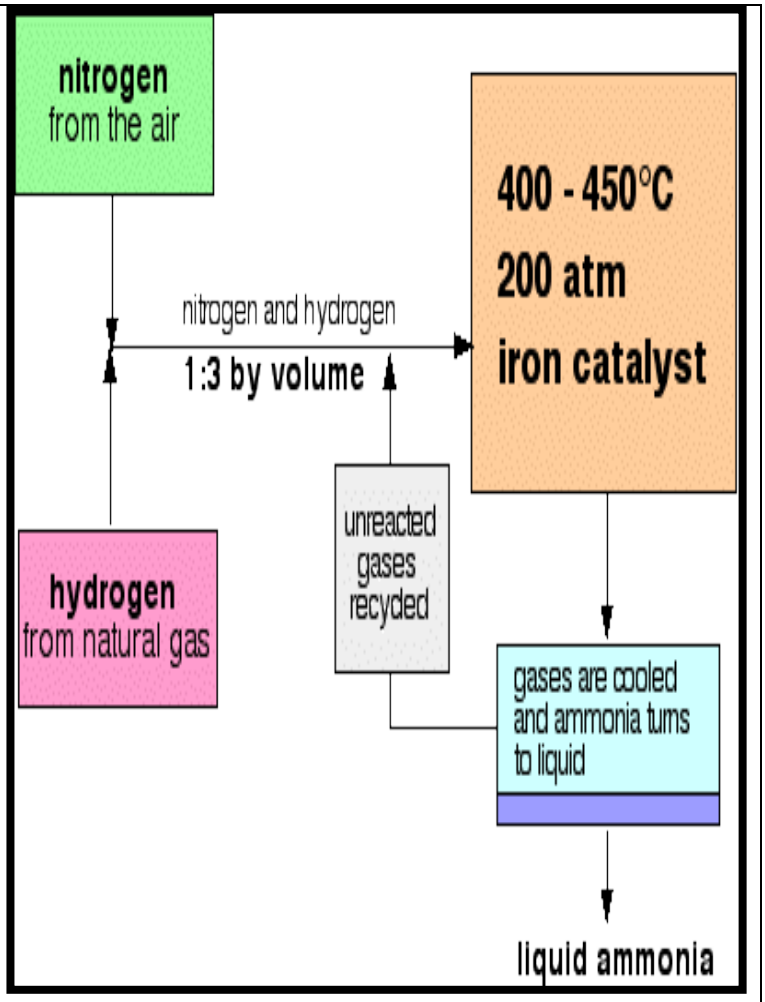
HABER PROCESS (PRODUCTION OF AMMONIA)

- Is the industrial process of manufacturing ammonia
- Iron or iron oxide is used as a catalyst
- The chemical reaction which takes place during the Haber process is represented by the following equation.

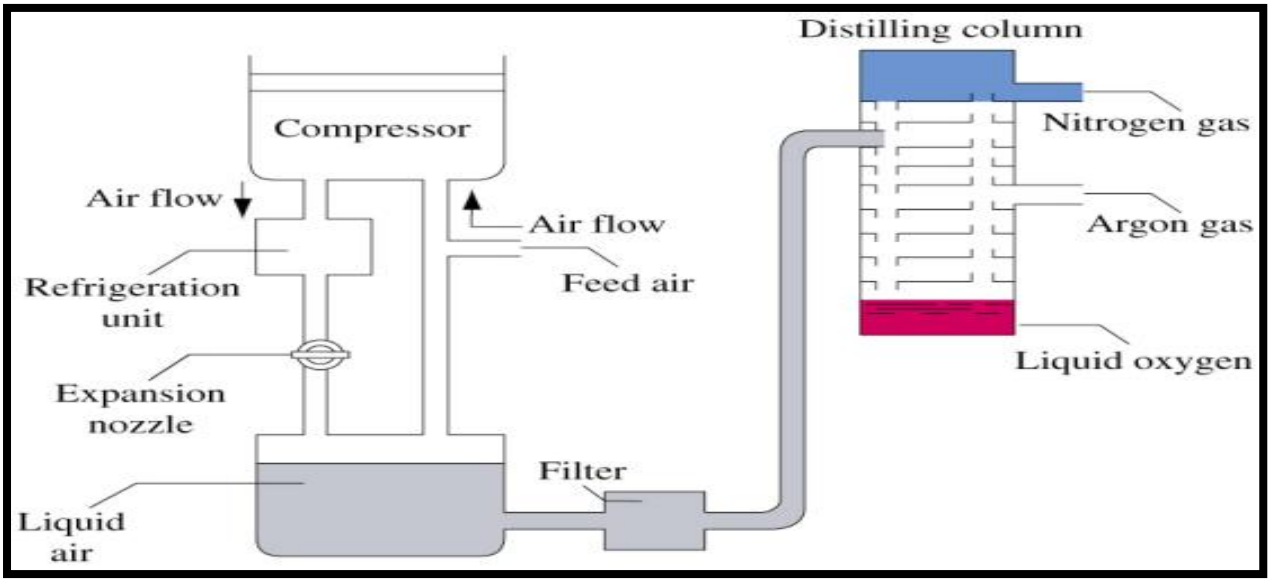
$$\text{nitrogen} + \text{hydrogen} \rightleftharpoons \text{ammonia}$$
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Schematic representation of a Haber process.	Flow diagram of a Haber process



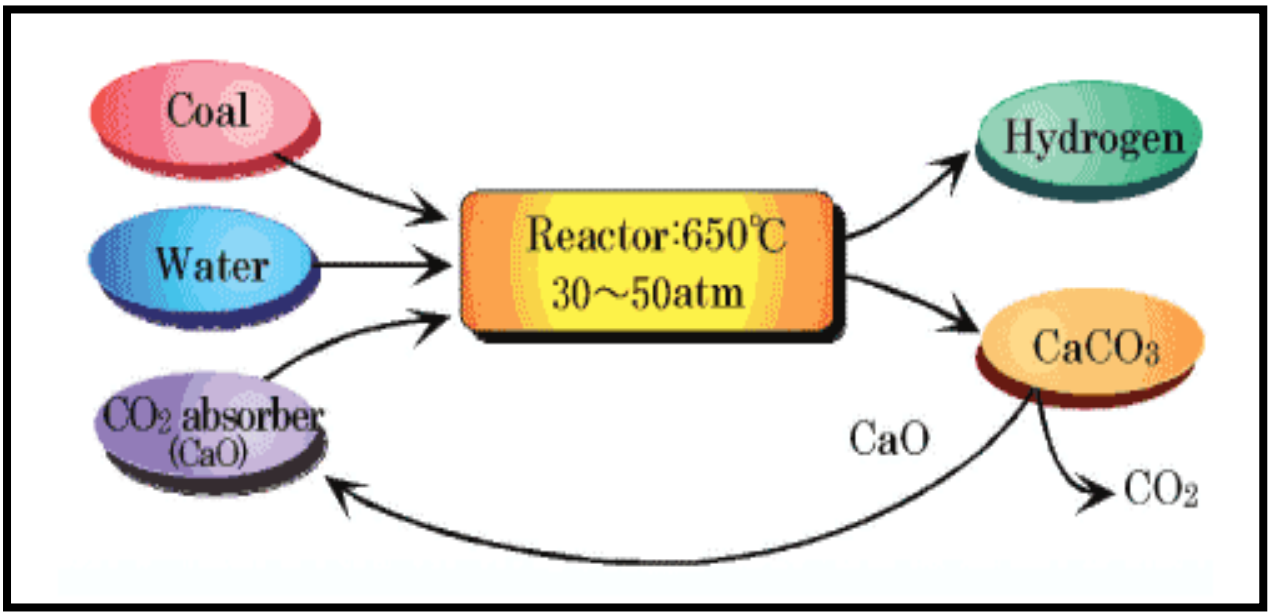


Nitrogen (N_2) is obtained through fractional distillation of air which is represented below:



H_2 is obtained at Sasol from coal and steam.

The following diagram represents the process of producing H_2



Ammonia is used:

- as a cleaning agent when dissolved in water.
- in the manufacture of fertilizers.
- in the manufacture of ammonium carbonate used in the textile industry.
- in the manufacture of nitric acid.

OSTWALD PROCESS (PRODUCTION OF NITRIC ACID)

- Ostwald process is the industrial process of manufacturing nitric acid
- Platinum(Pt) is used as a catalyst in the Ostwald process.

STEP 1: catalytic oxidation of ammonia

$$4\,NH_3 + 5\,O_2 \longrightarrow 4\,NO + 6\,H_2O$$

STEP 2:

$$2\,NO + O_2 \longrightarrow 2\,NO_2$$

STEP 3:

$$4\,NO_2 + 2\,H_2O + O_2 \longrightarrow 4\,HNO_3$$

Nitric acid is used in the:

- production of fertilizer e.g. ammonia + nitric acid → ammonium nitrate
- production of explosives

Exercise 2 (DBE Feb-March 2016)

Ammonium nitrate is an important fertilizer. It is produced by reacting nitric acid with ammonia. Both nitric acid and ammonia are prepared on a large scale in industry.

2.1 Write down the name of the industrial preparation of nitric acid. (1)

2.2 The catalytic oxidation of ammonia is one of the steps in the process named in question

2.3 Write down the NAMES or FORMULAE of the TWO products formed in this step (2)

2.4 Write down a balanced equation for the preparation of ammonium nitrate. (3)

2.5 Calculate the mass, in kilogram, of ammonium nitrate that can be made from 6,8 x 10^4 kg of ammonia and excess nitric acid.
(One moe of ammonia produces one mole of ammonia nitrate.) (3)

2.6 Ammonium nitrate is often mixed with potassium chloride and ammonium phosphate. Give a reason why it is mixed with these compounds. (1)

Solutions to Exercise 2

2.1 Ostwald process

2.2 NO / Nitrogen Monoxide
H_2O / Water

2.3 $NH_3 + HNO_3 \rightarrow NH_4NO_3$

2.4

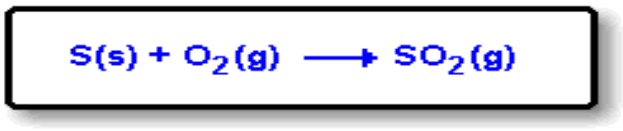
$$n(NH_3) = \frac{m}{M}$$
$$= \frac{6,8 \times 10^7}{17} \checkmark$$
$$= 4 \times 10^6 \text{ mol}$$
$$\downarrow$$
$$n(NH_4NO_3) = n(NH_3)$$
$$= 4 \times 10^6 \text{ mol}$$
$$m(NH_4NO_3) = nM$$
$$= (4 \times 10^6)(80) \checkmark$$
$$= 3,2 \times 10^8 \text{ g}$$
$$= 3,2 \times 10^5 \text{ kg} \checkmark$$

2.5 To make a NPK fertilizer / fertilisers which contain all three primary nutrients.

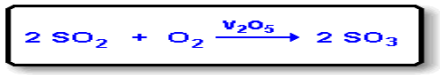
CONTACT PROCESS (PRODUCTION OF SULPHURIC ACID)

- Contact process is the industrial process of manufacturing sulphuric acid.

STEP 1:



STEP 2:



STEP 3:

$$SO_3 + H_2SO_4 \longrightarrow H_2S_2O_7$$

STEP 4:

$$H_2S_2O_7 + H_2O \rightarrow 2\,H_2SO_4$$

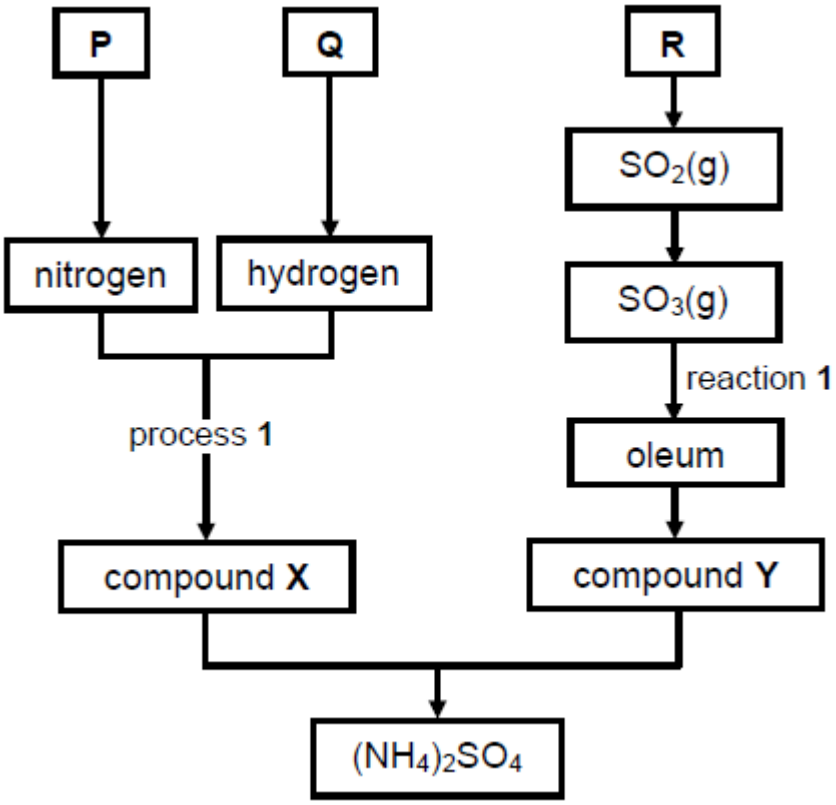
NB: SO_3 in step 2 is not dissolved in water directly because the reaction is highly exothermic and forms a mist

Sulphuric acid is used in:

- Paints
- Battery acid
- Synthetic fibres
- Detergents
- the production of fertilisers e.g. ammonia + sulphuric acid→ ammonium sulphate

Exercise 3 (May – June 2016)

Chemical company produces ammonium sulphate, $(NH_4)_2SO_4$,starting from the raw materials P, Q and R, as shown in the flow diagram below.



Write down the NAME of raw material:

3.1 P

3.2 Q

3.3 R

Write down the:

3.4 NAME of process 1

3.5 NAME of compound X

3.6 FORMULA of compound Y

3.7 Balanced equation for reaction1

The company compares the nitrogen content of ammonium sulphate with that of ammonium nitrate, NH_4NO_3

3.8 Determine by performing the necessary calculations, which ONE of the two fertilisers has the higher percentage of nitrogen per mass. (4)

3.9 Write down the name of the process that should be included in the flow diagram above if the company wants to prepare ammonium nitrate instead of ammonium sulphate. (1)

Solutions to exercise 3

3.1 Air

3.2 Natural gas / Methane / Coal

3.3 Sulphur / Iron sulphide

3.4 Haber

3.5 Ammonia

3.6 H_2SO_4

3.7 $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$

3.8

$$\%N[NH_4NO_3] = \frac{28}{80}\checkmark \times 100 = 35\%$$
$$\%N[(NH_4)_2SO_4] = \frac{28}{132}\checkmark \times 100 = 21{,}21\%$$ ✓

Ammonium nitrate (has the highest percentage of nitrogen) (4)

3.9 Ostwald (1)

Disadvantages of inorganic fertilisers

1. Cause eutrophication
2. Acidify ground water
3. Promotes growth of alien plants & cause blue baby syndrome

EUTROPHICATION

- Eutrophication is the process by which an ecosystem (river or dam) becomes enriched with inorganic plant nutrients especially phosphorus and nitrogen resulting in excessive plant growth.

How does eutrophication lead to dead zones?

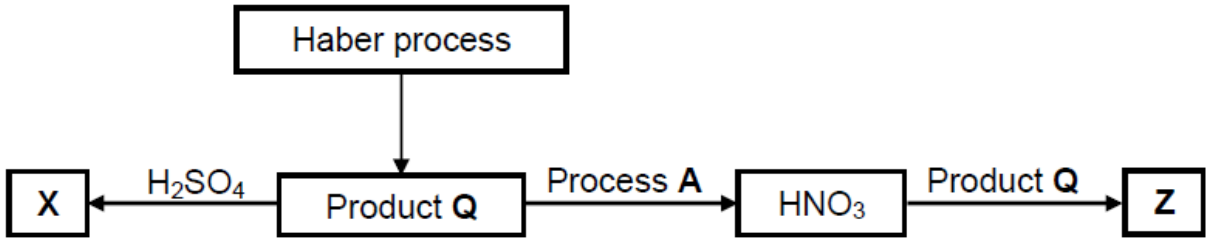
- nitrogen-rich or phosphate fertilisers are washed into rivers or lakes which results in algae bloom. The amount of oxygen becomes depleted and aquatic organisms die.

Ways in which human accelerates eutrophication

- Over-application of fertilisers
- Emissions from vehicles
- Factory emissions
- Sewage; waste disposal systems
- Stock farming

QUESTION 1 (DBE FEB-MARCH 2018 Q10)

1.1 The diagram below shows processes involved in the production of fertilizer X and fertilizer Y



Write down the:

1.1.1 Balanced equation for the formation of product Q (3)

1.1.2 FORMULA of fertilizer X (1)

1.1.3 NAME of process A (1)

1.1.4 NAME of fertilizer Z (1)

1.2 A 10 kg bag of NPK fertilizer is labelled 6 : 1 : 5(22)

1.2.1 What is the meaning of NPK? (1)

1.2.2 What is the meaning of (22) on the label? (1)

1.2.3 Calculate the mass of potassium in the bag (4)

QUESTION 2 (DBE JUNE 2019 Q10)

2.1 The four steps in the manufacture of an inorganic fertilizer are listed below. These steps are NOT written in the order in which they occur.

STEP I: Sulphuric acid reacts with ammonia to produce ammonium sulphate.

STEP II: Sulphur dioxide reacts with oxygen to produce Sulphur trioxide

STEP III: Oleum is diluted with water to produce sulphuric acid.

STEP IV: Sulphur trioxide is bubbled in concentrated sulphuric acid to produce oleum.

Write down the:

2.1.1 Correct order in which the steps occur in the preparation of the inorganic fertilizer by using the numbers I to IV (1)

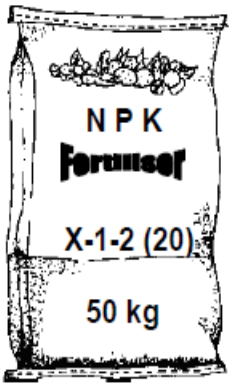
2.1.2 Balanced chemical equation for step I (3)

2.1.3 NAME of the catalyst used in step II (1)

2.1.4 Balanced chemical equation for step IV (3)

2.1.5 Reason why Sulphur trioxide is NOT dissolved in water in step IV (1)

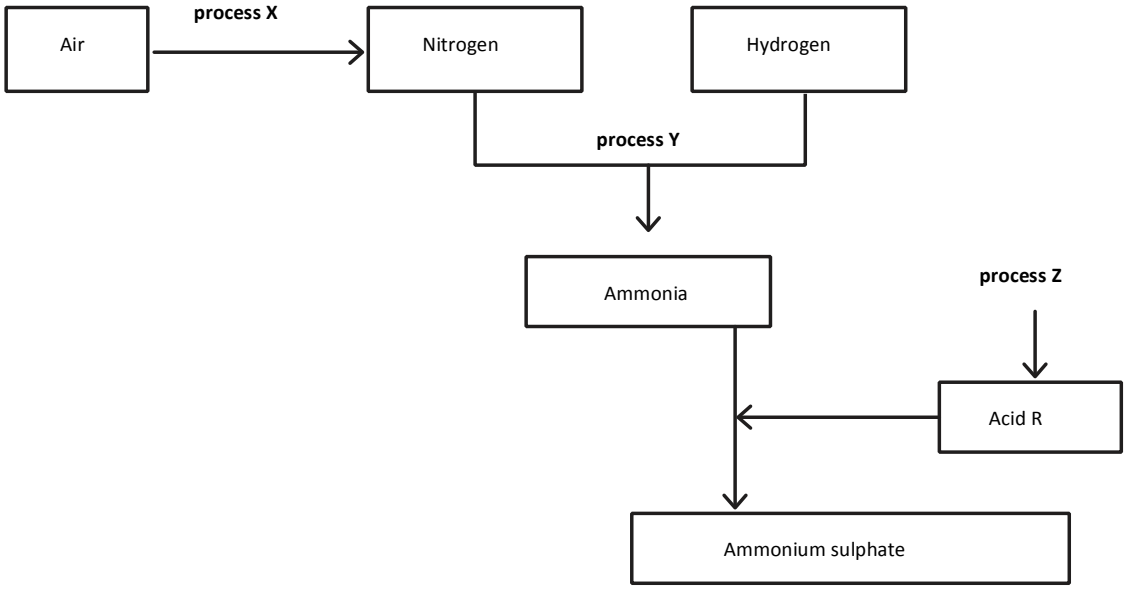
2.2 The diagram below shows a bag of NPK fertiliser. One of the numbers of the NPK ratio on the bag is labelled as X.



If the mass of potassium in the bag is 3,33 kg. Calculate the value of X (4)

QUESTION 3

3. The flow diagram below represents processes used in the fertiliser industry.



Write down:

3.1 The name of industrial process X (1)

3.2 A balanced equation for process Y (3)

3.3 The name of industrial process Z (1)

3.4 A balanced equation for the preparation of ammonium sulphate using acid R. (3)

3.5 The name of the type of reaction taking place in QUESTION 2.4. (1)

Ammonium nitrate is one of the most common compounds used as fertiliser.

3.6 Write down the NAME or FORMULA of the acid needed to prepare ammonium nitrate from ammonia.

(1)

3.7 Write down TWO properties of ammonium nitrate that make it suitable for use as a fertiliser.

(2)

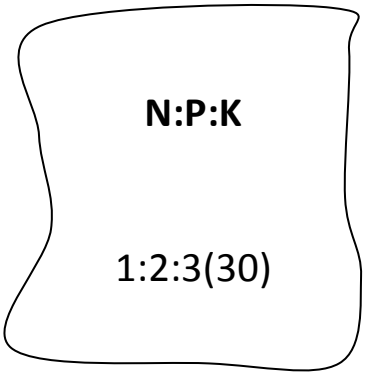
QUESTION 4

There is likely to be a gap between food production and demand in several parts of the world by 2020. Demand is influenced by population growth and urbanisation, as well as income levels and associated changes in dietary preferences. Fertilisers are very important in the demand for more food. However, over-fertilising may have disastrous effects on humans and the environment.

4.1 Supply TWO reasons why the world needs a fertiliser industry. (2)

4.2 State TWO effects of over-fertilising on the environment. (2)

The farmer Mr Clayton decided to fertilise his vegetable garden. He finds the following information on a **50-kg** bag of fertiliser at the nursery:



4.3 What is the meaning of the (30) on the bag? (1)

4.4 Calculate the % P of the fertiliser in the bag. (2)

4.5 What will Clayton observe if his garden has a shortage of phosphates? (1)

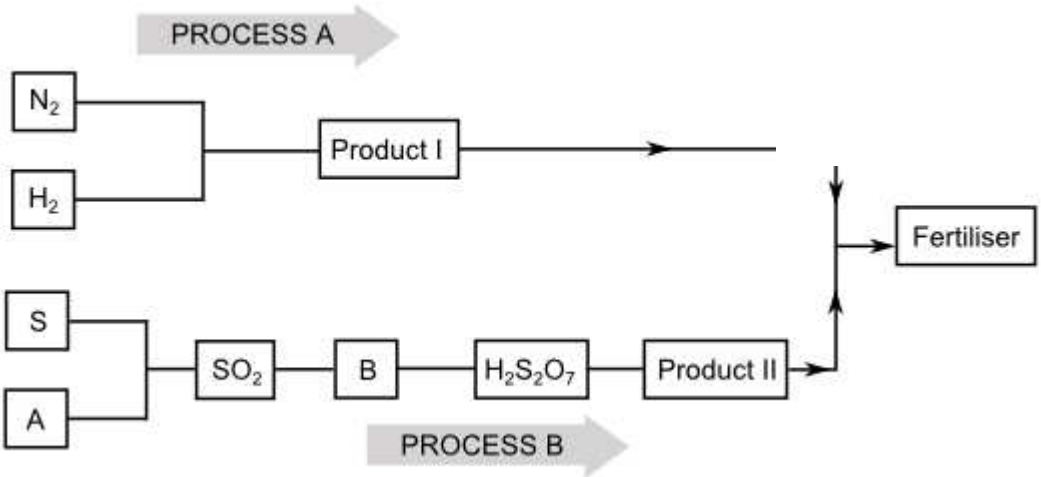
4.6 Calculate the mass of carrier material present in this bag of fertiliser. (2)

4.7 Calculate the mass of P present in this bag of fertiliser. (2)

4.8 Which primary nutrient will mainly be gained by the vegetables during a rain- and thunderstorm? (1)
[13]

QUESTION 5

Plants need sun, water and nutrients to grow. The nutrients can be taken from air or soil. If there is a sufficient supply of nutrients in the soil, crops are likely to grow well and produce high yields. If even one of the nutrients needed is in short supply, plant growth is limited and crop yields are reduced. Fertilisers are needed to obtain high yields because they supply crops with the nutrients the soil lacks. By adding fertilisers, crop yields can often be doubled or even tripled. The following flow diagram shows two industrial processes needed for the manufacturing of fertilisers.



5.1 Give the name of process A. (1)

5.2 Write the balanced equation for the reaction taking place in process A. (3)

5.3 Give the name of product I. (1)

5.4 Give the name of process B. (1)

5.5 Write down the chemical formulae for reagents A and B. (2)

5.6 Write down the chemical formula for the substance added to reagent B to produce $H_2S_2O_7$ (1)

5.7 Give the name for $H_2S_2O_7$ (1)

5.8 Give the name of the fertiliser formed in the reaction between product I and product II. (1)

5.9 The label on a fertiliser bag has the following numbers on it: **7:2:3** Explain the meaning of these numbers. (3)

QUESTION 6

A 50 kg bag of fertilizer contains some information as shown below:

6.1 What information is represented by the numbers 3:2:5 (26) printed on the bag. (3)

6.2 Calculate the percentage of nitrogen in this bag. (2)

6.3 Is this fertiliser suitable for growing tomatoes? Give a reason for your answer. (2)

6.4 A member of a community came across a dam near the farm and saw the dam with a thick green covering on it. According to the community member the area was filled with a stench that was unbearable. The community member also noticed rotten fish floating on the surface.

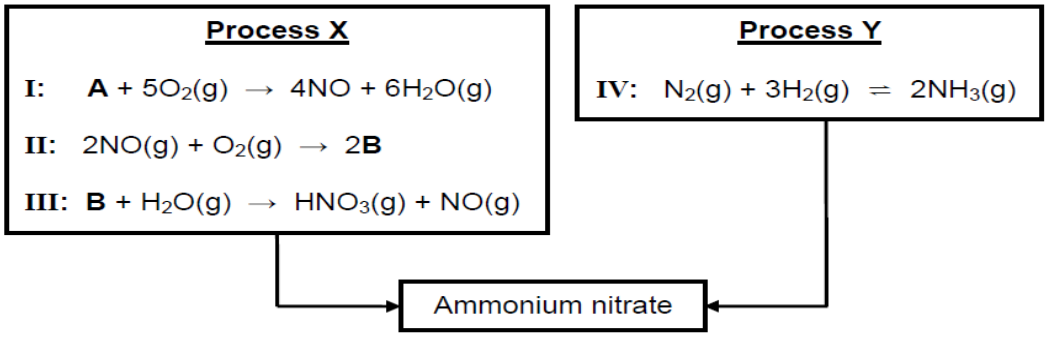
6.4.1 NAME the phenomenon taking place in the dam. (2)

6.4.2 State a possible cause of the phenomenon in 6.4.1 (2)

6.4.3 Suggest TWO possible ways to prevent the phenomenon named in 6.4.1 from occurring. (2)

QUESTION 7 (DBE NOV 2017)

7.1 The equations below represent two industrial processes involved in the preparation of ammonium nitrate.



Write down the:

7.1.1 NAME of substance A (1)

7.1.2 FORMULA of substance B (1)

7.1.3 NAME given for reaction I (1)

7.1.4 NAME or FORMULA of the catalyst used in reaction I (1)

7.1.5 Name of process X (1)

7.1.6 Name of process Y (1)

7.1.7 Balanced equation for the preparation of ammonium nitrate from the products obtained in process X and process Y (3)

7.2 A 15 kg bag of fertiliser contains 5% phosphorus, 10% nitrogen and 15% potassium. Calculate the:

7.2.1 Mass of phosphorus in the bag (2)

7.2.2 Mass of filler in the bag (3)