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KWAZULU-NATAL

DEPARTMENT OF EDUCATION

WINTER & SPRING PROGRAM

PHYSICAL SCIENCES

GRADE 12

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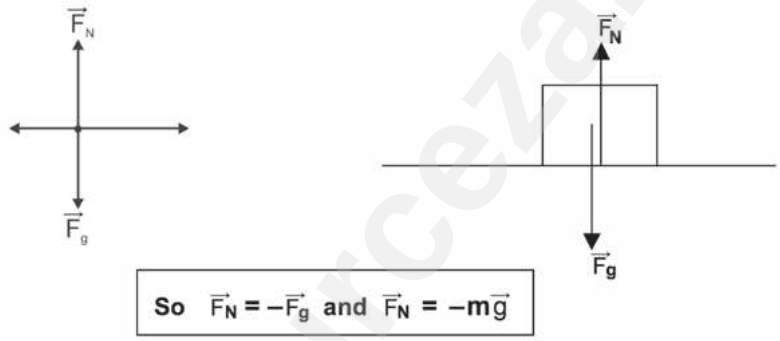
FORCES

Different kinds of forces: weight, normal force, frictional force, applied force (push, pull), tension (strings or cables)

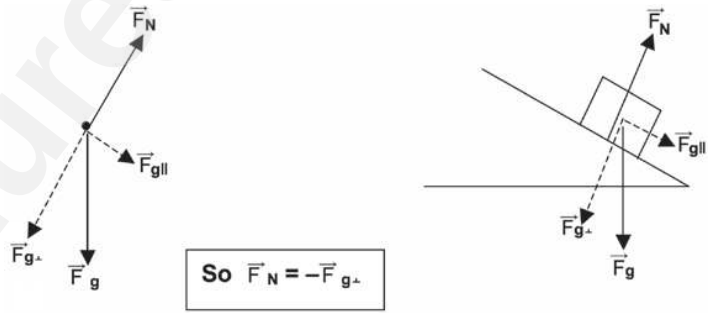
- **Define *normal force*, N,** as the force or the component of a force which a surface exerts on an object with which it is in contact, and which is perpendicular to the surface.
- **Define *frictional force*, f,** as the force that opposes the motion of an object and which acts parallel to the surface.

Object resting on a horizontal surface.
When an object is resting or moving 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



Object resting on an inclined surface:
When an object is resting or moving on an 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.
An object resting on an inclined plane (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.

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- **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
- 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.

- Solve problems using $f_k = \mu_k N$, where f_k is the kinetic frictional force and μ_k the coefficient of kinetic friction.

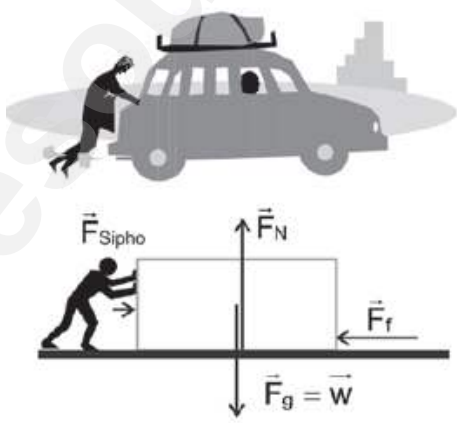
FORCE DIAGRAMS, FREE-BODY DIAGRAMS [see Mind The Gap Part 1 page 8]

- Steps for drawing force or free body diagrams. Follow the steps in this example.

Example:

An object on a horizontal surface (plane):

Sipho exerts a force to the right while pushing a car along a rough, flat road.
Draw a force diagram and a free body diagram to represent the situation.



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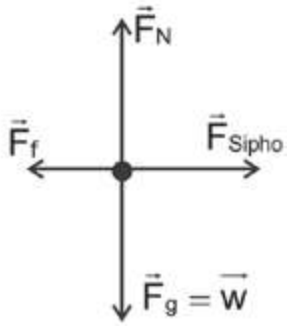
Free body diagram:



- 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.

NEWTON'S FIRST, SECOND AND THIRD LAWS OF MOTION

- **State Newton's first law of motion:** A body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it. Discuss why it is important to wear seatbelts using Newton's first law of motion.

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

- **State Newton's third law of motion:** When one body exerts a force on a second body, the second body exerts a force of equal magnitude in the opposite direction on the first body.
  - ✓ Identify action-reaction pairs.
  - ✓ List the properties of action-reaction pairs.

Newton's Law of Universal Gravitation [see Mind The Gap Part 1 pp28-32]

- **State 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.
- Solve problems using

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

- Calculate acceleration due to gravity on a planet using.

$$g = \frac{Gm}{r^2}.$$

- Describe *weight* as the gravitational force the Earth exerts on any object on or near its surface.
- Calculate weight using the expression w = mg.
- Calculate the weight of an object on other planets with different values of gravitational acceleration.
- Distinguish between *mass* and *weight*.
- Draw force diagrams and free-body diagrams for objects that are in equilibrium or accelerating.
- Apply Newton's laws of motion to a variety of equilibrium and non-equilibrium problems including:

A single object:

- Moving on a horizontal plane with or without friction
- Moving on an inclined plane with or without friction
- Moving in the vertical plane (lifts, rockets, etc.)

Two-body systems (joined by a light inextensible string):

- Both on a flat horizontal plane with or without friction
- One on a horizontal plane with or without friction, and a second hanging vertically from a string over a frictionless pulley.
- Both on an inclined plane with or without friction
- Both hanging vertically from a string over a frictionless pulley
- Explain *weightlessness*.

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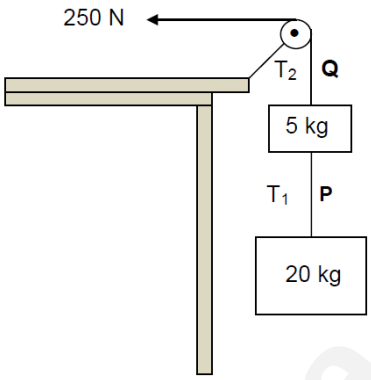
QUESTION 2 (NOVEMBER 2014)

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.



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

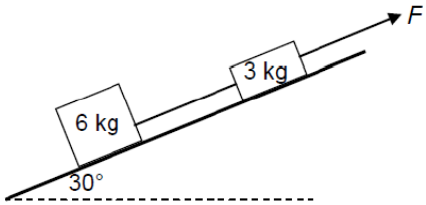
2.2 Draw a labelled free-body diagram indicating ALL the forces acting on the **5 kg block**. (3)

2.3 Calculate the magnitude of the tension T_1 in string **P**. (6)

2.4 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 2 (EXAMPLER 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 30^0 with the horizontal, with a force of magnitude F. Ignore the mass of the string.



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

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

2.2 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)

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

2.4 Calculate the:

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

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

2.5 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 $m.s^{-2}$? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

MOMENTUM

- Define *momentum* as the product of an object's mass and its velocity.
- Describe the *linear momentum* of an object as a vector quantity with the same direction as the velocity of the object.
- Calculate the momentum of a moving object using $p = mv$.
- Describe the *vector nature of momentum* and illustrate it with some simple examples.

Change in Momentum [see "Mind The Gap page 35]

- Draw vector diagrams to illustrate the relationship between the initial momentum, the final momentum and the change in momentum for each of the above examples.

Newton's second law of motion in terms of momentum [Impulse-Momentum Theorem]

- **State Newton's second law of motion in terms of momentum**: The resultant/net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force.
- Express Newton's second law of motion in symbols: $F_{net} = \frac{\Delta p}{\Delta t}$
- Calculate the change in momentum when a resultant/net force acts on an object and its velocity:
  - Increases in the direction of motion, e.g. 2nd stage rocket engine fires
  - Decreases, e.g. brakes are applied
  - Reverses its direction of motion, e.g. a soccer ball kicked back in the direction it came from

Impulse

- Define *impulse* as the <u>product</u> of the <u>resultant/net force</u> acting on an object and the <u>time</u> the resultant/net force acts on the object.
- Deduce the <u>impulse-momentum theorem</u>: $F_{net}\Delta t = m\Delta v$.

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- Use the impulse-momentum theorem to calculate the force exerted, the time for which the force is applied and the change in momentum for a variety of situations involving the motion of an object in one dimension.
- Explain how the concept of impulse applies to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds.

Conservation of momentum and elastic and inelastic collisions

- Explain what is meant by *a closed/an isolated system* (in Physics), i.e. a system on which the resultant/net external force is zero.
  A closed/an isolated system excludes external forces that originate outside the colliding bodies, e.g. friction. Only internal forces, e.g. contact forces between the colliding objects, are considered.
- State the principle of conservation of linear momentum: The total linear momentum of a closed system remains constant (is conserved).
- **Distinguish between *elastic collisions* and *inelastic collisions* by calculation. [see "Mind The Gap page 46].**

QUESTION 4 (EXAMPLER 2014)

Two boys, each of mass m, are standing at the back of a flatbed trolley of mass 4 m. The trolley is at rest on a frictionless surface. The boys jump off simultaneously at one end of the trolley with a horizontal velocity of 2 $m.s^{-1}$. The trolley moves in the opposite direction.

4.1 Write down the principle of conservation of linear momentum in words. (2)
4.2 Calculate the final velocity of the trolley. (5)
4.3 The two boys jump off the trolley one at a time. How will the velocity of the trolley compare to that calculated in QUESTION 4.2? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

QUESTION 3 (SEPTEMBER 2014 KZN)

A truck of mass 3 000 kg is travelling at 29,17 $m{\cdot}s^{-1}$ to the right. At the same time a car of mass 1 000 kg is travelling at 22 $m{\cdot}s^{-1}$ in the same direction ahead of the truck.

.

Ignore the effects of friction

The truck collides with the car and they stick together after the collision.

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

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3.2 Calculate the velocity of the truck-car system immediately after the collision. (5)

3.3 Is the collision between the truck and the car elastic or inelastic? (1)

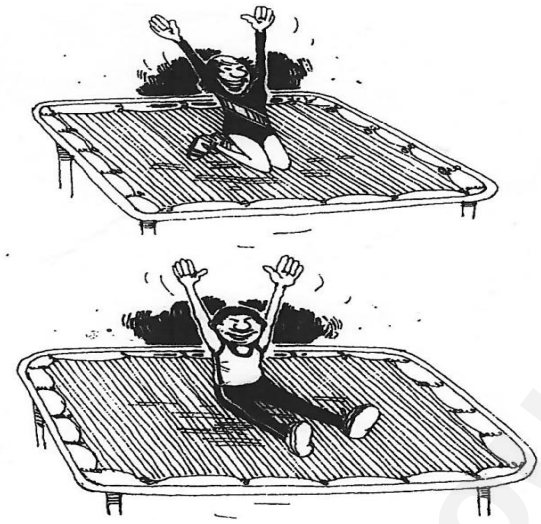
3.4 On impact the truck exerts a force of magnitude F on the car and the car experiences an acceleration of magnitude *a*.

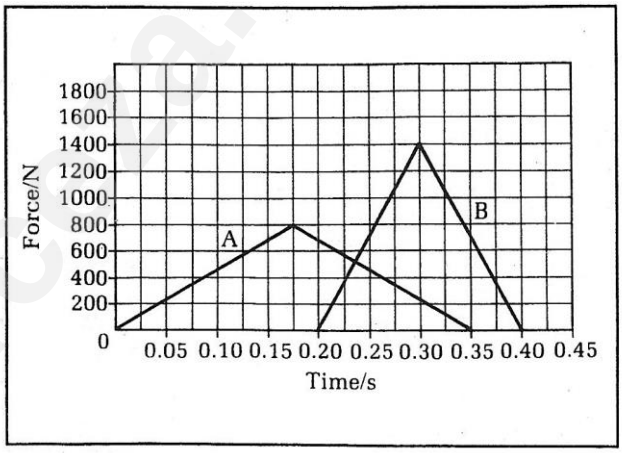
3.4.1 Will the magnitude of the force that the car exerts on the truck, on impact, be GREATER THAN, LESS THAN or EQUAL TO, F. (1)

3.4.2 Name and state the Law of motion that explains the answer to question 3.4.1. (3)

QUESTION 4 (SEPTEMBER 2014 KZN)

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 on the right shows 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.

4.1 Define IMPULSE. (2)

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

4.3 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)

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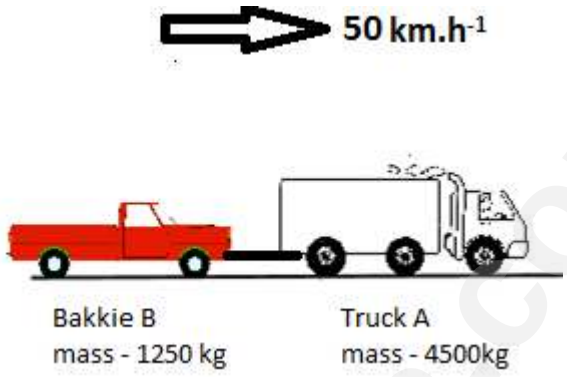
QUESTION 2 (SEPTEMBER 2014 WC)

2.1 Truck A, of mass 4 500 kg travels at a CONSTANT VELOCITY OF 50 km·h^{-1} while towing Bakkie B, of mass 1 250 kg. The engine of Truck A produces a force of 11 270 N. The road surface exerts a friction force of 8 820 N on Truck A.



2.1.1 Write down Newton's Second Law of motion in words. (2)
2.1.2 Draw a free-body diagram showing ALL the forces acting on Truck A. The length of the vectors should be an indication of their relative magnitudes. (6)
2.1.3 Calculate the coefficient of kinetic friction for tyre rubber on the road surface. (3)
2.1.4 Calculate the force of friction exerted by the road surface on Bakkie B. (3)
2.1.5 Calculate the tension in the tow rope. (3)

VERTICAL PROJECTILE MOTION

- Explain that projectiles fall freely with gravitational acceleration '***g***' accelerate downwards with a constant acceleration irrespective of whether the projectile is moving upward or downward or is at maximum height
- Know that projectiles take the same time to reach their greatest height from the point of upward launch as their greatest height from the point of upward launch as the time they take to fall back to the point of launch. This is known as time symmetry.
- Know that projectiles can have their motion described by a single set of equations for the upward and downward motion
- Use equations of motion to determine the position, velocity and displacement of a projectile at any given time
- Draw position vs. time (***x vs. t***), velocity vs. time (***v vs. t***) and acceleration vs. time (***a vs. t***) graphs for 1D projectile motion
- Give equations for position versus time and velocity versus time for the graphs of 1D projectile motion
- Given ***x vs. t***, ***v vs t*** or ***a vs t*** graphs determine position, displacement, velocity or acceleration at any time t.

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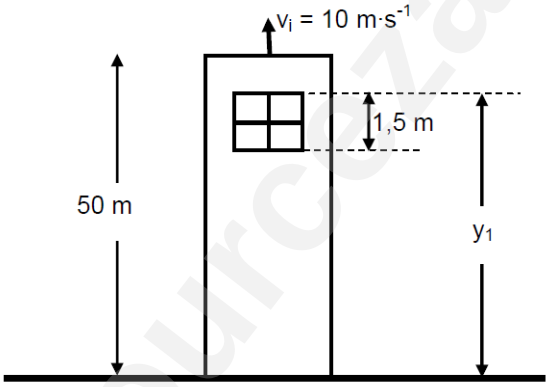
- Given ***x vs. t***, ***v vs t*** or ***a vs. t*** graphs describe the motion of the object e.g. graphs showing a ball, bouncing, thrown vertically upwards, thrown vertically downward, and so on

HINTS:

- At maximum height, the object's :
  velocity = 0 $m.s^{-1}$, kinetic energy = 0 J and potential energy is maximum.
- gravitational acceleration is always 9.8 $m.s^{-2}$ downwards.
- for rising and falling objects, the value of ***velocity***, is the same but in the opposite direction.

QUESTION 3 (MAR. 2012)

A stone is thrown vertically upward at a velocity of 10 $m{\cdot}s^{-1}$ from the top of a tower of height 50 m. After some time the stone passes the edge of the tower and strikes the ground below the tower. Ignore the effects of friction.



3.1 Draw a labelled free-body diagram showing the force(s) acting on the stone during its motion. (1)

3.2 Calculate the:

3.2.1 Time taken by the stone to reach its maximum height above the ground. (4)

3.2.2 Maximum height that the stone reaches above the ground. (4)

3.3 USING THE GROUND AS REFERENCE (zero position), sketch a position-time graph for the entire motion of the stone. (3)

FOR ENRICHMENT:

3.4 On its way down, the stone takes 0,1 s to pass a window of length 1,5 m, as shown in the diagram above.
Calculate the distance (y_1) from the top of the window to the ground. (7)

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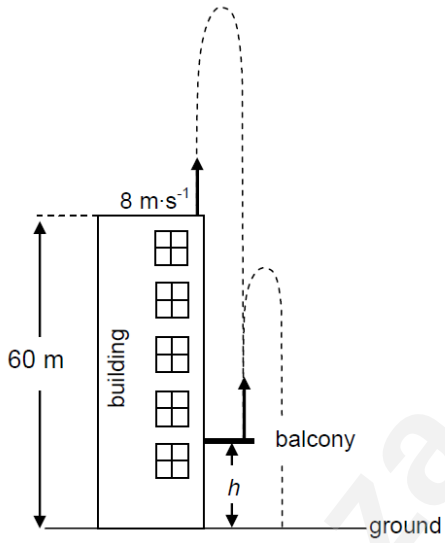
QUESTION 3 (NOV. 2012)

An object is projected vertically upwards at 8 m·s^{-1} from the roof of a building which is 60 m high. It strikes the balcony below after 4 s. The object then bounces off the balcony and strikes the ground as illustrated below. Ignore the effects of friction.



3.1 Is the object's acceleration at its maximum height UPWARD, DOWNWARD or ZERO? (1)

3.2 Calculate the:

3.2.1 Magnitude of the velocity at which the object strikes the balcony. (4)

3.2.2 Height, *h*, of the balcony above the ground. (5)

The object bounces off the balcony at a velocity of 27,13 m·s^{-1} and strikes the ground 6 s after leaving the balcony.

3.3 Sketch a velocity-time graph to represent the motion of the object from the moment it is projected from the ROOF of the building until it strikes the GROUND.

Indicate the following velocity and time values on the graph:

- The initial velocity at which the object was projected from the roof of the building
- The velocity at which the object strikes the balcony
- The time when the object strikes the balcony
- The velocity at which the object bounces off the balcony
- The time when the object strikes the ground (6)

[16]

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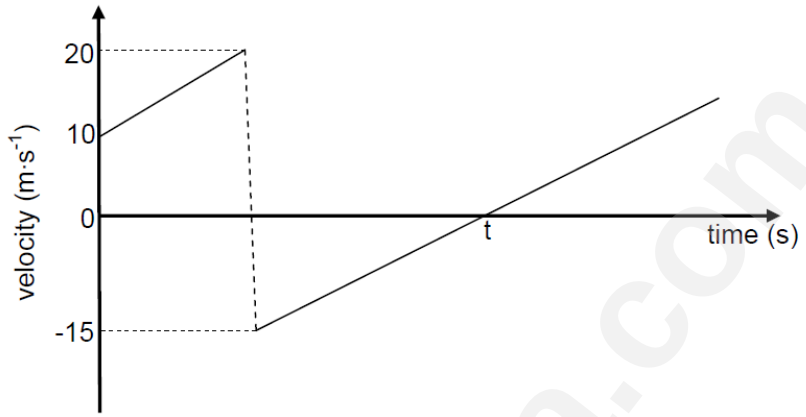
QUESTION 3 (Nov. 2013)

A ball of mass 0,15 kg is thrown vertically downwards from the top of a building to a concrete floor below. The ball bounces off the floor. The velocity versus time graph below shows the motion of the ball. Ignore the effects of air friction. TAKE DOWNWARD MOTION AS POSITIVE.



3.1 From the graph, write down the magnitude of the velocity at which the ball bounces off the floor. (1)

3.2 Is the collision of the ball with the floor ELASTIC or INELASTIC? Refer to the data on the graph to explain the answer. (3)

3.3 Calculate the:

3.3.1 Height from which the ball is thrown. (4)

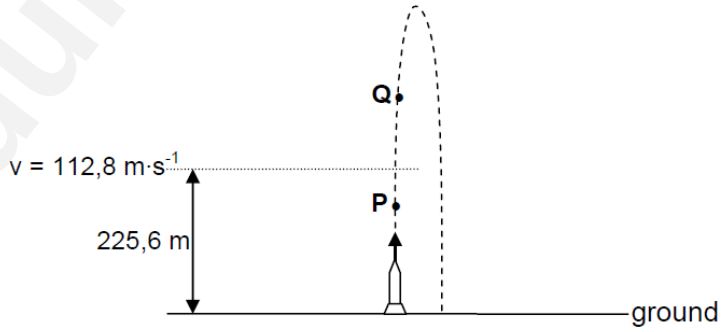
3.3.2 Magnitude of the impulse imparted by the floor on the ball. (3)

3.3.3 Magnitude of the displacement of the ball from the moment it is thrown until time *t*. (3)

[14]

QUESTION 3 (MARCH 2014)

A stationary rocket on the ground is launched vertically upwards. After 4 s, the rocket's fuel is used up and it is 225,6 m above the ground. At this instant the velocity of the rocket is 112,8 m·s^{-1}. The diagram below shows the path followed by the rocket. Ignore the effects of air friction. Assume that g does not change during the entire motion of the rocket.



3.1 Write down the direction of the acceleration of the rocket at point:

3.1.1 **P** (1)

3.1.2 **Q** (1)

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3.2 At which point (**P** or **Q**) is the rocket in free fall? Give a reason for the answer. (2)

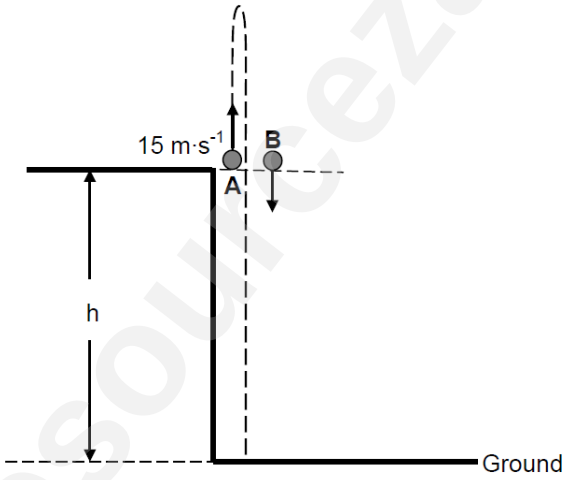
3.3 TAKING UPWARD MOTION AS POSITIVE, USE EQUATIONS OF MOTION to calculate the time taken from the moment the rocket is launched until it strikes the ground. (6)

3.4 Sketch a velocity vs time graph for the motion of the rocket from the moment it runs out of fuel until it strikes the ground. Take the time when the rocket runs out of fuel as t = 0 s. Indicate the following values on the graph:

- Velocity of the rocket when it runs out of fuel.
- Time at which the rocket strikes the ground. (5)

QUESTION 3 (NOVEMBER 2014)

A ball, **A**, is thrown vertically upward from a height, h, with a speed of 15 $m \cdot s^{-1}$. AT THE SAME INSTANT, a second identical ball, **B**, is dropped from the same height as ball **A** as shown in the diagram below.
Both balls undergo free fall and eventually hit the ground.



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

3.2 Calculate the time it takes for ball **A** to return to its starting point. (4)

3.3 Calculate the distance between ball **A** and ball **B** when ball **A** is at its maximum height. (7)

3.4 Sketch a velocity-time graph in the ANSWER BOOK for the motion of ball **A** from the time it is projected until it hits the ground.

Clearly show the following on your graph:

- The initial velocity
- The time it takes to reach its maximum height
- The time it takes to return to its starting point. (4)

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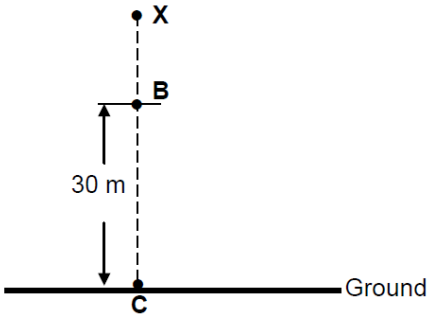
QUESTION 3 (MARCH 2015)

An object is released from rest from a point X, above the gound 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.



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

3.2 Calculate the:

3.2.1 Magnitude of the velocity of the object at point B. (4)

3.2.2 Height of point X above the ground. (5)

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

3.3 Sketch an acceleration – time graph for the entire motion of the object. (3)

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WORK ENERGY AND POWER

Work

- Define the work done on an object by a constant force F as $F\Delta x \cos\theta$, 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: $W_{nc} = \Delta K + \Delta U$
- 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: $\mathbf{P} = \frac{\mathbf{W}}{\Delta \mathbf{t}}$, where **P** is Power in Watts(W), **W** is the work done in Joules (J) and $\Delta \mathbf{t}$ is the change in time in seconds (s).

- Calculate the power involved when work is done.

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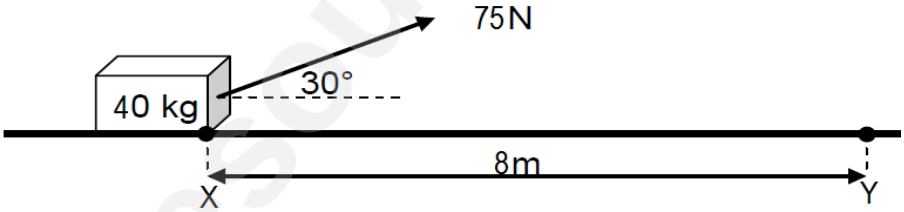
- Perform calculations using $P_{ave} = Fv_{ave}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

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.

WORKSHEET 1: WORK, ENERGY AND POWER

1. Buhle pulls a crate of mass 40 kg from rest along a horizontal floor by applying a constant force of magnitude 75 N at an angle of 30° to the horizontal. A frictional force of magnitude 20 N acts on the crate whilst moving along the floor.



1.1. Draw a labelled free-body diagram to show ALL the forces acting on the crate during its motion.

1.2. Give a reason why each of the vertical forces acting on the crate do NO WORK on the crate.

1.3. Calculate the net work done on the crate as it reaches point X, 8 m from the starting point Y.

1.4. Use the work-energy theorem to calculate the speed of the crate at the instant it reaches Point Y.

1.5. Buhle now applies a force of the same magnitude, but at a GREATER ANGLE to the horizontal, on the crate.

1.6. How does the work done by the worker now compare to the work done by the worker in QUESTION 1.3? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. Give a reason for the answer. (No calculations are required.)

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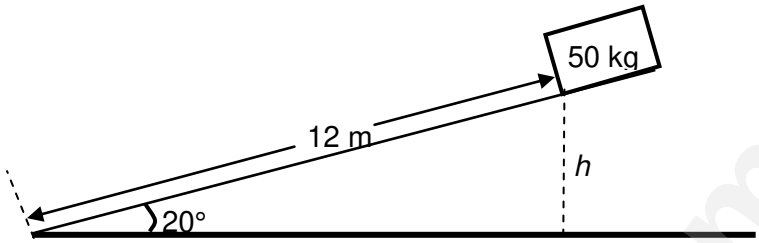
2. A box of mass 50 kg starts from rest at height h and slides down a rough slope of length 10 m, which makes an angle of 20° with the horizontal. It undergoes a constant acceleration of magnitude 3 m·s^{-2} while sliding down the slope.



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

2.2 Draw a free-body diagram to show ALL the forces acting on the cardboard box **while it slides down the slope.** (3)

The box reaches the bottom of the slope.

2.3 Calculate the following:

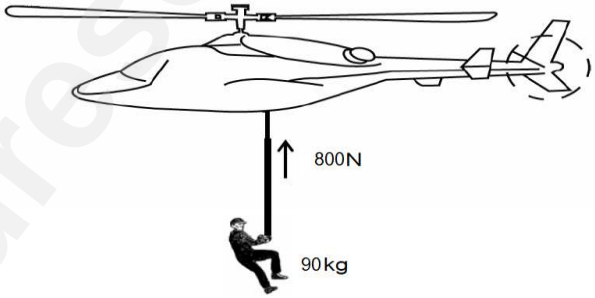
2.3.1 The kinetic energy of the box, using the equations of motion (5)

2.3.2 The work done on the box by the gravitational force (4)

2.3.3 The work done on the box by the frictional force, using the work-energy theorem (4)

2.3.4 The magnitude of the frictional force acting on the box (3)

3. A rescue helicopter is stationary (hovers) above Akwande. Akwande with mass of 90 kg is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 3 m·s^{-1}. The tension in the cable is 800 N. Assume that there is no sideways motion during the lift. Air friction is not to be ignored.



3.1 State the work-energy theorem in words.

3.2 Draw a labelled free-body diagram showing ALL the forces acting on Akwande while being lifted upwards

3.3 Write down the name of a non-contact force that acts on Akwande during the upward lift.

3.4 Use the WORK-ENERGY THEOREM to calculate the work done on Akwande by friction after oving through the height of 20 m.

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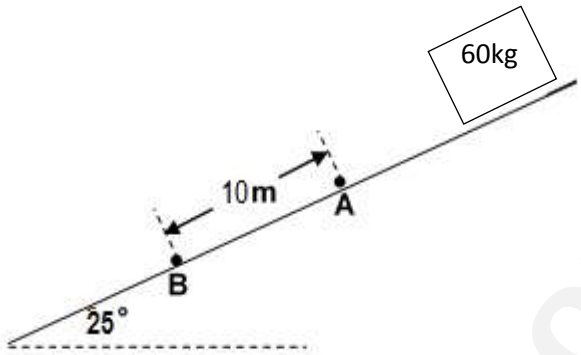
4. A crate of mass 60 kg slides down a rough incline that makes an angle of 25° with the horizontal, as shown in the diagram below. The crate experiences a constant frictional force of magnitude 80 N during its motion down the incline.



4.1 Draw a labelled free-body diagram showing ALL the forces acting on The crate while sliding down. (3)

4.2 Give a reason why perpendicular forces does no work on the crate. (2)

The crate passes point **A** at a speed of 2 $m \cdot s^{-1}$ and moves a distance of 10 m before reaching point **B** lower down on the incline.

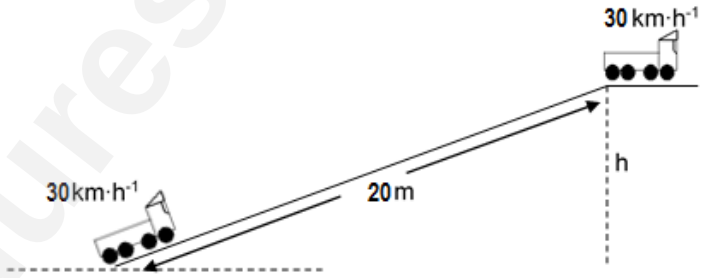
4.3 Calculate the net work done on the crate during its motion from point **A** to point **B**. (5)

4.4 Write down the work-energy theorem in words. (2)

4.5 Use the work-energy theorem to calculate the speed of the crate at point **B**. (4)

[16]

5. In South Africa the transportation of goods by trucks adds to the traffic problems on our roads. A 10 000 kg truck travels up a straight inclined road of length 20 m at a constant speed of 30 $km \cdot h^{-1}$. The total work done by the engine of the truck to get there is 650000 J. The work done to overcome friction is 85000 J.



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

5.2 Draw a labelled free-body diagram showing ALL the forces acting on the truck while moving up the inclined road. (4)

5.3 Convert 30km.hr $^{-1}$ to $m.s^{-1}$

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5.4 Calculate :

5.4.1 Force applied by the engine (3)

5.4.2 Frictional force acting on the truck (3)

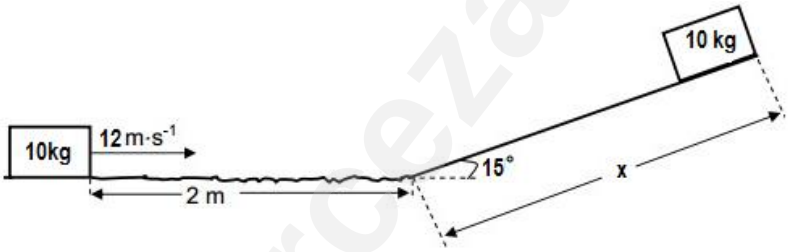
5.4.3 The height, h, reached by the truck at the top of the road (6)

5.4.4 The instantaneous power delivered by the engine of truck (6)

5.3 Arrestor beds are constructed as a safety measure to allow trucks to come to rest when their brakes fail whilst going downhill. Write down TWO design features of such arrestor beds. (2)

[14]

6 A 10 kg block slides at a constant velocity of $12 m.s^{-1}$ along a horizontal surface. It then strikes a rough surface, causing it to experience a constant frictional force of 70N. The block slides 2m under the influence of this frictional force before it moves up a frictionless ramp inclined at an angle of 15^0 to the horizontal, as shown in the diagram below. The block moves a distance x up the ramp, before it comes to rest.

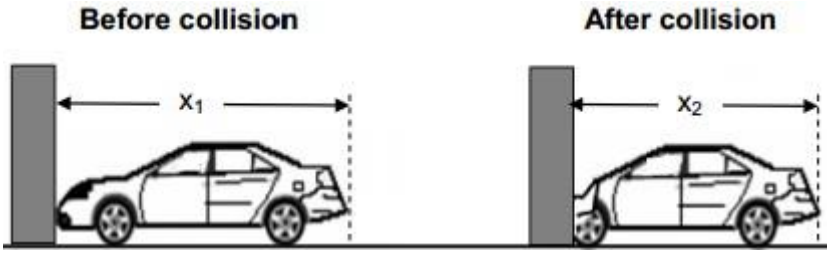


6.1 Calculate that the speed of the block at the bottom of the ramp (5)

6.2 Draw a free-body diagram to show all the forces acting on the block in a direction parallel to the incline, whilst the block is sliding up the ramp (2)

6.3 Calculate the distance, x, the block slides up the ramp (5)

7. In order to measure the net force involved during a collision, a car is allowed to collide head-on with a flat, rigid barrier. The resulting crumple distance is measured. The crumple distance is the length by which the car becomes shorter in coming to rest. In one of the tests, a car of mass 1200kg strikes the barrier at a speed of $20 m.s^{-1}$. The crumple distance, $(x_1 - x_2)$, is measured as 1,02m. (Ignore the effects of frictional forces during crumpling.)



7.1 Draw a labelled free-body diagram showing ALL the forces acting on the car during the collision. (3)

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

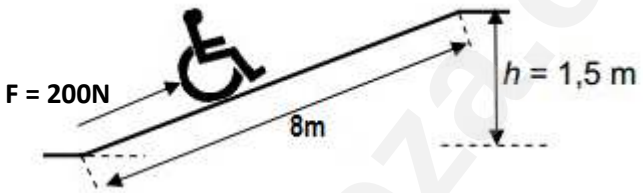
7.3. Assume that the net force is constant during crumpling.

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

7.3.2 Calculate the time it takes the car to come to rest during crumpling (4)

8. Zama applies a force F= 200N to help his friend in a wheelchair to move up a ramp of length 10m and a vertical height of 1,5m, as shown in the diagram below. The combined mass of his friend and the wheelchair is 90kg. There is constant frictional force acting between the wheels of the wheelchair and the surface. The rotational effects of the wheels of the wheelchair may be ignored.

The wheelchair moves up the ramp at constant velocity.



8.1 What is the magnitude of the net force acting on the wheelchair as it moves up the ramp? Give a reason for your answer. (2)

8.2 What is the magnitude of the net work done on the wheelchair on reaching the top of the ramp? (1)

8.3 Draw a labelled force diagram showing all the forces acting on the wheelchair. (4)

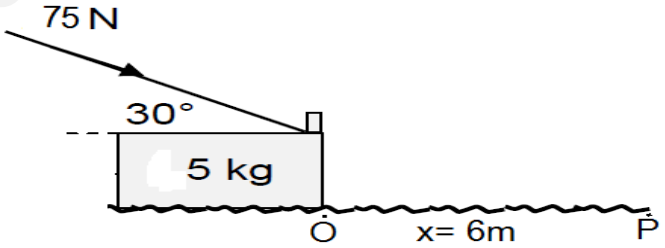
8.4 Calculate the following:

8.4.1 Work done on the wheelchair by force F (3)

8.4.2 Work done by the frictional force on the wheelchair. (5)

8.4.3 The magnitude of the frictional force exerted on the wheelchair by the surface (4)

9 The learner applies a force of 75N on a stationary block at an angle of 30° to the 5 kg block by means of a rigid rod, causing the block to move a distance of 6m from point O to P across a flat, rough, horizontal surface, as shown in the diagram below. Velocity of the block at P is $3m.s^{-1}$.



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

9.2 Draw a free-body diagram to show ALL the forces acting on the block **while sliding along the surface.** (4)

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9.3 Calculate the following:

9.3.1 Net work done on the block (4)

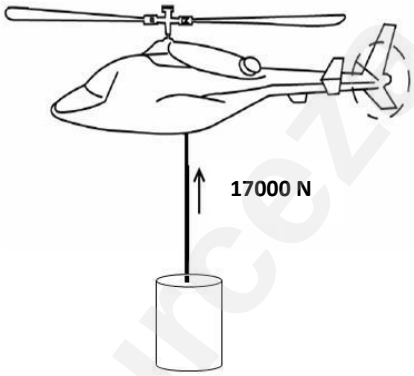
9.3.2 The work done on the box by force, F (3)

9.3.3 The work done on the box by the frictional force, using the work-energy theorem (4)

9.3.4 The magnitude of the frictional force acting on the box (3)

10. 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.

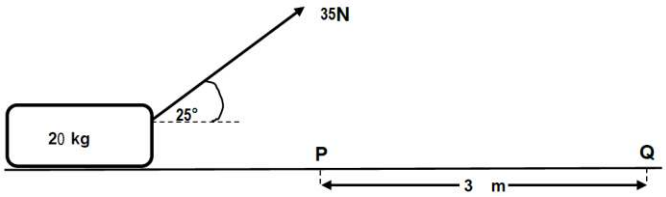


10.1 State the *work-energy theorem* in words. (2)

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

10.3 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)

11. A worker applies a constant force of 35 N on a crate of mass 20 kg, at an angle of 25° with the horizontal.When the crate reaches point P, its velocity is $14 m.s^{-1}$ and 3 m further it reaches point Q at a velocity of $10 m.s^{-1}$.



11.1 Draw a labelled free-body diagram to show the horizontal forces acting on the crate during its motion. The length of the vectors should be an indication of their relative magnitudes. (3)

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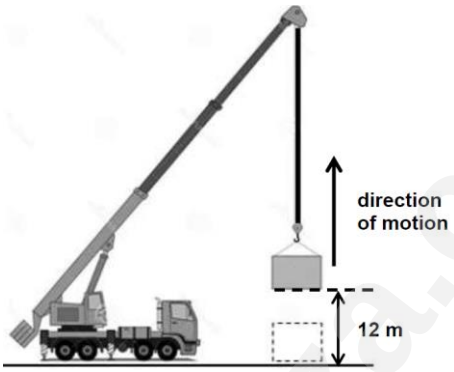
11.2 State the Work-Energy theorem in words. (2)

11.3 calculate the net work done on the crate between points P and Q.

11.4 Use ENERGY PRINCIPLES to calculate the magnitude of the frictional force acting on the crate.

12. A container of mass 120 kg, hanging from a steel cable attached to a crane is accelerated vertically upwards from **rest** through a height of 12 m, as shown in the diagram below. The container reaches a maximum speed of 5 m.s^{-1} after being lifted through a height of 12 m.



12.1 Draw a labelled free body diagram showing all the forces acting on the container as it is accelerated upwards. (3)

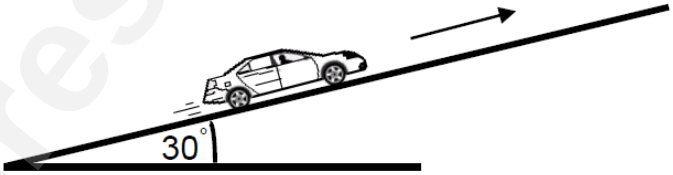
12.2 If the tension in the cable is 800 N, calculate the work done by the cable to move the container to a height of 12 m. (3)

12.3 State the Work Energy Theorem in words. (2)

12.4 Use **Energy Principles** to calculate the work done on the container by friction while it is moving to a height of 12 m. (4)

12.5 Calculate the magnitude of the frictional force acting on the container. (3)

13. A car of mass 700 kg moves up a rough inclined plane as shown in the diagram below.



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

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

The car now starts from rest at the base of the slope and accelerates up the inclined plane. The car's engine exerts a force of 6 000 N and the coefficient of kinetic friction between the wheels of the car and surface is 0,32.

13.3 Use energy principles to calculate the magnitude of the velocity of the car after moving a distance of 70 m up the incline. (8)

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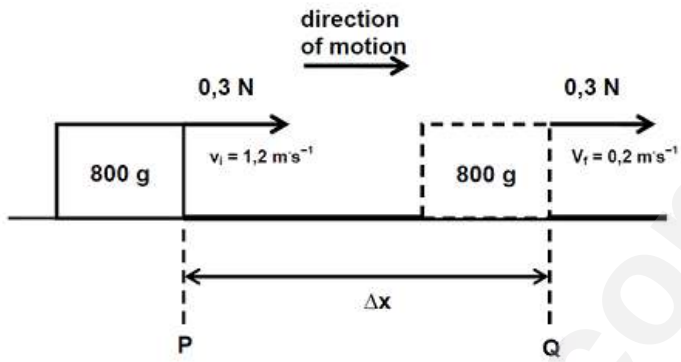
14. A block of mass 800 g moves under the influence of a force of 0,30 N. When the block reaches a velocity of 1,2 m.s^{-1}, it enters a rough surface. The block experiences a constant frictional force of 0,86 N as it moves from point P to point Q as shown below causing its speed to decrease to 0,2 m.s^{-1} after a displacement, **Δx**



14.1 Draw a labelled free body diagram showing all the forces acting on the block as it moves across the rough surface. (4)

14.2 Determine the net force acting on the block as it moves across the surface. (3)

14.3 State the Work Energy Theorem in words. (2)

14.4 Use **Energy Principles** to calculate the displacement, **Δx**, of the block (4)

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DOPPLER EFFECT

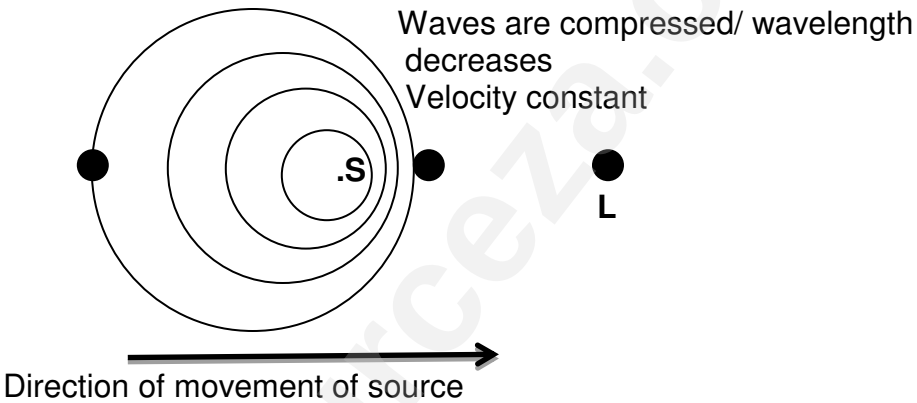
Is the apparent change in frequency of a wave, as a result of relative motion between the source and the observer.

When the source of a sound is moving towards you, the pitch sounds higher than that of the source. When the source moves away from you the pitch sounds lower. This is known as the doppler effect.

Source moving towards a stationary listener

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

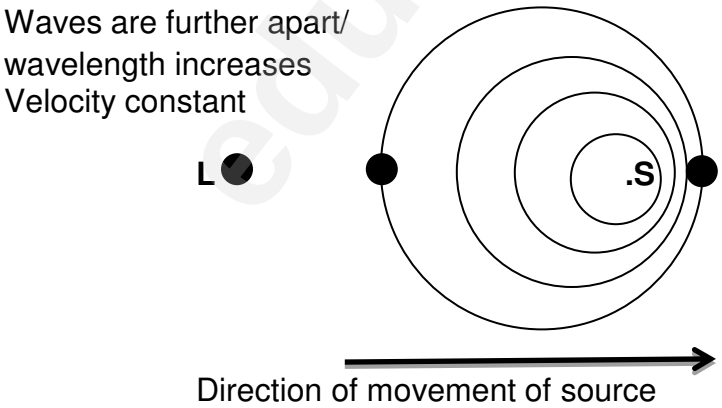
SKETCH OF WAVEFRONTS



Source moving away a stationary listener

- Wavelength increases/ waves are further apart
- Frequency decreases
- Velocity constant
- The pitch of sound decreases

SKETCH OF WAVEFRONTS



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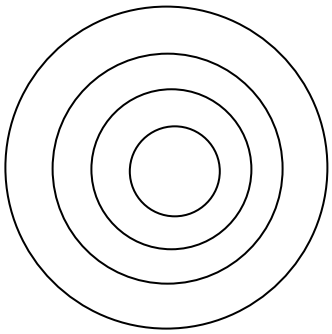
FOR A STATIONARY SOURCE/ LISTENER INSIDE A MOVING SOURCE/SOURCE NEXT TO THE LISTENER

The frequency is equal to(the same)/ wavelength is the same at all points.



No relative motion between the source and the observer.

EQUATION OF DOPPLER EFFECT

$$f_L = \frac{V \pm v_L}{V \pm v_s} \times f_s$$

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(air or water) $m.s^{-1}$

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.

RADAR GUNS

The traffic officers will point the radar gun to the oncoming traffic.

The radar gun will send the infrared waves to the oncoming car that is moving towards the traffic officer. The waves will be reflected back to the radar gun by the moving traffic. The radar gun then acts as the receiver of the waves. For classroom purposes, waves to be considered are the one coming from the traffic, so the oncoming traffic must be the moving source reflecting back waves to the radar gun. Radar gun becomes the receiver or listener. Now Doppler formula can be employed to solve for the unknowns

- Blood flow rate can be measured. (medical use)
- Speed of the planets and stars can be determined.
- Used to measure heartbeat of the unborn foetus in the womb. (medical use)
- Used in weather stations to detect precipitation.

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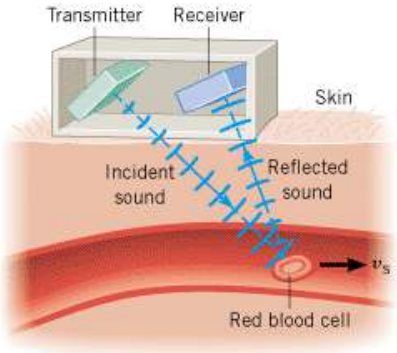
DOPPLER FLOW METER

Medical instrument that make use of Doppler effect in measuring blood flow rate



How does it work?

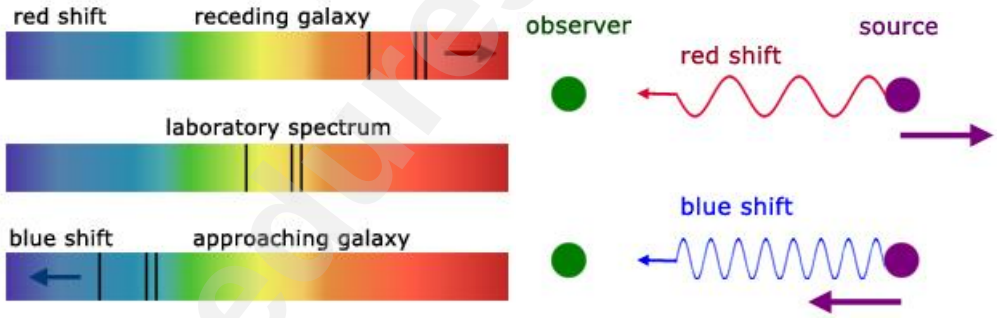
- Transmitter sends sound which is reflected off a red blood cell.
- Reflected sound has different frequency so velocity of blood cells can be measured.

RED SHIFT AND BLUE SHIFT

A **red shift** is the shift in the spectra of distant galaxies(STARS) toward longer wavelength OR toward 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.

NB: Astronomers have found that all **stars exhibit a red shift** – are moving away from the earth and from each other. This suggest the **universe is expanding**

A **blue shift** is any decrease in wavelength, with a corresponding increase in frequency, of an electromagnetic wave; the opposite effect is referred to as **red shift**. In visible light, this **shifts** the color from the **red** end of the spectrum to the **blue** end



- **Analogy to elucidate red shift**
  Shall we consider in particular a rising loaf of raisin bread, The raisins will see all other raisins moving away from it as the loaf expands

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If universe is expanding so it must be smaller at some time in the past and so at some time in the past the entire universe may have been a single point, very hot, small, dense, with no stars, planets or atoms.

Say that was about 14 billion years ago, it expanded very quickly thus the name Bing Bang – resulting in the formation of atoms, stars and galaxies.

QUESTION 1 FREE STATE 2015

Light emitted from distant stars demonstrates the phenomenon known as red shift.

1.1 Explain how the phenomenon known as *red shift* can be used to explain an expanding universe. (2)

1.2 A submarine can use the Doppler effect to detect the speed of ship. A submarine at rest and just below the surface of the water, detects the frequency of a moving ship as 437 Hz, 0,985 times the actual frequency of the sound emitted by the ship. The speed of sound in water is 1470 $m \cdot s^{-1}$.

1.2.1 Is the ship moving away from or towards the submarine? Give a reason for your answer. (2)

1.2.2 Calculate the speed of the ship. (5)

1.3 Name two applications of the Doppler effect in Medical Science. (2)

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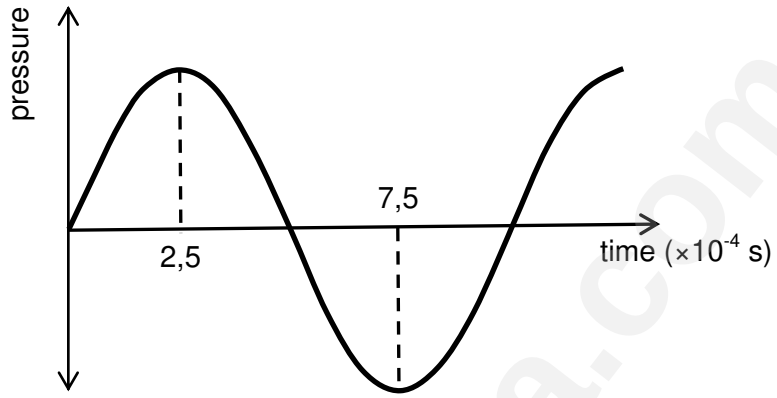
QUESTION 2 MPUMALANGA 2015

A man mounts a siren, which produces a constant frequency of 800 Hz, on the roof of his car. He drives at a constant speed up and down a straight road while a stationary learner measures the observed sound. At a certain stage of the journey, the learner obtains the following pressure-time graph of the sound wave:



2.1 What is the period of the detected sound wave? (1)

2.2 Calculate the frequency of the detected sound wave. (3)

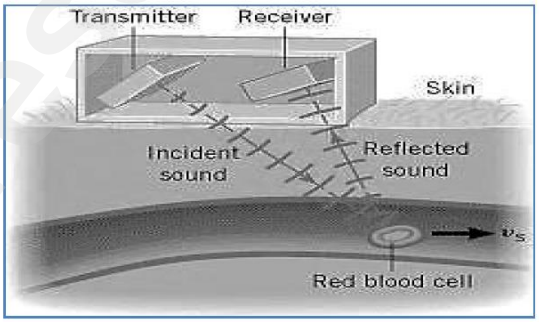
2.3 State the Doppler-effect in words. (2)

2.4 Calculate the speed of the moving car. Take the speed of sound in air as 340 m·s^{-1}. (5)

2.5 While the car is stationary, the frequency of the siren is changed to 900 Hz. Will the wavelength of the detected sound wave INCREASE, DECREASE or REMAIN THE SAME? Explain the answer. (3)

QUESTION 3 WESTERN CAPE 2014

Use the diagram below to answer the following questions:



3.1 Identify the medical device shown in the diagram. (1)

3.2 Explain very briefly how the device functions and what it may be used for. (2)

3.3 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.

3.3.1 Name the phenomenon observed. (1)

3.3.2 If the speed of sound in air is 340 m·s-1, calculate the speed of the fire truck. (4)

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QUESTION 4 FS 2014

Light emitted from distant stars demonstrates the phenomenon known as red shift.

4.1 Explain how the phenomenon known as *red shift* can be used to explain an expanding universe. (2)

4.2 A submarine can use the Doppler effect to detect the speed of ship. A submarine at rest and just below the surface of the water, detects the frequency of a moving ship as 437 Hz, 0,985 times the actual frequency of the sound emitted by the ship. The speed of sound in water is 1470 $m \cdot s^{-1}$.

4.2.1 Is the ship moving away from or towards the submarine? Give a reason for your answer. (2)

4.2.2 Calculate the speed of the ship. (5)

4.3 Name two applications of the Doppler effect in Medical Science. (2)

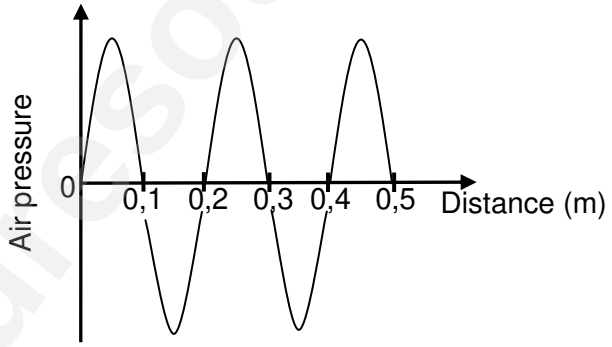
QUESTION 5 Nov 2012

A bird flies directly towards a stationary birdwatcher at constant velocity. The bird constantly emits sound waves at a frequency of 1 650 Hz. The birdwatcher hears a change in pitch as the bird comes closer to him.

5.1 Write down the property of sound that is related to pitch. (1)

5.2 Give a reason why the birdwatcher observes a change in pitch as the bird approaches him. (1)

The air pressure versus distance graph below represents the waves detected by the birdwatcher as the bird comes closer to him. The speed of sound in air is 340 $m \cdot s^{-1}$.



5.3 From the graph, write down the wavelength of the detected waves. (1)

5.4 Calculate the:

5.4.1 Frequency of the waves detected by the birdwatcher (3)

5.4.2 Magnitude of the velocity at which the bird flies (5)

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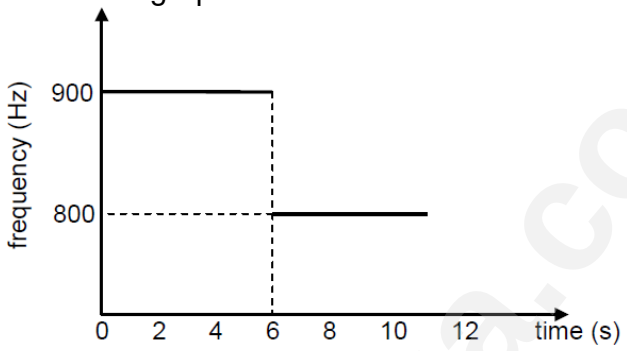
QUESTION 6 (FEB-MARCH 2013)

The siren of a stationary ambulance emits sound waves at a frequency of 850 Hz.
An observer, travelling in a car at a constant speed in a straight line, begins measuring the frequency of the sound waves emitted by the siren when he is at a distance *x* from the ambulance.

The observer continues measuring the frequency as he approaches, passes and moves away from the ambulance.

The results obtained are shown in the graph below.



6.1 The observed frequency suddenly changes at t = 6 s. Give a reason for this sudden change in observed frequency.

6.2 Calculate the:

6.2.1 Speed of the car (5)
(Take the speed of sound in air as 340 $m \cdot s^{-1}$.)

6.2.2 Distance *x* between the car and the ambulance when the observer BEGINS measuring the frequency (3)

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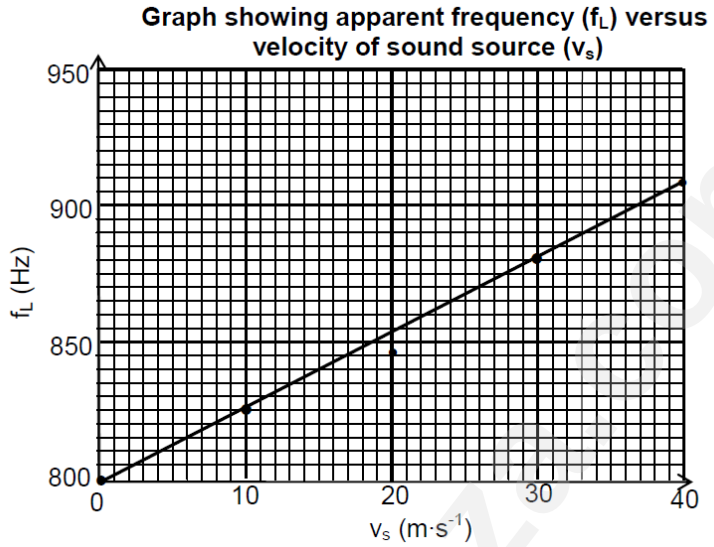
QUESTION 7 (MAY-JUNE 2015)

The graph below shows the relationship between the apparent frequency (*f*L) of the sound heard by a STATIONARY listener and the velocity (vs) of the source travelling TOWARDS the listener.



7.1 State the Doppler effect in words. (2)

7.2 Use the information in the graph to calculate the speed of sound in air (5)

7.3 Sketch a graph of apparent frequency (f_L) versus velocity (v_s) of the sound source if the source was moving AWAY from the listener. It is not necessary to use numerical values for the graph. (2)

QUESTION 8 FEB-MARCH 2009

Dolphins use ultrasound to scan their environment. When a dolphin is 100 m from a rock, it emits ultrasound waves of frequency 250 kHz whilst swimming at 20 $m \cdot s^{-1}$ towards the rock. Assume that the speed of sound in water is 1 500 $m \cdot s^{-1}$.

8.1 Calculate the frequency of the sound waves detected by a detector on the rock. (4)

8.2 When the dolphin is 50 m from the rock, another ultrasound wave of 250 kHz is emitted.

How will the frequency of the detected sound waves compare with the answer calculated in QUESTION 8.1? Write down only HIGHER, LOWER or REMAINS THE SAME. Explain your answer. (2)

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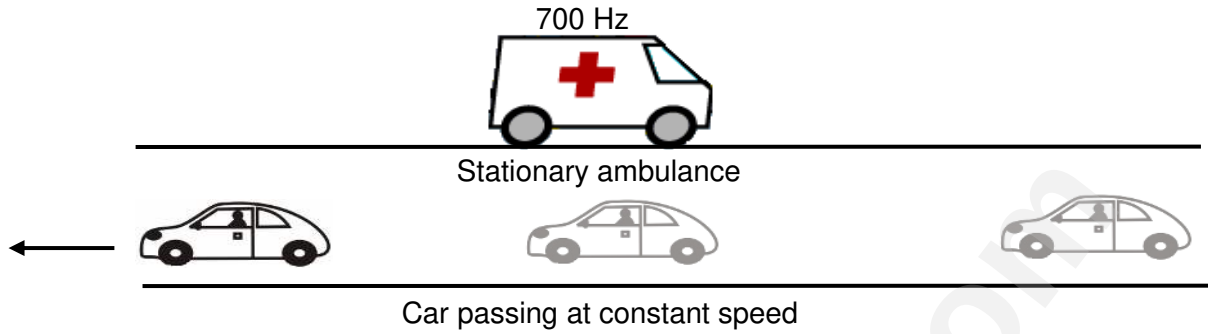
QUESTION 9 DBE ADDITIONAL EXEMPLAR 2008

The sketch below shows a stationary ambulance. The siren of the ambulance emits sound waves of frequency 700 Hz.



The driver of a car approaching the ambulance and passing it at constant speed, observes the frequency of the emitted sound waves to change by 80 Hz.

9.1 Name and state the wave phenomenon illustrated on the previous page. (3)

9.2 Take the speed of sound in air as 340 $m \cdot s^{-1}$ and calculate the speed at which the car passes the ambulance. (5)

QUESTION 10 KZN PREP 2008

An ambulance moving at 40 $m \bullet s^{-1}$ approaches a traffic light where a blind man and his dog wait to cross the road. The siren of the ambulance emits sound waves at a frequency of 350 Hz. The pitch of the sound that the man hears gets higher as the ambulance moves towards him and decreases as the ambulance passes him and moves away

10.1 Use a sketch of wave fronts to show why the pitch of the sound that the blind man hears is:

10.1.1 higher as the ambulance approaches him (2)

10.1.2 lower as the ambulance moves away from (2)

10.2 If the speed of sound in air is accepted as 340 $m \bullet s^{-1}$, determine the apparent frequency of the sound waves that the man hears while the ambulance approaches him. (5)

10.3 Explain how this effect can benefit a blind person. (2)

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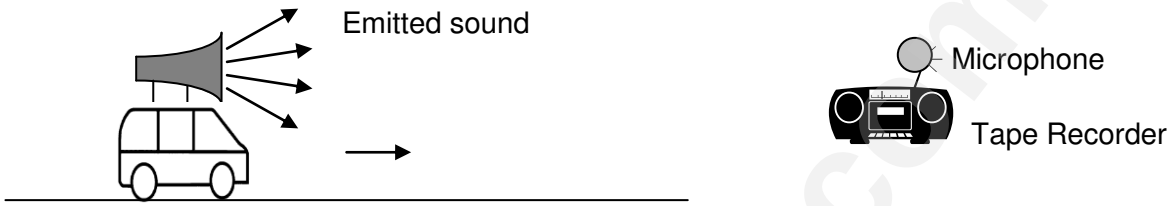
QUESTION 11 KZN PREP 2012

During an experiment to determine if the Doppler effect is symmetrical, learners are given a siren that sounds a single note of frequency 426 Hz. They attach it to a remote controlled car and move the car at a constant speed on a frictionless runway past a stationary tape recorder which is mounted at the side but in line with the middle of the runway. The tape recorder records the sound of the siren.



11.1 Define the Doppler effect (2)

11.2 List TWO factors that must be kept constant during this experiment. During the experiment the speed of the remote controlled car was maintained at a constant 19,8 $km.hr^{-1}$ and while the speed of sound in air was 343 $m.s^{-1}$. (2)

11.3 Calculate the frequency of the note from the siren when the remote controlled car ...

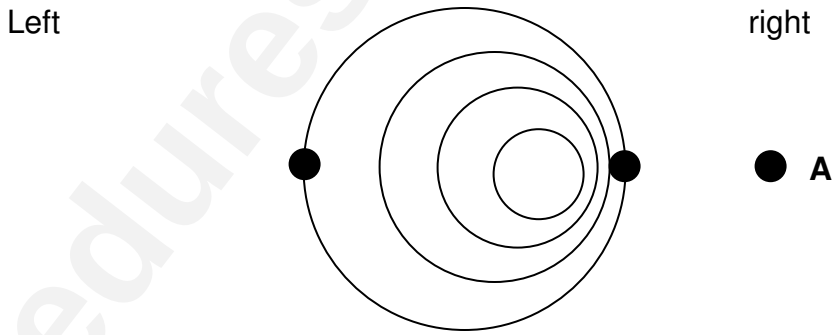
11.3.1 approaches the tape recorder (4)

11.3.2 passes the tape recorder. (3)

11.4 Use your answers to question 6.3 to explain whether the Doppler effect is symmetrical. (3)

QUESTION 12

The sketch below shows a moving source of sound waves. It illustrates the phenomenon known as the Doppler Effect.



12.1 According to the sketch, is the source moving to the left or to the right?. (2)

12.2 What happens to the observed wavelength of the waves to the left of the source? (2)

12.3 Assume you are standing at point A which is located to the right of the sketch. How will the pitch of the sound you hear differ from its pitch when the source is stationary? (2)

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12.4 A ship travelling at a constant speed of 5,19 $m \cdot s^{-1}$ emits sound waves from its siren at a frequency of 440 Hz. A submarine lying motionless under water, in front of the ship,detects the sound waves coming from the ship at a frequency of 441,56 Hz.
Use the given information to determine the speed of sound waves in water. (6)

QUESTION 6 (NOVEMBER 2014)

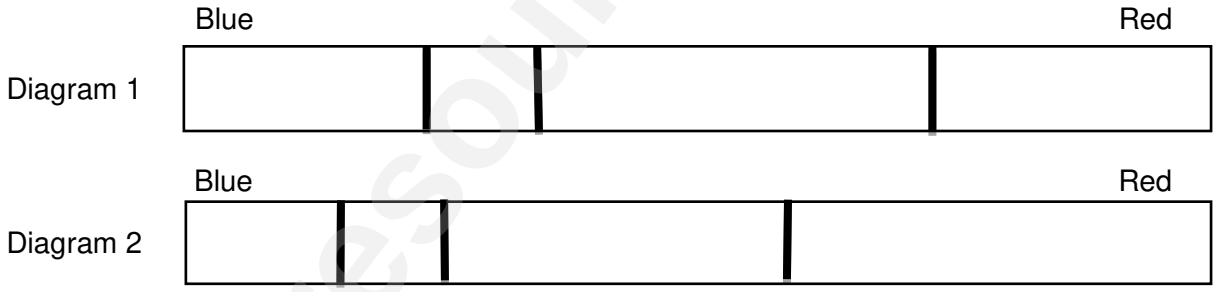
6.1 The siren of a stationary ambulance emits a note of frequency 1 130 Hz. When the ambulance moves at a constant speed, a stationary observer detects a frequency that is 70 Hz **higher** than that emitted by the siren.

6.1.1 State the Doppler effect in words. (2)

6.1.2 Is the ambulance moving *towards* or *away from* the observer? Give a reason for the answer. (2)

6.1.3 Calculate the speed at which the ambulance is travelling. Take the speed of sound in air as 343 $m \cdot s^{-1}$. (5)

6.2 A study of spectral lines obtained from various stars can provide valuable information about the movement of the stars.
The two diagrams below represent different spectral lines of an element. Diagram **1** represents the spectrum of the element in a laboratory on Earth. Diagram **2** represents the spectrum of the same element from a distant star.



Is the star moving *towards* or *away from* the Earth? Explain the answer by referring to the shifts in the spectral lines in the two diagrams above. (2)

QUESTION 6 (NOV. 2013)

An ambulance approaches a stationary observer at a constant speed of 10,6 $m \cdot s^{-1}$, while its siren produces sound at a constant frequency of 954,3 Hz. The stationary observer measures the frequency of the sound as 985 Hz.

6.1 Name the medical instrument that makes use of the Doppler effect. (1)

6.2 Calculate the velocity of sound. (5)

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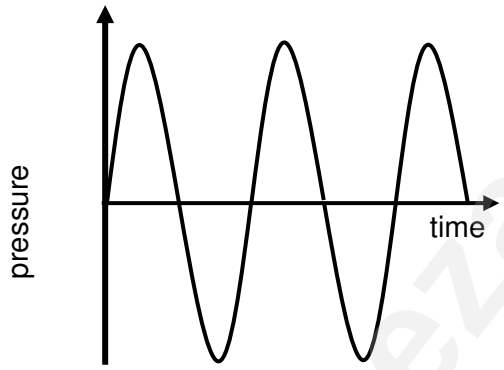
6.3 How would the wavelength of the sound wave produced by the siren of the ambulance change if the frequency of the wave were higher than 954,3 Hz? Write down only INCREASES, DECREASES or STAYS THE SAME. (1)

6.4 Give a reason for the answer to QUESTION 6.3. (2)

QUESTION 6 (SEPTEMBER 2014)

The following is a pressure versus time graph (not drawn to scale) for the sound waves emitted from the siren of a stationary ambulance as detected at a given point.



The ambulance now moves towards the detector at a speed of 31,50 $m \cdot s^{-1}$. The detector records a reading of 445 Hz.

6.1 Copy the above graph in your answer book and label it P. On the same system of axes draw the graph that best represents the sound wave, that was emitted by the siren of the ambulance as it moved towards the detector. (2)

6.2 Describe the phenomenon observed in QUESTION 6.1. (2)

6.3 Calculate the frequency of the sound waves emitted by the siren of the ambulance. The speed of sound in air is 340 $m \cdot s^{-1}$. (6)

6.4 Describe ONE positive impact of the above phenomenon in medicine. (3)

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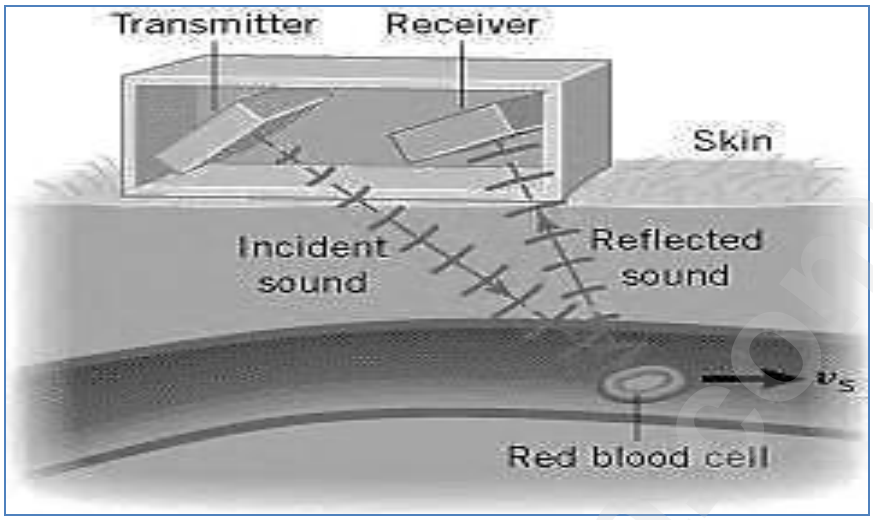
QUESTION 5 (SEPTEMBER 2014 WC)

Use the diagram below to answer the following questions.



5.1 Identify the medical device shown in the diagram. (1)

5.2 Explain very briefly how the device functions and what it may be used for. (2)

5.3 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.

5.3.1 Name the phenomenon observed. (1)

5.3.2 If the speed of sound in air is 340 $m \cdot s^{-1}$, calculate the speed of the fire truck. (4)

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ELECTROSTATICS

LEARNERS MUST BE ABLE TO DO THE FOLLOWING:

- Define electrostatics, electric field and electric field at a point.
- Understand that like charges repel, unlike charges attract.
- Name the unit of charge, electrostatic force, electric field strength.
- Convert unit of charge to Coulomb's
- Describe what it means to say that, ''charge is conserved"
- Apply the principle of conservation of charge.
- Apply the principle of quantisation of charge.**(n=** $\frac{Q}{q_e}$**)**
- State Coulomb's Law
- Apply Coulomb's Law for charges in two dimensions (2D) – for three charges in a right-angled formation (limit to charges at the 'vertices of a right-angled triangle').
- Draw electric field patterns for a one point charge, two point like and unlike charges and a charged sphere.(Restrict to situations in which the charges are identical in magnitude)
- Solve problems using the equation E=$\frac{F}{q}$
- Calculate the electric field at a point due to a number of point charges, using the Equation **E=k**$\frac{Q}{r^2}$ to determine the contribution to the field due to each charge. Restrict to three charges in a straight line.

QUESTION 1 (SEPTEMBER 2014 WC)

1.1 The centres of two identical metallic spheres, each carrying a charge Q, are a distance r apart. Which ONE of the following pairs of changes (that are made simultaneously) will double the electrostatic force that one charged sphere exerts on the other?

	Distance between centres of spheres	Magnitude of charges
A	decrease distance to $\frac{r}{2}$	double the charge on each sphere
B	decrease distance to $\frac{r}{2}$	reduce the charge on one sphere to $\frac{Q}{2}$
C	decrease distance to $\frac{r}{\sqrt{2}}$	reduce the charge on one sphere to $\frac{Q}{2}$
D	decrease distance to $\frac{r}{\sqrt{2}}$	double the charge on each sphere

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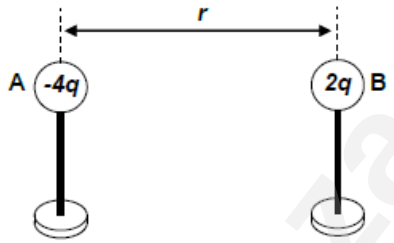
1.2 Which ONE of the following combinations is correct regarding the properties of electric field lines?

	Direction	Strength of field
A	Positive to negative	Strongest where the lines are the most dense
B	Negative to positive	Weakest where the lines are the least dense
C	North to south	Strongest where the lines are the most dense
D	North to south	Weakest where the lines are the least dense

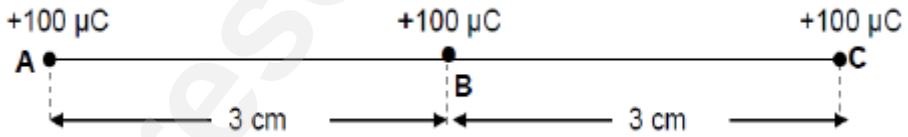
1.3 Two charged spheres, A and B, are placed on insulated stands a distance ***r*** apart, as shown below. The magnitude of the electrostatic force between them is F.



A **8F** **B** **F** **C** ½***F*** **D** ⅛***F***

QUESTION 6 (SEPTEMBER 2014 WC)

Three +100 μC point charges, **A**, **B** and **C**, are equally spaced on a straight line in a vacuum. The charges are a distance of 3 cm from each other as shown in the sketch below.



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

6.2. Draw the electric field lines associated with charge **A** only. (2)

6.3. Calculate the magnitude of the electric field strength at the position where charge **B** is and due to charge **A** only. (3)

6.4. Write down Coulomb's Law in words. (2)

6.5. Calculate the net electrostatic force experienced by point charge C due to charges **A** and **B**. (8)

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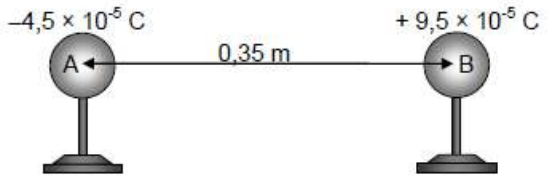
QUESTION 8 (Start on a new page.)

The diagram below shows two spheres, A of charge $-4,5 \times 10^{-5}$ C and B of charge $+ 9,5 \times 10^{-5}$ C on insulated stands. The distance between the centres of the two spheres is 0,35 m.



8.1 Draw the field pattern diagram for the net electric field present between the two Charges. (3)

8.2 Calculate the magnitude and direction of the electrostatic force exerted by sphere B on sphere A. (4)

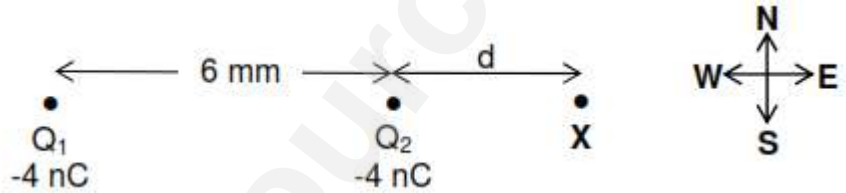
8.3 Calculate the strength of the electric field at B as a result of charge A. (4)

A third sphere C of $+ 5,2 \times 10^{-5}$C is placed between sphere A and B at 0,2m away from A.

8.4 Calculate the net force experienced by C due to charges A and B. (6)

QUESTION 7 (Start on a new page.)

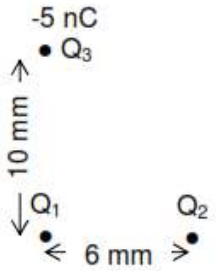
In the diagram below, a point charge, Q_2 , with a charge of -4 nC is placed 6 mm east of an identical point charge Q_1 . Point **X** is a distance **d** east of Q_2.



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

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

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



7.3 Write down Coulomb's law in words. (2)

7.4. Calculate the net force that the charge Q_1 will experience due to the charges Q_2 and Q_3 (8)
.

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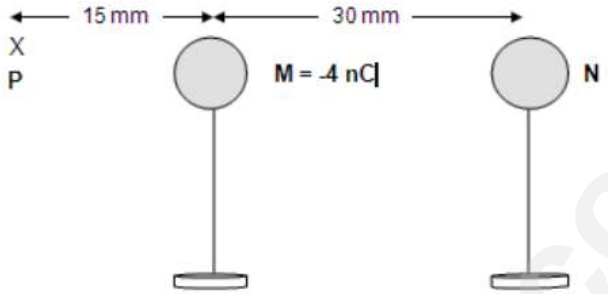
QUESTION 7 (Start on a new page.)

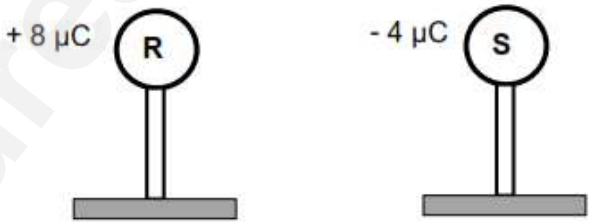
Two metal spheres, **M** and **N,** are on insulated stands. **M** with charge of -4 nC is placed 30 mm away from **N**. **P** is a point at a distance 15 mm from sphere **M** as shown below.
The NET ELECTRIC FIELD STRENGTH at point **P** due to presence of **M** and **N** is 2×10^5 N•C^{-1} eastwards.



7.1. Define the term *ELECTRIC FIELD* at a point. (2)
7.2 Calculate the magnitude and direction of the electric field at point **P** due to the presence of sphere **M**. (5)
7.3 Calculate the magnitude of the charge on sphere **N** (5)
7.4 Is the charge on sphere **N,** POSITIVE or NEGATIVE? (1)
7.5 Sketch the net electric field pattern due to the two spheres, **M** and **N** (3)
7.6 Calculate the magnitude of the electric force that an electron will experience when placed at point **P** (3)

QUESTION 7

The diagram below shows two small identical metal spheres, **R** and **S**, each placed on a wooden stand. Spheres **R** and **S** carry charges of + 8 µC and - 4 µC respectively.
Ignore the effects of air.



7.1 Explain why the spheres were placed on wooden stands. (1)
Spheres **R** and **S** are brought into contact for a while and then separated by a small distance.
7.2 Calculate the net charge on each of the spheres. (2)
7.3 Draw the electric field pattern due to the two spheres **R** and **S**. (3)

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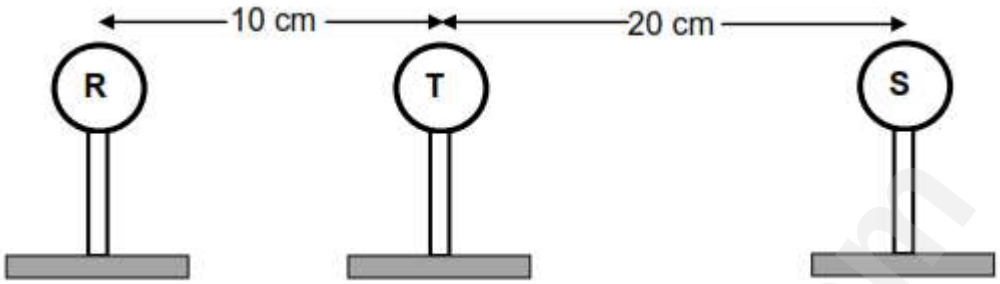
After **R** and **S** have been in contact and separated, a third sphere, **T**, of charge + 1 μC is now placed between them as shown in the diagram below.



7.4 Draw a free-body diagram showing the electrostatic forces experienced by sphere **T** due to spheres **R** and **S**. (2)

7.5 Calculate the net electrostatic force experienced by **T** due to **R** and **S**. (6)

7.6 Define the *electric field at a point*. (2)

7.7 Calculate the magnitude of the net electric field at the location of **T** due to **R** and **S**. (Treat the spheres as if they were point charges.) (3)

[19]

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ELECTRIC CIRCUIT

LEARNERS MUST BE ABLE TO DO THE FOLLOWING:

- **Define current, resistance and potential difference.**
- State Ohm's law in words: The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.
- **Explain what is meant by emf of a cell or a battery(e.g what is the meaning of emf of 12 V of a cell or battery)**
- Determine the relationship between current, potential difference and resistance at constant temperature using a simple circuit.
- State the difference between *ohmic conductors* and *non-ohmic conductors* and give an example of each.
- Solve problems using $R = \frac{V}{I}$ for series and parallel circuits (maximum four resistors).
- **Draw and interpret electric circuits graphs(Ohm's law and determining internal resistance)**
- Define *power* as the rate at which work is done.
- Solve problems using $P = \frac{W}{\Delta t}$
- Solve problems using $P = VI$,$P = I^2R$ and $P = \frac{V^2}{R}$
- Solve circuit problems involving the concepts of power and electrical energy.
- Deduce that the kilowatt hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour.
- Calculate the cost of electricity usage given the power specifications of the appliances used, the duration and the cost of 1 kWh.
- Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel (maximum four resistors).
- Explain the term *internal resistance as the opposition to the flow of charge within the battery or cell*.
- Solve circuit problems using *emf* = Vload + Vinternal resistance or emf =IR+ Ir.
- Solve circuit problems, with internal resistance, involving series-parallel networks of resistors (maximum four resistors).

WESTERN CAPE

1.8 When electrical energy must be transported over long distances, the energy loss can be minimized if:

A the current is high and the voltage is low
B the voltage is high and the current is low
C both the current and voltage is low
D both the current and voltage is high

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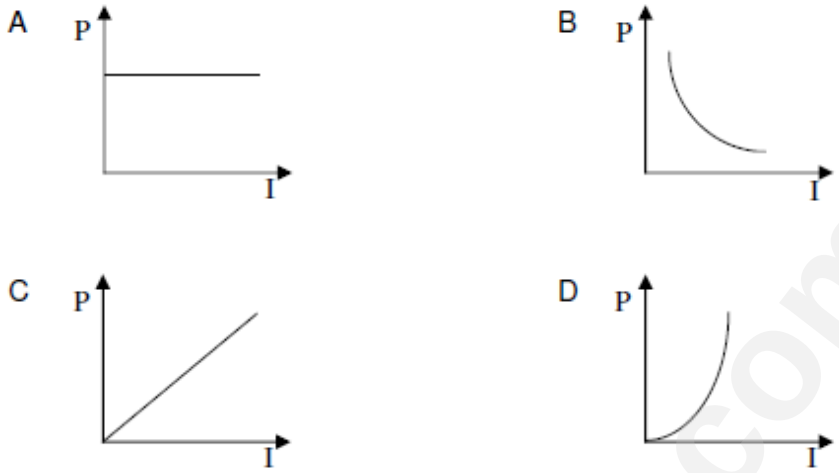
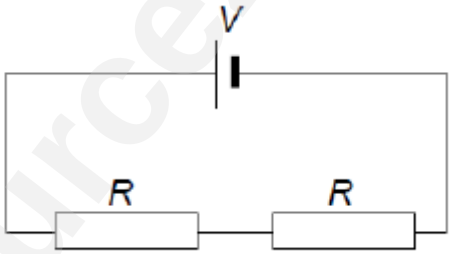
1.9. Which ONE of the following graphs best represents the relationship between the electrical power and the current in a given ohmic conductor?



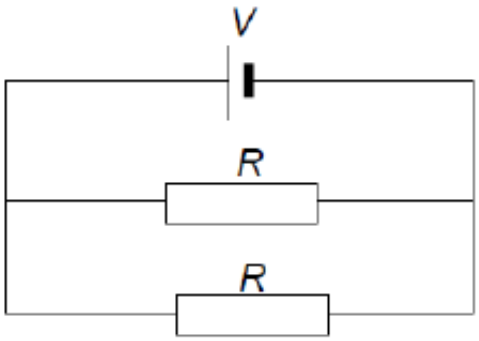
1.10 . The two resistors in circuit 1 below are identical. They are connected in series to a cell of emf *V* and negligible internal resistance. The power dissipated by each resistor is *P*.

Circuit 1



The two resistors are now connected in parallel, as shown in circuit 2 below.

Circuit 2



The power dissipated by each resistor in the circuit 2 is …

A 2P B 4P C 8P D 16P

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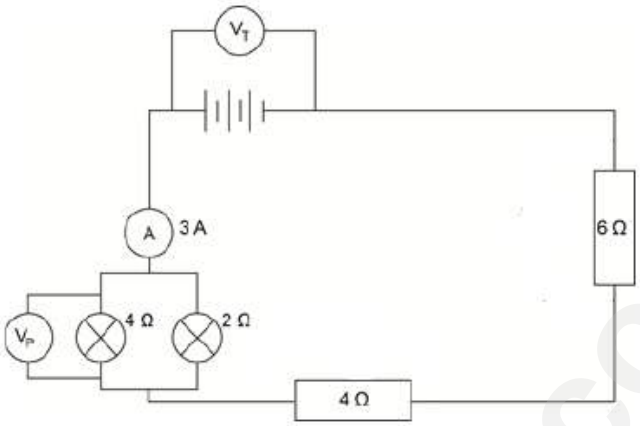
1.8 The circuit diagram shows two light bulbs of resistance 4 Ω and 2 Ω each connected in parallel to the circuit. The two resistors of resistance 4 Ω and 6 Ω each are connected in series to the circuit.



If the 2Ω light bulb burns out what happens to the reading on V_P ?

A Stays the same
B Decreases
C Increases
D Becomes zero

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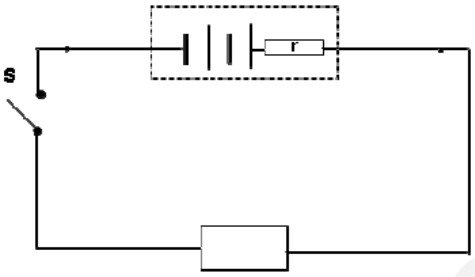
QUESTION 7 (SEPTEMBER 2014 WC)

Candice and Andisiwe conduct an investigation to determine the emf and the internal resistance (r) of an unknown battery by experiment using three resistors. They use the circuit below with first one resistor in series, then two resistors in series and then three resistors in series. They also connect a voltmeter and an ammeter in this circuit.



When switch S was closed, they obtained the following results:

Number of resistors	Voltmeter reading (v)	Ammeter reading (A)
3	10,2	1,5
2	9,6	2,0
1	7,8	3,5

7.1 Sketch this circuit in your answer book. Show in your sketch where the learners connected the ammeter and the voltmeter. (2)

7.2 Calculate the value of ε and r that they obtained in their investigation by using their results. (7)

(9)

QUESTION 8

In the circuit represented below, the battery has an unknown internal resistance and an emf of 12 V. When current flows through the circuit, the voltmeter across the battery reads 10 V and a voltmeter across R2 reads 4 V

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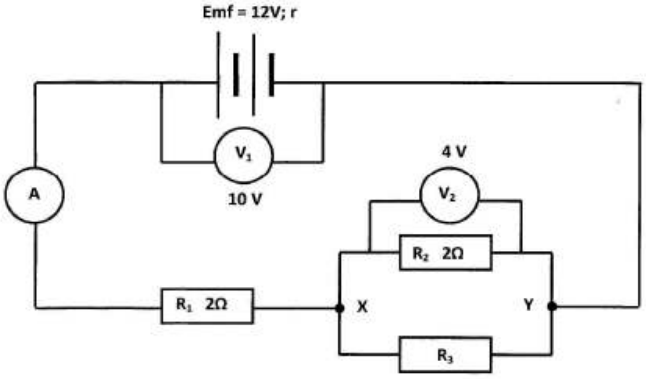


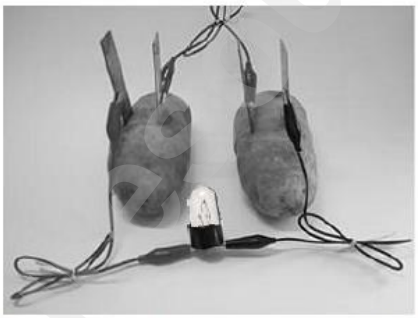
8.1. Explain what is meant by the emf of a cell. (1)
8.2 Calculate the current through R1 (4)
8.3 Determine the internal resistance of the battery (3)
8.4 Determine the resistance of R3. (4)
8.5 Explain what would happen to the current and resistance in the circuit if R3 was removed from the circuit and replaced with a wire of negligible resistance. Hence what will happen to the reading on V1. (4)

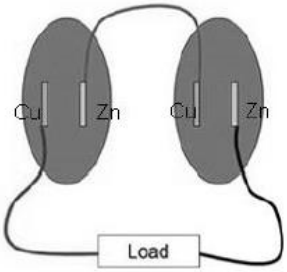
QUESTION 9

Sandile and Peter built a battery for the science fair. They used potatoes for the cells with zinc and copper plates as electrodes.

Sandile and Peter were curious to find out how many potato cells connected in series would be needed to make a penlight bulb glow.

9.1 Write a suitable hypothesis for the investigation. (2)





http://www.sciencebuddies.org/science-fair-projects/project_ideas/Energy_p010.shtml#procedure

9.2 Write down the dependent variable for the investigation. (1)

Sandile and Peter started with two potatoes connected in series as shown in the picture above. They used a voltmeter directly over the outer electrodes and measured a potential difference of 1,6 V. Next they connected a 1,5 V penlight bulb between the electrodes. The learners found that the bulb did not glow. When they measured the potential difference across the globe it was 0,02V.

9.3 What is the emf of the battery with two potato cells connected in series? (1)
9.4 Give a reason why the potential difference across the bulb was only 0,02V. (1)
9.2 Write down the dependent variable for the investigation. (1)

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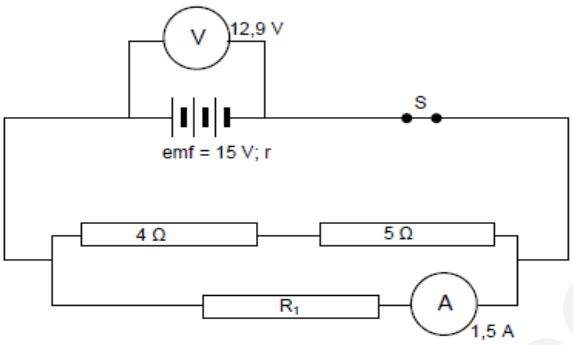
QUESTION 10

The circuit diagram below shows two resistors of resistance 4 Ω and 5 Ω each connected in parallel to resistor R1 of unknown resistance. The battery has an emf of 15 V and an unknown internal resistance.



10.1 State Ohm's law in words. (2)

When switch S is closed, the ammeter has a reading of 1,5 A and the voltmeter has a reading of 12,9 V.

10.2 Calculate the resistance of resistor R1. (3)

10.3 Calculate the equivalent resistance of the parallel circuit. (3)

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

ELECTRODYNAMICS

Electrical machines (generators, motors)

- State the energy conversion in generators.
- Use the principle of electromagnetic induction to explain how a generator works.
- Explain the functions of the components of an AC and a DC generator.
- State examples of the uses of AC and DC generators.
- State the energy conversion in motors.Use the motor effect to explain how a motor works.
- Explain the functions of the components of a motor.
- State examples of the use of motors.

Alternating current

- State the advantages of alternating current over direct current.
- Sketch graphs of voltage versus time and current versus time for an AC circuit.
- Define the term *rms* for an alternating voltage or an alternating current. The rms value of AC is the DC potential difference/current which dissipates the same amount of energy as AC.

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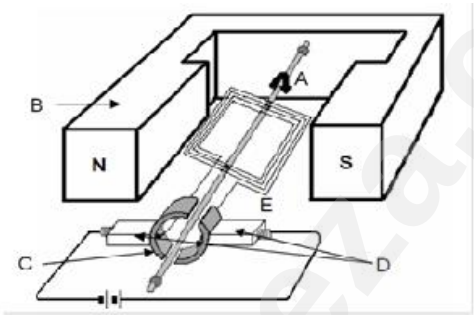
Solve problems using $I_{rms} = \frac{I_{max}}{\sqrt{2}}$, $V_{rms} = \frac{V_{max}}{\sqrt{2}}$.

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

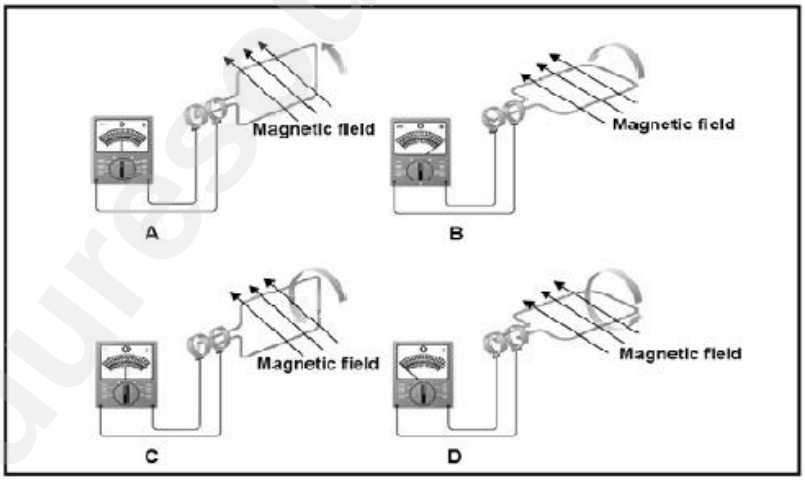
QUESTION 9 (SEPTEMBER 2014 WC)

Electric motors are used in pumps, fans and compressors. Electric motors can be either AC or DC. The diagram below illustrates one of these types of electric motors.



9.1 What type of electric motor (AC or DC) is illustrated in the diagram? Give a reason for your answer.

9.2 The diagrams A to D below show four positions in sequence during the anti-clockwise rotation of the coil of a simple AC generator.



9.2.1 Name the fundamental principle on which generators work. (1)

9.2.2 What is the purpose of the slip rings in an AC generator? (1)

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9.2.3 By referring to the relative positions of the coil in positions A to D, draw the corresponding graph of potential difference versus time for one full rotation (A to D to A). Indicate the positions of the coil (by using the letters A to D) on your graph. (3)

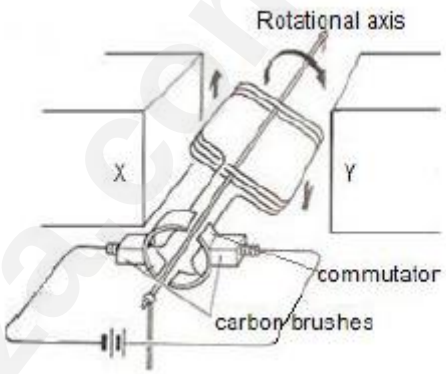
9.3 A certain AC generator (alternator) produces a peak current (Imax) of 6,43 A when connected to an electrical heater of resistance 48,4 _.

9.3.1 Calculate the rms current (Irms) produced by the generator

9.3.2 Calculate the peak voltage (Vmax) output of the generator. (5)

QUESTION 11

11.1 Study the diagram of an electric **motor** given below. The coil rotates between the opposite poles X and Y of two magnets.



11.1.1 Is this a DC or an AC motor? Give a reason for your answer. (2)

11.1.2 State TWO changes that can be made to this motor to increase the rate of rotation. (2)

11.1.3 What is the polarity of the two magnetic poles X and Y? (2)

11.2 **Generators** need a source of mechanical energy to turn the coil inside a magnetic field. The picture below shows an example of a wind generator.

A wind generator has rotor blades that are 100 m in diameter. When the wind blows at maximum speed, the generator produces a maximum AC-current of 80 A in a resistor of 510 Ω.

11.2.1 Calculate the rms potential difference across the resistor. (5)

11.2.2 Calculate the average power produced by the generator. (3)

11.2.3 Draw a sketch graph of the change in current generated by this AC-generator. Show TWO full cycles for the change in current on the graph. Indicate the appropriate values of the current on the axis. (4)

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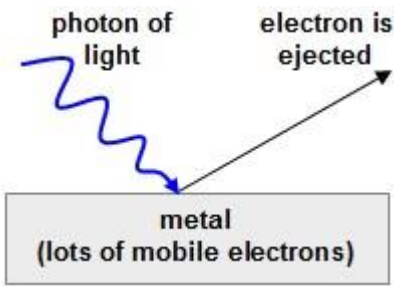
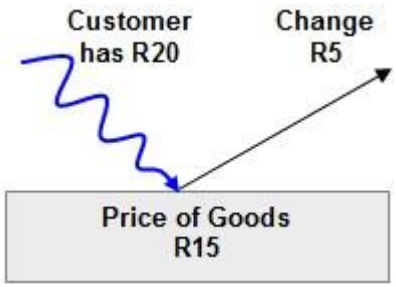
PHOTOELECTRIC EFFECT

What is the PHOTO-ELECTRIC EFFECT?
The photoelectric effect is the **emission of electrons** from the surface of a substance **when light is shone** onto it.



This does not happen for any type of light or metal.
Certain conditions must be met.

Study the ANALOGY.



To buy the goods, the incoming customer must have **sufficient money** to pay for the goods.
He can **leave with change**.

In a similar way, an **incoming photon of light** must have **sufficient energy** to **"buy" (eject)** an **electron** from the metal.
All the **excess energy ("change") becomes the kinetic energy** of the ejected electrons (photoelelctrons).

Unrealistic values are used below, but the example is just to show you the names and relationships between the various energies.

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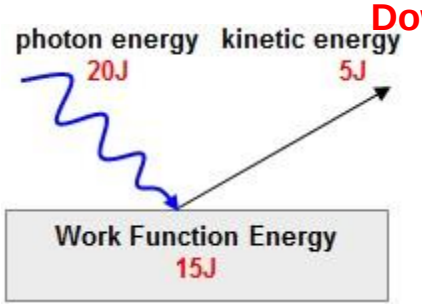

For electrons to be emitted, the incoming light (photon) must have **sufficient energy** to **overcome the work function of the metal** to free the electrons.

These free electrons can now be used as electricity as in solar cells.

What does the Photoelectric Effect tell us about the nature of light?
(What is the significance of the photoelectric effect?)

The photoelectric effect:

1. **confirms that light has a particle nature.**
2. **establishes the quantum theory (light energy is quantized)**

Terminology

Work Function W_0:
minimum amount of energy required to remove an electron from the surface of a substance

Threshold Frequency f_0:
lowest frequency of light that can cause ejection of electrons from a substance

Quanta:

- packages of energy (energy unit)
- radiated energy is quantized
- it exists in multiples of a smallest possible value

Photons:

- quanta of electromagnetic radiation
- the incoming (incident) light

Photoelectrons:
electrons that are ejected from the metal

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The **PHOTO ELECTRIC EFFECT** shows that light has a **PARTICLE NATURE**

- the **particle nature** of light is more pronounced at the **high frequency** end of the spectrum
- the **wave nature** of light is more pronounced at the **low frequency** end of the spectrum

DUAL NATURE of LIGHT
Since light can behave **both** as a **particle or as a wave**, it is said that light has a **dual** nature. (dual means 2)

It is said that light travels as a wave, but interacts as a particle when it strikes a substance.

PhotoElectric Effect Equations

Equation to convert frequency to energy.

$$E = hf$$

- **E** : energy of photon, units J
- **h** : this is Plank's constant.
  value of 6,63 x 10^{-34} J.s
- **f** : frequency f the light , units Hz

Equation to convert period T to frequency.

$$T = \frac{1}{f}$$

- **T**: period, measured in seconds

Equation to convert wavelength to frequency

$$c = f\lambda$$

- **c** : speed of light, units $m.s^{-1}$
  constant value of 3 x 10^{8}
- **λ** : wavelength, measured in meters

Photoelectric Equation

$$E = W_0 + E_{k(max)}$$

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- **E** : energy of the photon
- **W_0** : work function of the metal
- **$E_{k(max)}$** : kinetic energy of the photoelectrons

Mass of an electron m_e and Kinetic Energy

The mass of an electron is: 9,11 X10^{-31} kg

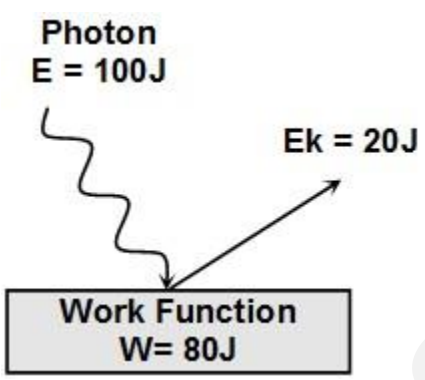
You would need this mass if you wanted to calculate the actual speed of a photoelectron from kinetic energy :

What is the effect of:

- **Intensity (brightness, power) on the Photoelectric effect?**
- **and Frequency on the Photoelectric effect?**

INTENSITY (brightness, power)

The following diagram shows a dim light of frequency f being used to perform the photoelectric effect.



Question:
What would happen if the light was made brighter, with the same frequency f?
There would be **MORE electrons** released since there would be more beams of light.

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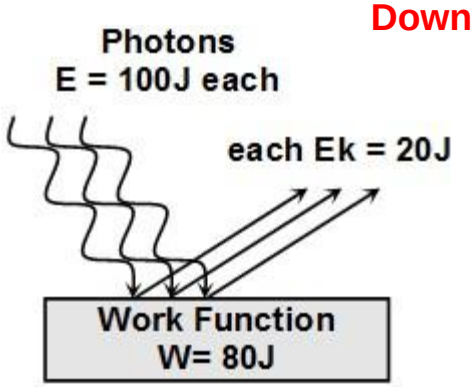
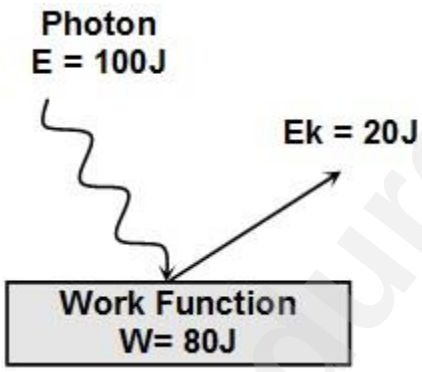


But the **kinetic energies** of each electron would **remain unchanged**.
It is important to note that if this was a solar cell, **more current would flow due to the increased number of electrons**, i.e. the brighter light increases the current strength due to the increase in the number of electrons.

In other words :
Brighter light:

- more photons
- produces more photoelectrons
- hence produces a greater current in a solar cell
- but does not increase the kinetic energies of each of the photoelectrons

FREQUENCY
The following diagram shows a light of frequency f being used to perform the photoelectric effect.



Question:
What would happen if the frequency was increased? (Not the intensity.)

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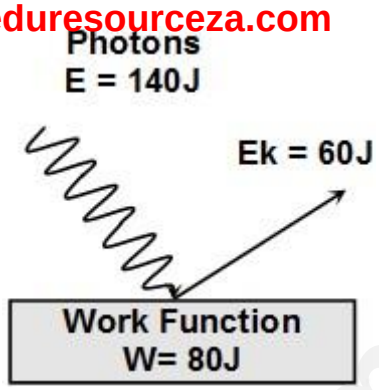
The **photons** would now have **greater energy (140J)**. But since the work function of the metal is still the same, the **kinetic energy of the photoelectrons would increase (60J)**. (But the same number of electrons would be ejected since the photon was not made brighter.)



In other words: Higher frequency light

- increases the kinetic energy of each photoelectron
- would not change the number of electrons ejected, number of electrons remain the same
- more electrons ejected per second

Some past papers state that there will an increase in current in the photocell. However other material say that the current would remain unchanged. This is because although the speed of the electrons have increased from where they have been ejected, the electron speed is unchanged inside the conductor! Hence current unchanged.

Exercise

1. A photon of light has a frequency 5 x 10^{16} Hz. Determine :

1.1. the energy of this photon

1.2. .the period

2. A photon of light has wavelength of 4 x 10^{-8} m. Determine :

2.1. the frequency of the photon

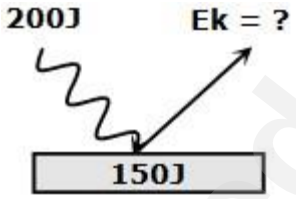
2.2. the energy of the photon

3. The period of a light beam is 5 x 10^{-9}s.

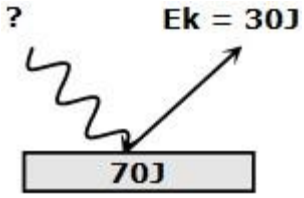
3.1. Calculate its frequency.

3.2. Calculate the energy

4. What is the kinetic energy of the photoelectrons in this example? (unrealistic values used)



5. What is the energy of the photons? (unrealistic values used)



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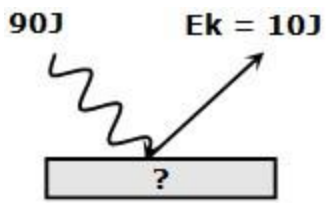
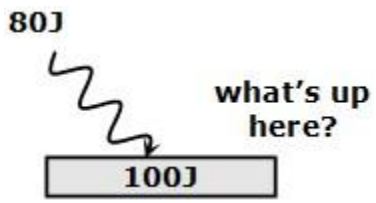
6. What is the work function for this metal? (unrealistic values used)



7. Why will the photoelectric effect not occur in this example?



7. The incoming photon has insufficient energy to overcome the work function of the metal. So electrons will not be ejected. No matter how bright you make this beam of light, the photon energy would remain the same at 80J, and no electrons would be emmitted

Exercise

1. The frequency of a photon of light is 3 x 10^{15}Hz. It is shone onto nickel metal which has a work function of 8 x 10^{-19}J. 1.

1.1. Calculate the energy of the photon.

1.2. Calculate the kinetic energy of the ejected electrons.

1.3. Calculate the speed of the electrons.

1.4. What would happen to the photo-electron speed if the same light was made brighter?

QUESTION 1 (DBE November 2015)

In an experiment to demonstrate the photoelectric effect, light of different wavelengths was shone 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 $\frac{1}{\lambda}$ (× 10^6 m^{-1})	MAXIMUM KINETIC ENERGY $E_{k(max)}$ (× 10^{-19} J)
5,00	6,60
3,30	3,30
2,50	1,70
2,00	0,70

1.1. What is meant by the term photoelectric effect? (2)

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1.2. Draw a graph of $E_{k(max)}$(y-axis) versus $1/\lambda$ (x-axis) (3)

1.3. USE THE GRAPH to determine:

1.3.1 The threshold frequency of the metal in the photoelectric cell. (4)

1.3.2 Planck's constant. (4)

QUESTION 2 (ieb Hilton College Trial 2012)

A metal plate is illuminated with an ultra violet radiation of frequency 1.67×10^{15} Hz. The maximum kinetic energy of the liberated electrons is 3.0×10^{-19} J.

2.1 Calculate the energy of one photon. (3)

2.2 Calculate the work function of the metal. What does this number represent? (4)

2.3 The radiation is maintained at the same frequency, but the intensity is doubled. State and explain what changes, if any, occur to the number of electrons released per second and the maximum kinetic energy of these electrons. (4)

QUESTION 3 (ieb November 2012)

Photoelectric Effect Experiment

Electromagnetic radiation of varying frequency is shone on the sodium metal cathode of a photocell. The maximum kinetic energy of the photoelectrons emitted is recorded.

Table to show how the maximum kinetic energy (E_k) of a photoelectron emitted from sodium metal varies with the frequency (f) of the electromagnetic radiation.

Frequency (x 10^{14} Hz)	Maximum kinetic energy (eV)
7	0,59
8	1,00
9	1,42
10	1,83
11	2,24

3.1 Plot a graph of maximum kinetic energy versus frequency as represented by these results for sodium metal. Use the GRAPH PAPER PROVIDED on your Answer Sheet. The scale on the y-axis has been marked for you. You must fill in your own scale for the x-axis which must start at ZERO. (6)

3.2. Define *threshold frequency.* *(2)*

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3.3. Read off the threshold frequency for sodium metal from the graph. (2)

3.4. If the maximum kinetic energy of the photoelectrons emitted is 2,0 eV then determine:

3.4.1. The **frequency** of the radiation incident on the sodium metal cathode. (1)

3.4.2. The **wavelength** of the radiation incident on the sodium metal cathode. (3)

3.4.3. The **energy** of the radiation incident on the sodium metal cathode. (3)

3.5. State and explain how the graph would change (if at all) when the intensity of the light is increased for each of the frequencies used. (3)

3.6. The magnitude of the value given by the **y-intercept is equal to the work function (W_f)** of the metal.

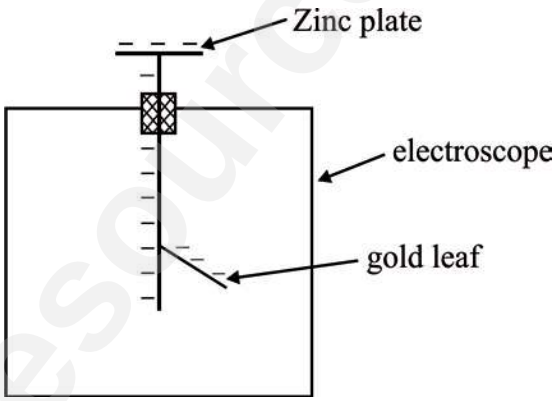
3.6.1. Extend your graph backwards to cut the y-axis and hence state the work function of the metal (in eV). (1)

3.6.2. Convert your answer to Question 3.6.1 to joules. (1)

3.6.3. Use the photoelectric effect equation, $\mathbf{E = W_f + \frac{1}{2} mv^2}$, to explain why the y-intercept is equal to the work function (W_f). (3)

QUESTION 4(Ieb November 2015)

4.1. An electroscope with a negatively charged zinc plate is shown below. The gold leaf is deflected due to like charges repelling each other.



When visible light is shone on the plate, nothing is observed. When ultraviolet light is shone on the negatively charged electroscope, the gold leaf collapses.

4.1.1 Name the phenomenon described. (2)

4.1.2 Explain why visible light has no effect while the ultra-violet light collapses the gold leaf. (3)

4.2. The work-function of caesium is $3{,}36 \times 10^{-19}$ J.

4.2.1. Define *work-function*. (2)

4.2.2. Calculate the lowest frequency photon that can eject an electron from caesium. (3)

4.2.3. Calculate the maximum kinetic energy of an electron ejected from caesium by a photon of wavelength 400 nm. (4)

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QUESTION 5 (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

5.1. Plot a graph of 1/λ (x axis) against EK (y axis). (7)

5.2. 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

5.2.1. The work function, W_0 (2)

5.2.2. Planck's constant, h (3)

QUESTION 6 MPUMALANGA 2015

Learners perform an experiment to investigate the effect of the wavelength of light on the photo-electric effect. They irradiate a metal disc **M** with three light sources of different wavelengths and note the ejection of the photoelectrons from the metal.
The results obtained are shown in the table below:

Light Source	Wavelength (×10^{-9} m)	Ejection of photoelectrons
A	480	Electrons ejected and moving away from the metal
B	620	No electrons ejected
C	570	Electrons ejected and NOT moving away from the metal

6.1 Define *the photo-electric effect* in words. (2)

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

6.3 Give a reason why light source A and not light source B will eject electrons from the metal disc **M**. (2)

6.4 Calculate the work function of the metal **M**. (3)

6.5 Calculate the maximum speed with which the electrons will be ejected from the metal disc **M** when it is irradiated with light source **A**. (5)

6.6 Light source **A** is BLUE light and light source **B** is ORANGE light. Which colour is possibly light source **C**? Choose only between VIOLET, GREEN or RED. (1)

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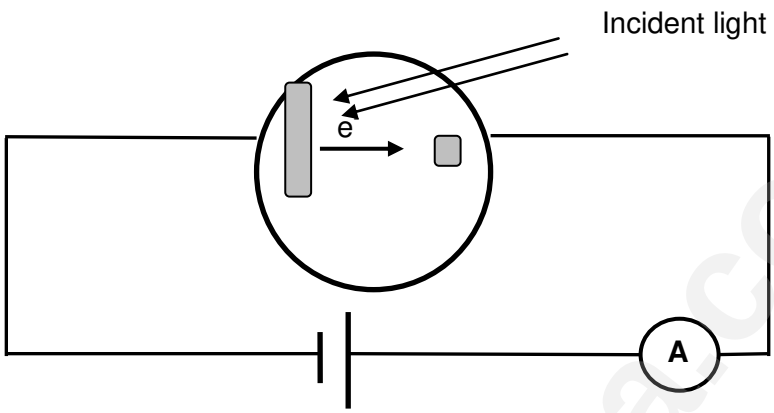
QUESTION 7 FREE STATE 2015

The diagram below shows a circuit in which a photocell is irradiated alternately with red and blue light to demonstrate the photo-electric effect.



7.1 An ammeter reading is recorded when the photocell is irradiated with red light. Give an explanation for this observation. (2)

7.2 Blue light with the same intensity as the red light is now used to irradiate the photocell. How will this influence the following:

7.2.1 The kinetic energy of the photo-electrons (Write down only INCREASE, DECREASE or STAYS THE SAME.) (1)

7.2.2 The ammeter reading. (Write down only INCREASE, DECREASE or STAYS THE SAME.) Give an explanation for your answer. (4)

7.3 The wavelength of the blue light used in the demonstration is $4,5 \times 10^{-7}$ m. Calculate the threshold frequency (cut-off frequency) of the metal used in the photo cell if the average speed of an emitted photo-electron is equal to $4,78 \times 10^{5}$ m·s^{-1}. (6)

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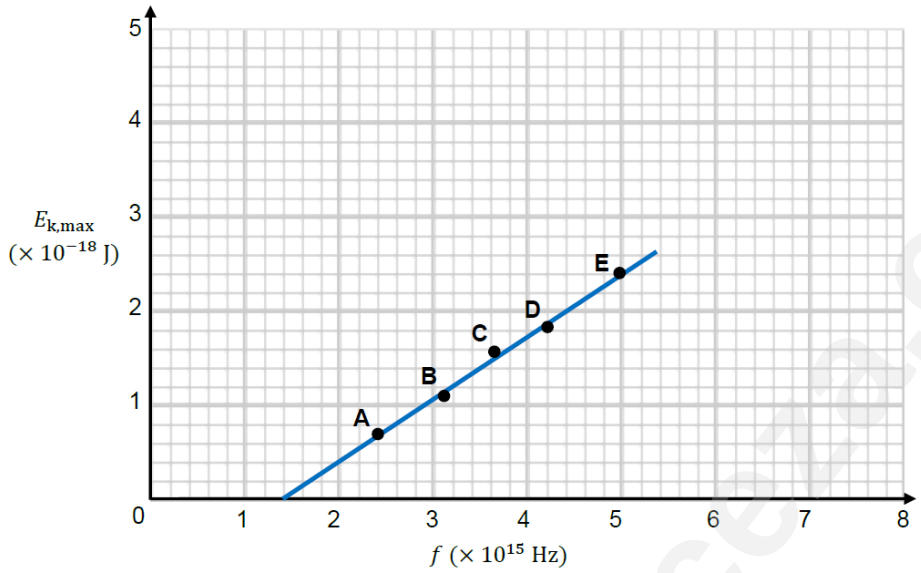
QUESTION 8

A group of physicists perform an experiment where they shine five different light sources (A, B, C, D and E) onto the platinum cathode of a photocell.

They measure the maximum kinetic energies of the ejected photoelectrons and produce the following graph of their results.



8.1 What does the gradient of the above graph represent? (1)

8.2 Define the term threshold frequency. (2)

8.3 Use the - intercept of the graph in order to calculate the work function of the metal. (3)

8.4 In one of the experiments the brightness of one of the light sources was increased. How would this affect… (Answer only INCREASES, DECREASES or REMAINS THE SAME for both of the following subquestions.)

8.4.1 the number of electrons ejected per second? (1)

8.4.2 the kinetic energy of the ejected electrons? (1)

8.5 Calculate the speed of an ejected electron when light source E is used. (4)

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ORGANIC MOLECULES

Tips for examination

- Definitions: hydrocarbon - organic compound that contains hydrogen and carbon ONLY, functional group, homologous series, saturated and saturated compounds, isomers
- Explain functional group for different homologous series and give examples (exam guideline pg 16)
- Isomers: types-1.chain isomers 2. positional isomers 3. functional isomers
- IUPAC naming and formulae-from structural formula to name and from name to structural formula.

(refer to page 5-6 and 7-12 Mind the Gap)

- identify the functional
- identify the longest chain with the functional group
- number the carbon chain so that the carbon with the functional group takes the lowest number
- identify the side chains
- name the compound using alphabetical order of the side chains
- Examples
- 4-ethyl-3-methylheptan-3-ol and NOT 3-methyl-4-ethylheptan-3-ol
- 4-ethyl-3,3-dimethylheptan-2-ol and **NOT** 3,3-dimethyl-4-ethylheptan-2-ol *(the di- is not taken into account)*

Structure and Physical Properties- (refer to page 15-21 Mind the Gap)

- strength of intermolecular forces
- type of functional group
- chain length
- branched chains

REACTIONS: (refer to page 31-37 Mind the Gap)

Hydrolysis	Hydration
• Is a substitution reaction. • Product is alcohol. **<u>Reaction conditions</u>** • NaOH and water • Solution heated mildly	• Is an addition reaction. • Product is alcohol. **<u>Reaction condition</u>** • Conc H_2SO_4 (catalyst) and water added

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Major product versus minor product

- This occurs when more than one product can form in a reaction.

Addition reaction

propene + water → propan-1-ol or propan-2-ol

Two products are possible. The product that is formed in the larger amount is called the major product, in this case the MAJOR PRODUCT is propan-2-ol.

How do we determine the major product?

- When H and OH are going to be added across a double bond, the carbon with a greater number of hydrogen atoms receives the H. The adjacent carbon receives the OH group.

Example:

but-1-ene + H_2O → butan-2-ol (major) + butan-1-ol (minor)

Elimination reaction

- The carbon with the least number of hydrogens gets a hydrogen removed from it.

Butan-2-ol + conc.H_2SO_4(heated) two products are possible namely but-2-ene and but-1-ene

How do we determine the major product?

- When an H and an OH are removed from a parent chain the C with the lesser number of hydrogen atoms will release the H. The adjacent carbon will release the OH group. Hence but-2-ene is the major product.

<u>Hydrolysis versus dehydrohalogenation</u>

Hydrolysis

- When 2-chloropropane is reacted with dilute NaOH, the product formed is propan-2-ol. This is an example of a substitution reaction The reaction vessel is heated gently.

Dehydrohalogenation

- When 2-chloropropane is heated strongly with NaOH that is dissolved in ethanol, the product formed is propene. This is an example of an elimination reaction.

PHYSICAL PROPERTIES OF ORGANIC COMPOUNDS

- affected by the nature and strengths of intermolecular forces
- molecular size
- branching
- type of functional group

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Types of intermolecular forces

- van der Waals
- hydrogen bonds

Van der Waals forces		Hydrogen bonds
London forces	Dipole-dipole	
• very weak • found between non-polar molecules	• slightly stronger than London forces • found between slightly polar molecules	• strongest intermolecular force • found in strongly polar molecules
Examples		
Alkanes	Aldehydes	Alcohols
Alkenes	Ketones	Carboxylic acids
Alkynes	Esters	
	Alkyl halides	

PLASTICS AND POLYMERS

• Definition: monomer and polymer • Distinguish between addition and condensation polymerisation . **(refer to page 42-46 Mind the Gap)** • Identify monomers from the given reactions. • Write an equation for the production of polyethene • State industrial uses of polyethene	REFER TO QUESTION 2 NOV 2014

VERY IMPORTANT!!!!!!

When answering a question relating to intermolecular forces, the learner must:

* Mention and specify the type of intermolecular force.
* Mention the amount of energy required to break the intermolecular forces.
* Mention the structure of the molecule.

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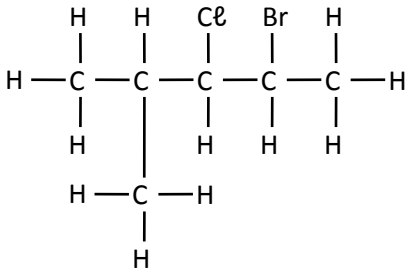
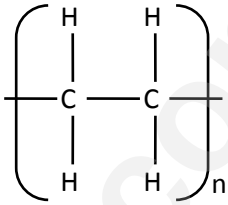
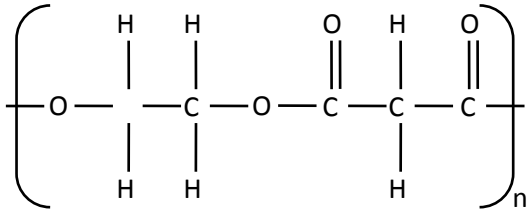
QUESTION 2 (NOVEMBER 2014)

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

2.1 Write down the LETTER that represents the following:

2.1.1 An aldehyde (1)

2.1.2 A condensation polymer (1)

2.1.3 A compound which has a carbonyl group bonded to two carbon atoms as its functional group (1)

2.2 Write down the IUPAC name of:

2.2.1 Compound **C** (3)

2.2.2 The monomer of compound **D** (1)

2.3 Write down the structural formula of:

2.3.1 Compound **A** (2)

2.3.2 Compound **F** (2)

2.4 The table contains compounds which are functional isomers.

2.4.1 Define the term *functional isomer*. (2)

2.4.2 Write down the LETTERS that represent two compounds that are functional isomers. (1)

[14]

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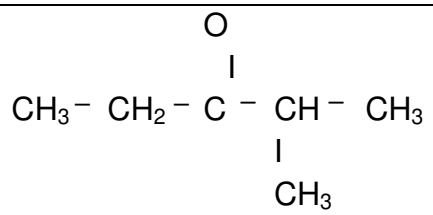
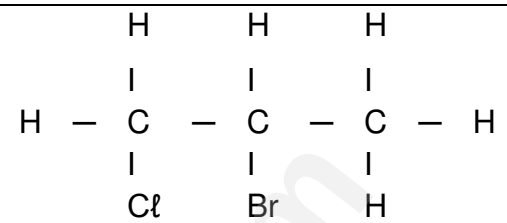
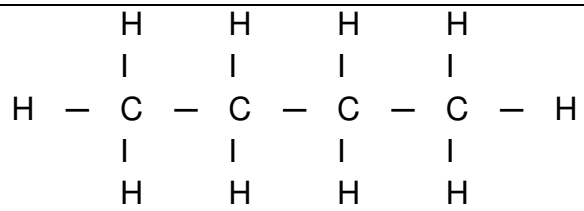
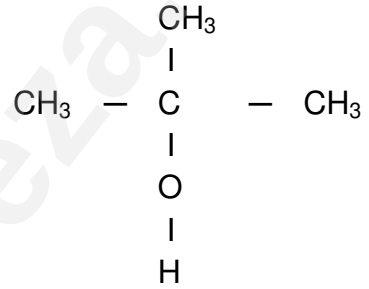
QUESTION 2 (SEPTEMBER 2014 KZN)

Consider the following representation of organic molecules **A** to **F** listed in the table below:

A		**B**	
C		**D**	Methanal
E	2-methylhex-3-yne	**F**	

2.1 Write down the letter that represents a compound that:

2.1.1 Is an aldehyde (1)
2.1.2 Is a saturated hydrocarbon (1)
2.1.3 Has a general formula C_nH_{2n-2} (1)

2.2 Write down the homologous series to which each of the following compounds belongs:

2.2.1 **A** (1)
2.2.2 **B** (1)
2.2.3 **F** (1)

2.3 Write down the:

2.3.1 Molecular formula of the next compound in the same homologous series as compound **C**. (1)
2.3.2 Structural formula of compound E (2)
2.3.3 IUPAC name of compound **B** (2)
2.3.4 Functional group of compound **D** (1)

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STRUCTURE AND PHYSICAL PROPERTY RELATIONSHIPS

QUESTION 3 (NOVEMBER 2014)

3.1 Give a reason why alkanes are *saturated* hydrocarbons. (1)

3.2 Write down the structural formula of:

3.2.1 The functional group of alcohols (1)

3.2.2 A tertiary alcohol that is a structural isomer of butan-1-ol (2)

3.3 Learners investigate factors that influence the boiling points of alkanes and alcohols. In one of the investigations they determine the boiling points of the first three alkanes.

3.3.1 Write down an investigative question for this investigation. (2)

3.3.2 Fully explain why the boiling point increases from methane to propane. (3)

3.4 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)

[12]

QUESTION 3 (EXEMPLAR 2014)

QUESTION 3 (SEPTEMBER 2014 KZN)

Two compounds **A** and **B**, have the molecular formula $C_2H_4O_2$.

3.1 What is meant by the term **structural isomers**? (2)

3.2 Compound A has a lower vapour pressure than compound B.

3.2.1 How will the boiling point of compound A compare to that of compound B. Only write HIGHER THAN, LOWER THAN, or EQUAL TO. (1)

3.2.2 Write down the name of compound A. (1)

3.2.3 To which class of organic compound does compound B belong? (1)

3.2.4 Write down the structural formula for compound B and give its IUPAC name. (3)

3.2.5 Explain in terms of intermolecular forces and energy why compound A has a lower vapour pressure than compound B. (3)

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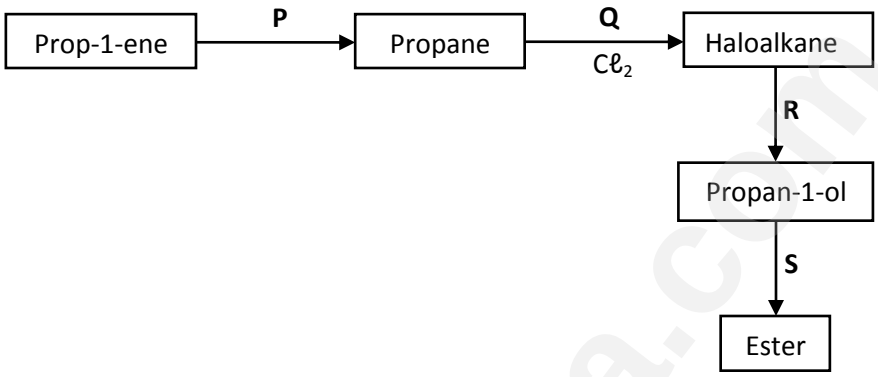
SUBSTITUTION, ADDITION AND ELIMINATION REACTIONS

QUESTION 4 (November 2014)

The flow 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.



4.1 Write down the type of reaction represented by:

4.1.1 **Q** (1)

4.1.2 **R** (1)

4.2 For reaction **P** write down the:

4.2.1 Type of addition reaction (1)

4.2.2 Balanced equation using structural formulae (3)

4.3 Write down the structural formula of the haloalkane formed in reaction **Q**. (2)

4.4 In reaction **S** propan-1-ol reacts with ethanoic acid to form the ester.For this reaction write down the:

4.4.1 Name of the reaction that takes place (1)

4.4.2 FORMULA or NAME of the catalyst needed (1)

4.4.3 Structural formula of the ester formed (2)

4.4.4 IUPAC name of the ester formed (2)

4.5 The propan-1-ol formed in reaction **R** can be converted to prop-1-ene. Write down the FORMULA or NAME of the inorganic reagent needed. (1)

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RATE AND EXTENT OF REACTION

- Firstly, before one could embark on trying to understand the **rate** of **reaction**; needs to look back into the topic. This topic has two words i.e. rate and Reaction. Hence, it is essential to start by explaining the meaning of each word/term.

RATE

- Rate is the amount of time taken for a change to occur i.e. how fast/slow did the change occur. In our interest the change refers to the reaction. Also the change may be measured by mass, volume, concentration.

- Mathematically, the rate is denoted as follows:

$$Rate = \frac{\Delta m}{\Delta t} \quad or \quad Rate = \frac{\Delta c}{\Delta t} \quad or \quad Rate = \frac{\Delta v}{\Delta t}$$

CHEMICAL REACTIONS

- A chemical reaction is the conversion of reactant(s) to product(s).

Types of reactions

- In grade 9, Natural Sciences a chemical reaction is defined as the combination of two or more substances to form a new substance. In the hypothetical equation below A combines with B to form C. And this type of a reaction is a **synthesis reaction**.

$$A + B \rightarrow C$$

- However, there are other types of reaction: i.e. **decomposition reaction** where one substance breaks apart to form two or more substances

$$C \rightarrow A + B$$

REACTION RATE

- A reaction rate is the change in concentration of reactants or products per unit time.

- This definition is also shown mathematically

$$Rate = \frac{\Delta[products]}{\Delta t} \quad \text{Or} \quad Rate = \frac{\Delta[reactants]}{\Delta t}$$

<u>Note</u>:
Questions may also include calculations of rate in terms of change in mass/volume/ number of moles per time.
Units of rate of reaction can be $g \cdot s^{-1}$ / $dm^3 \cdot s^{-1}$ / $mol \cdot s^{-1}$.

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Collision Theory

- Collision theory states that for any reaction to take place reactants must collide. Due to those collisions there are two possibilities i.e. **ineffective** collision and **effective** collision.
- An **ineffective collision** is whereby reactants collided but could not yield products.
- This is shown by the following hypothetical equation:

  A + B → A + B

- Whereas, an effective collision is whereby reactants collided to form products (new substance)
- This is shown by the following hypothetical equation:

  A + B → C + D

- In collision theory, in order for reactants to collide effectively and rate be measured they must meet the following requirements.

  1. Have **sufficient kinetic energy** to overcome repulsion of their electron clouds and nuclei.
  2. Be **correctly orientated** so that the reactive sides of one approach the reactive side of the other

<u>Factors Affecting the Rate of Reaction</u>

Chemical reactions are used in many industries to produce bulk materials that are essential for daily lives. Therefore, for industries to sustain production, they need to have faster chemical reactions to produce more products at minimal time. The following factors have an effect on the rate of chemical reaction

1. Concentration (for solutions only)
2. Pressure (for gases only)
3. Surface area (for solids)
4. Temperature
5. Catalyst
6. Nature of reacting substance

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1. Concentration

- Concentration is defined as the number of particles per unit volume.
- Concentration only applies where there is at least one reactant that is a solution.

  When concentration increases the rate of reaction also increases or vice versa

- **According to collision theory:** If the concentration of reactants is increased; the number of particles per unit volume increases, resulting in the increase of the number of particles with the correct orientation. The number of effective collisions per unit time increases. Hence, the rate of reaction will increase.
- Also, if the concentration of reactants is decreased; the number of particles per unit volume decreases, resulting in reduction of particles with the correct orientation. The number of effective collisions per unit time decreases. Hence, the rate of reaction will decrease.

2. Pressure

- In physics pressure is defined as the force per unit area.
- Pressure is applicable to gases only.
- **According to collision theory:** If the pressure in a system is increased; the distance between the particles decreases, resulting in the increase of the number of particles with the correct orientation. The number of effective collisions increases, hence the rate of reaction increases.
- Also, if the pressure in a system is decreased; the distance between the particles increases, resulting in the decrease of the number of particles with the correct orientation. The number of effective collisions decreases, hence the rate of reaction decreases.

3. Temperature

- Temperature is the measure of the average kinetic energy of molecules.

  When the temperature increases also the rate of reaction increases or vice versa

- When temperature is increased, the average kinetic energy of molecules increases, resulting in more effective collisions, hence the rate of reaction increases.

4 Positive Catalyst

- A positive catalyst is a chemical substance that increases the rate of chemical reaction without itself undergoing permanent change.
- Adding a positive catalyst in a reaction reduces the activation energy, resulting in more particles making effective collisions, hence the rate of reaction increases.

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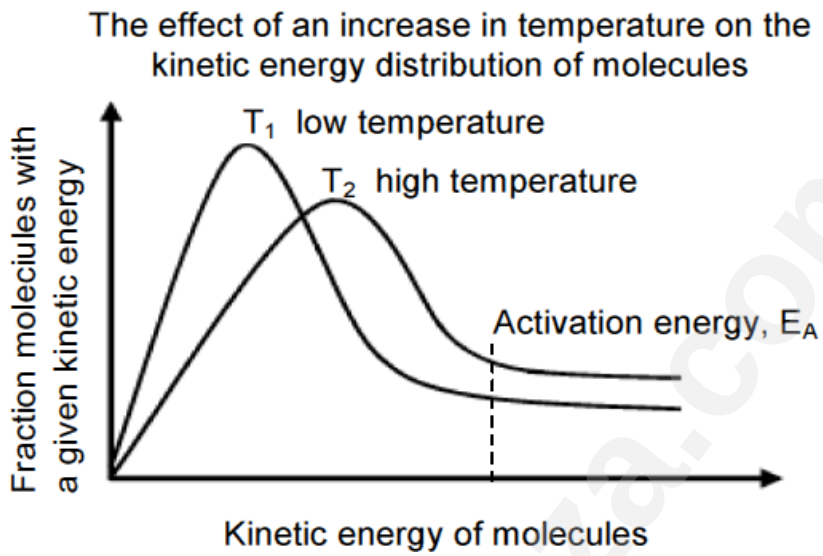
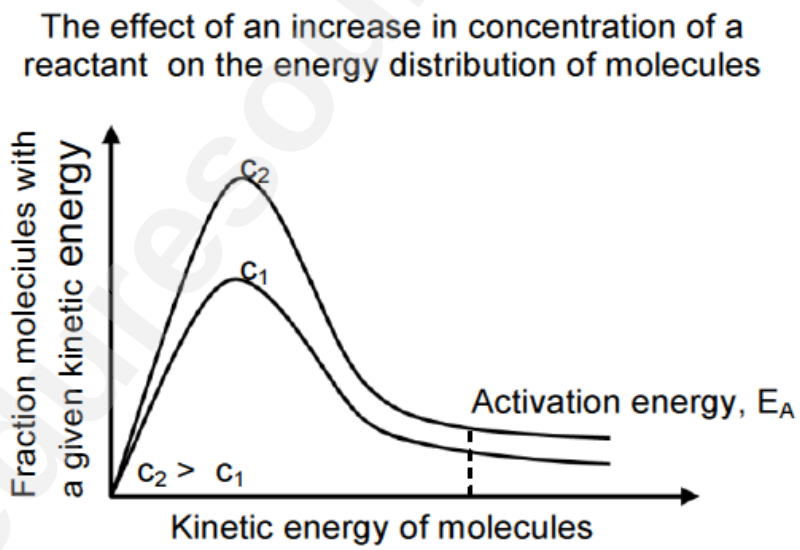
The Maxwell-Boltzmann Distribution Curves





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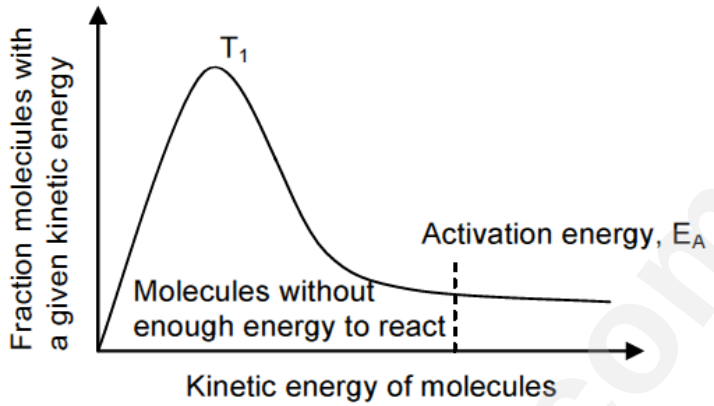
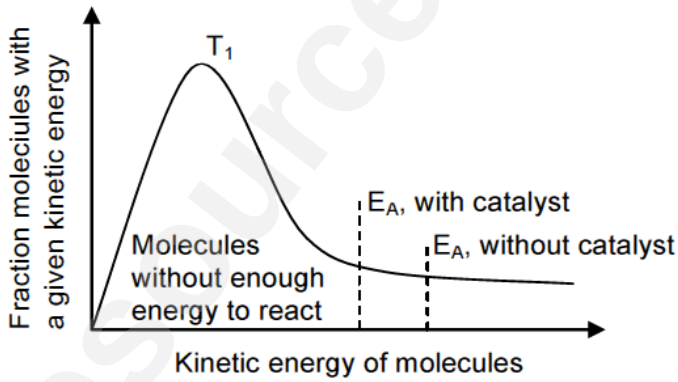
Maxwell-Boltzmann-distribution :
Distribution of kinetic energy of reactant molecules



Maxwell-Boltzmann-distribution : Distribution of kinetic energy of reactant molecules when a catalyst is used



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If a catalyst is added, the activation energy is decreased, hence the number of molecules that make effective collisions increases. Therefore the reaction rate increases.

5 Surface area

- Surface area refers to the total number of reactive sites exposed for the reaction to occur. When the surface area increases the rate of reaction also increases or vice versa.
- The reactive site exposed is in line with correct orientation of reactants for enhancing effective collision
- This applies when one of the reactants is a solid
- Solid can come in the form of Chunk, granules and powder
- In all these forms of solids, the molecules expose to react are only the visible part
- So, when the solid state changes from block/chunk to granules and eventually to powder.
- **According to collision theory:** when the surface area increases, the number of reactive sites available for collisions per unit time increases. There will be more effective collisions.
- Hence, the rate of reaction increases.

6. Nature of reactants

- Reaction rate is determined by bond energy, hence the lower the bond energy the higher the rate of reaction
- E,g magnesium reacts with hydrochloric acid faster than copper

ENERGY and CHEMICAL CHANGE

- In a chemical reaction energy is used to break old bonds, and energy is released when new bonds form.
- Therefore during a reaction energy of the system changes; and that change in energy is called enthalpy change (heat of reaction)
- Enthalpy change is calculated using the following equation:
  $\Delta H = H_{products} - H_{reactant}$
- Also in a reaction products are not formed directly, however an intermediate molecule forms. This intermediate molecule is neither a reactant nor a product and is called **Activated Complex**
- However, activated complex eventually breaks up to form products
- An activated complex is defined as the molecule which is highly unstable, high energy and it breaks up to form products.
- The potential energy of this activated complex is equal to the activation energy of the reaction.
- There are two types of reactions as far as energy is concerned i.e.

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1. Exothermic reaction
2. Endothermic reaction.

Exothermic Reaction

- Exothermic reaction is the reaction that releases energy
  1. Reactants absorb less energy than the energy that is produced
  2. Energy of reactants is greater that the energy of products
  3. the enthalpy change(heat of the reaction) of the reaction is negative
  4. also known as spontaneous reaction

  Example :$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$: ΔH = -ve

Endothermic Reaction

- chemical reaction that require (absorbs) energy

Properties of an Endothermic Reaction

1. Reaction that absorbs more energy it produces
2. Energy of reactants is less that the energy of products
3. the enthalpy change (heat of the reaction) of the reaction is positive
4. non-spontaneous reaction

Graph : Shows the energy profile for endothermic reaction

QUESTION 1 PREP EC 2016

Learners investigate some of the factors that influence the rate of a chemical reaction. In the experiment they add equal amounts of each of three different metals separately to equal volumes of EXCESS dilute hydrochloric acid solution.

In each experiment the acid completely covers the metal.
The data obtained is recorded as in the table below:

Experiment	Amount of metal powder	Change in temperature of solution (°C) (Tfinal –	Time taken to run to completion
1	0,1 mol Zn	+23	25,2
2	0,1 mol Mg	+37	8,3
3	0,1 mol Cu	0	No reaction

1.1 Is the reaction in **Experiment 1** ENDOTHERMIC or EXOTHERMIC? Give a reason for your answer. (Use the information in the table). (2)

1.2 Which factor influencing reaction rate is investigated? (1)

1.3 How will the total volume of hydrogen gas produced in **Experiment 2** compare with the total volume of hydrogen gas produced in **Experiment 1** at the end of the reactions?

Write down HIGHER THAN, EQUAL TO or SMALLER THAN.

Give a reason for your answer. (2)

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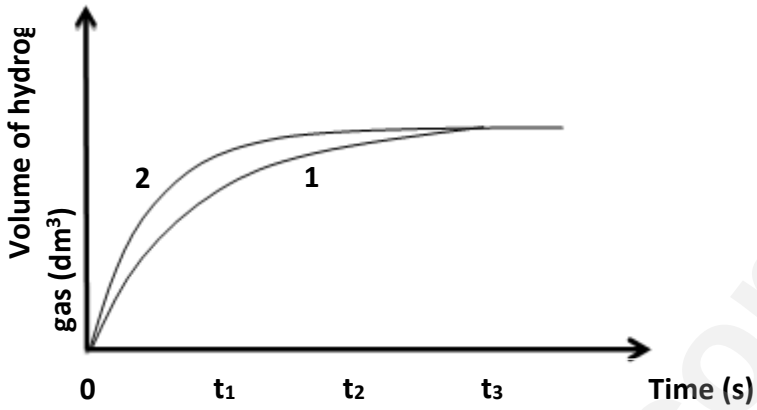
1.3 The graphs obtained for **Experiment 1** and **Experiment 2**, labelled as **1** and **2** respectively, are sketched on the same set of axes as shown below:



1.3.1 In which experiment does the reaction occur at a higher reaction rate at time t_1? (1)

1.3.2 Explain the answer to QUESTION 5.4.1 by referring to the relative strength of reducing agents involved. (2)

2. In another experiment, **Experiment 4**, the same reaction conditions are repeated as in **Experiment 2,** but the reaction mixture is heated. The rate of reaction is HIGHER for **Experiment 4** than **2**.

Explain why the reaction rate is HIGHER for **Experiment 4** than **2** by referring to the collision theory. (3)

QUESTION 2 PREP GAUTENG 2016

In an investigation of the rate of reaction, excess magnesium powder is added to dilute hydrochloric acid at room temperature. The following spontaneous reaction takes place:

$$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g) \qquad \Delta H < 0$$

2.1 Define the term *spontaneous reaction*. (2)

2.2 Write down the limiting reagent for the above reaction. (1)

2.3 How will each of the following changes affect the rate of the reaction between magnesium and hydrochloric acid according to the above reaction? Choose from INCREASES, DECREASE or REMAINS THE SAME.

2.3.1 The same mass of magnesium ribbon is used instead of powder. (1)

2.3.2 A more concentrated solution of hydrochloric acid is used. (1)

2.3.3 The diluted hydrochloric acid solution is heated before being added to the magnesium. (1)

2.4 Use the collision theory to explain your answer in QUESTION 2.3.3. (3)

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QUESTION 3

A chemist wishes to determine the rate of reaction of zinc with hydrochloric acid. The unbalanced equation for the reaction is:

$$Zn(s) + HC\ell(aq) \rightarrow ZnC\ell_2(aq) + H_2(g)$$

A piece of zinc is dropped into 0,1 cm^3 of 0,1 $mol{\cdot}dm^{-3}$ $HC\ell$ and the following data were obtained at 4 second intervals.

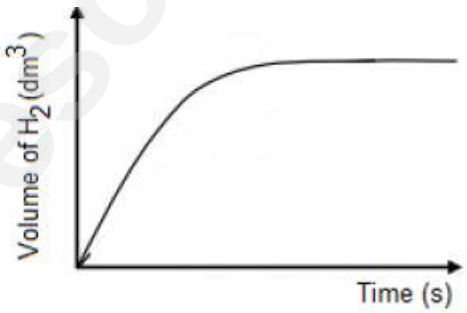
Time (s)	Mass of zinc (g)
0	0,016
4	0,012
8	0,010
12	0,009
16	0,008
20	0,008

3.1 Calculate the average rate of the reaction for the first 12 s in $mol{\cdot}s^{-1}$. (4)

3.2 Explain why the mass of the zinc remained constant after 16 s. (1)

3.3 Explain how the rate of the reaction changes as the time passes. Answer only INCREASES, DECREASES or REMAINS THE SAME. (1)

3.4 A graph that shows the amount of H_2 gas that was produced against time for this reaction is shown below:



Redraw the graph and indicate on the same set of axes:

3.4.1 a second graph, labelled **Y** that will be obtained if zinc powder of the same mass, instead of zinc granules was used. (2)

3.4.2 a third graph, labelled **X** that will be obtained if the same volume of $HC\ell$ with a **lower** concentration was used. (2)

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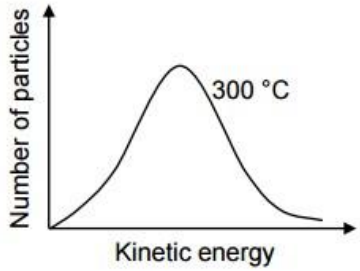
The Maxwell-Boltzmann distribution curve below represents the number of particles against kinetic energy at 300 °C.



3.5	Redraw this curve in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained at a temperature of 400 °C. Clearly label the curves as 300 °C and 400 °C respectively.
3.6	Using the collision theory, explain how an increase in temperature affects the rate of reaction.

QUESTION 4 PREP FS 2015

Learners use the reaction between sodium carbonate (Na_2CO_3) and a 0,1 mol·dm^{-3} sulphuric acid solution to investigate reaction rate.

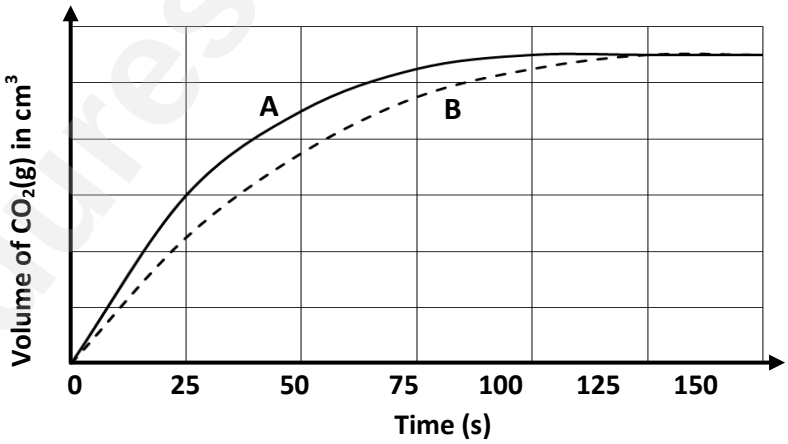
They pour 150 cm^3 of the sulphuric acid solution into a beaker and add ENOUGH sodium carbonate powder to neutralise the acid. The temperature of the reaction mixture is kept at 0 °C.

The balanced equation for the reaction is:

$$Na_2CO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell) + CO_2(g)$$

4.1 Define the term *reaction rate* in words. (2)

Graph **A** (solid line) below shows the volume of $CO_2(g)$ formed as a function of time. **Graph of volume of $CO_2(g)$ formed versus time**



4.2 How long (in seconds) did the reaction represented by graph **A** take to reach completion? (1)

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4.3 How does the reaction rate of the reaction represented by graph **A** at t = 5 s compare to that at t = 25 s? Write down HIGHER THAN, LOWER THAN or EQUAL TO. Use the collision theory to explain the answer. (3)

4.4 Calculate the maximum volume of $CO_2(g)$, in dm^3, that can be produced by this reaction at STP. (5)

4.5 The same reaction is now repeated using the same mass of Na_2CO_3 and the same volume of the 0,1 $mol \cdot dm^{-3}$ H_2SO_4. The volume of $CO_2(g)$ formed as a function of time is represented by graph **B** above.

Write down TWO possible changes that could have been made to the reaction mixture. (2)

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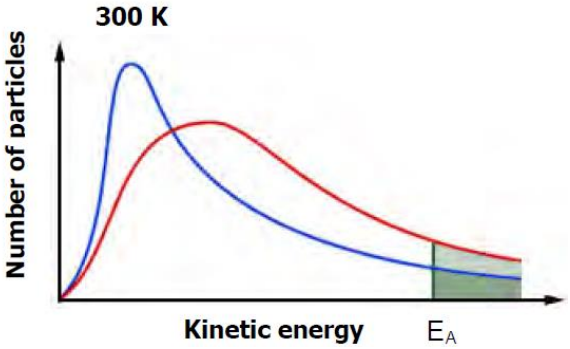
QUESTION 5

The mining of phosphate rock and its conversion to superphosphate is carried out in South Africa at Phalaborwa, in the Limpopo province, represented by the reaction equation below:
$Ca_3(PO_4)_2$ (s) + $2H_2SO_4$ (aq) → $Ca(H_2PO_4)_2$ (aq) + $2CaSO_4$ (s)

5.1 An increase in temperature will increase the rate of the above reaction. List any TWO other factors that will increase its rate. (4)

5.2 The figure below shows the Maxwell-Boltzmann distribution curves for the above reaction at two different temperatures. The activation energy for this reaction is indicated on the graph by the vertical line and labelled as EA.



5.2.1 Define the term, *activation energy*. (2)

5.2.2 Write down the name of the theory used to explain how reactions occur at the molecular level. (1)

5.2.3 Referring to the shaded areas in the distribution curves provided, use the theory named in QUESTION 5.2.2 to explain why an increase in temperature causes an increase in reaction rate. (3)

QUESTION 6

6.1 The collision theory can be used to explain how different factors affect the rate of a chemical reaction.

6.1.1 Name TWO conditions that determine whether a collision between two molecules, A and B, will lead to a chemical reaction. (2)

6.1.2 In terms of the collision theory, explain why the rate of a chemical reaction increases with increasing temperature. (2)

6.2 The reaction between nitrogen dioxide and carbon monoxide is represented below.
$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$ $\Delta H = -226$ kJ and E_a, is 132 kJ

6.2.1 Sketch a potential energy versus reaction coordinate graph for this reaction. Label the axes and indicate the following on your graph:
$\Delta H = -226$ kJ and $E_a = 132$ kJ (4)

6.2.2 Use a broken line on your graph to show the effect a catalyst would have on the potential energy as the reaction proceeds. (1)

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A group of learners use the reaction between hydrochloric acid and magnesium powder to investigate one of the factors that influence the rate of a chemical reaction. The reaction that takes place is:

$$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$$

The learners use the apparatus and follow the method shown below to conduct the investigation.

Method – Experiment 1:

Step 1: Place a spatula of magnesium powder in a conical flask and add 50 cm^3 $HC\ell$ (aq) of known concentration.

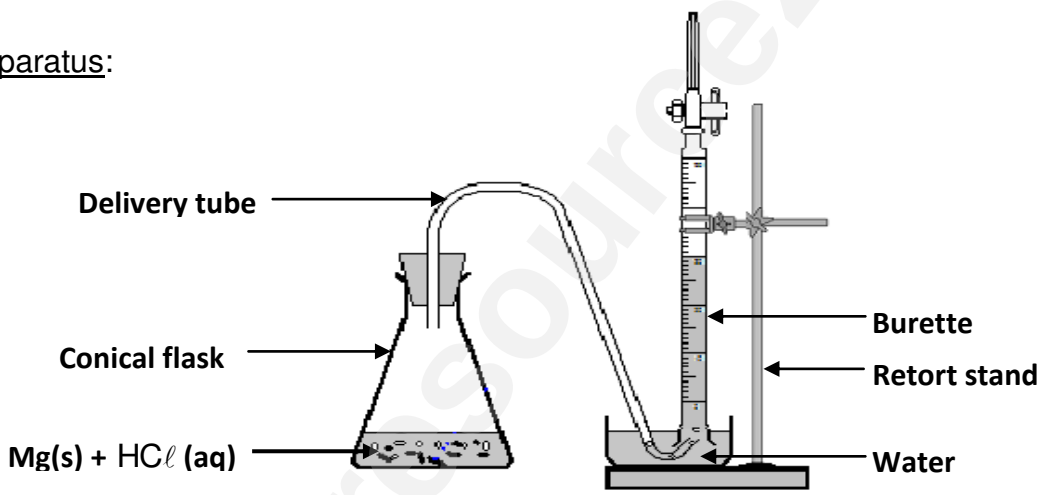
Step 2: Simultaneously start the stopwatch and close the flask with the rubber stopper containing the delivery tube.

Step 3 Measure the volume of the $H_2(g)$ formed in time intervals of 20 seconds.

Method – Experiment 2:

Repeat steps 1 to 3 above, but use only 25 cm^3 of the same $HC\ell$ (aq) diluted to 50 cm^3 with distilled water.

Apparatus:



7.1 How does the concentration of the acid used in Experiment 2 differ from the concentration of the acid used in Experiment 1? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

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

7.3 Why should the learners ensure that equal amounts of magnesium powder are used in each of the two experiments? (2)

7.4 The learners use an excess of $HC\ell$ (aq) for the two experiments. Give a reason why the excess $HC\ell$ (aq) will not influence the results. (2)

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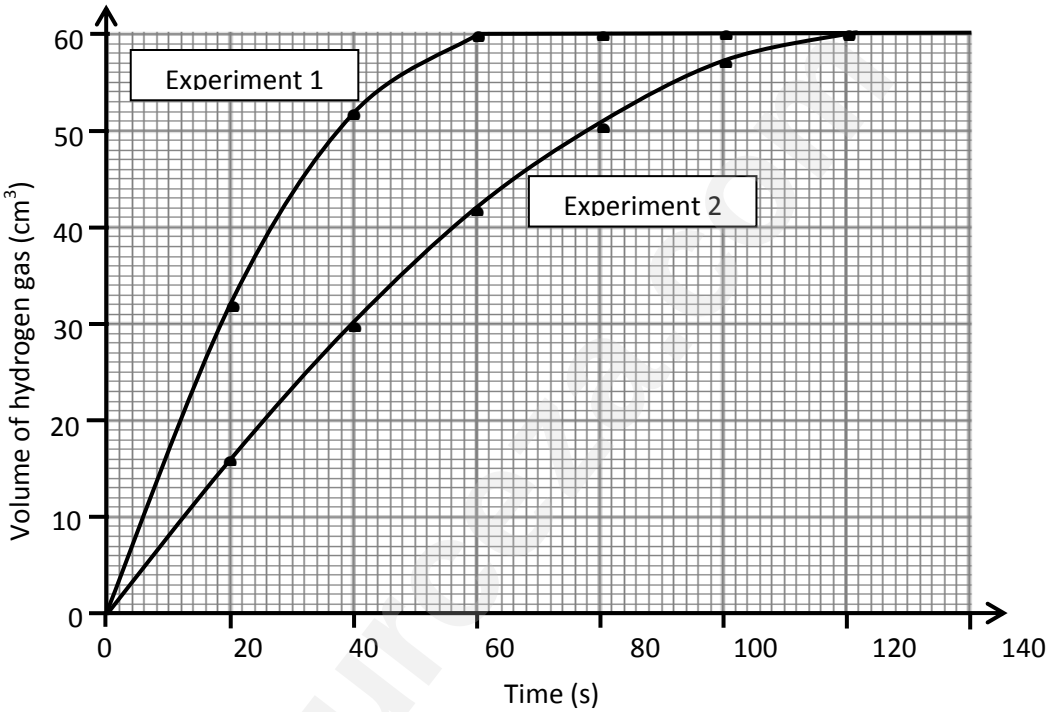
After completing the investigation, the learners represent the results obtained during each experiment on the graph below.

Graph of volume of hydrogen gas versus time



7.5 Write down the volume of hydrogen gas formed during the first minute in:

7.5.1 Experiment 1 (1)

7.5.2 Experiment 2 (1)

7.6 Which one of the experiments (Experiment 1 or Experiment 2) took place at the faster rate? Refer to the shape of the curves to motivate your answer. (2)

7.7 Give a reason why the final volume of gas produced is the same in both experiments. (1)

7.8 What conclusion can the learners draw from the results obtained? (2)

7.9 How will an increase in the temperature influence the following:

7.9.1 Final volume of gas obtained in each experiment (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1)

7.9.2 Volume of gas obtained in each experiment after 40 s (Write down only INCREASES, DECREASES or REMAINS THE SAME.) (1)

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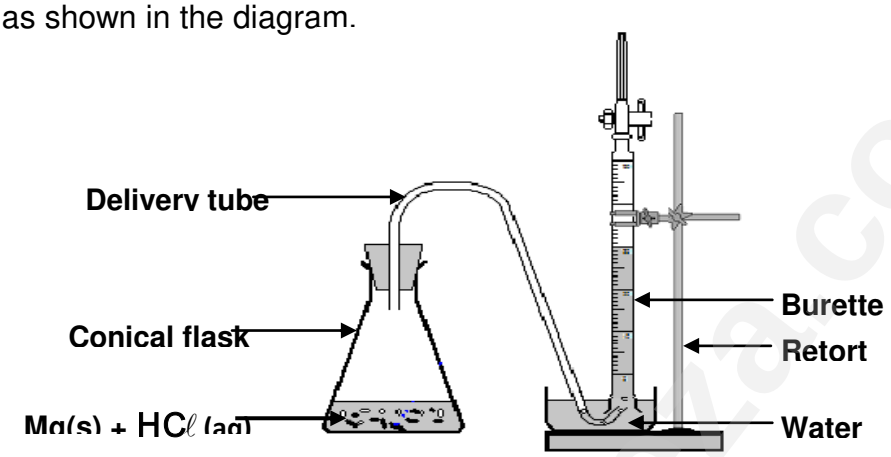
QUESTION 8

Three learners, Allan, Lebo and Eldonna are given the task to investigate the factors that affect the rate of reaction of magnesium ribbon with dilute hydrochloric acid. The balanced equation for the reaction is given below.

$$Mg_{(s)} + 2HC\ell_{(aq)} \rightarrow MgC\ell_{2\,(aq)} + H_{2(g)}$$

The hydrogen gas produced in the reaction is collected by the downward displacement of water as shown in the diagram.



The results of the three experiments are shown in the tables below.

Allan performed the experiment to determine the effect of temperature on the rate of reaction between Mg and HCℓ.

Temperature (°C)	Volume of hydrogen (cm^3) collected in 20 s			
	Reading 1	Reading 2	Reading 3	Average
10	9,6	9,2	10,0	9,6
20	19,5	18,7	19,1	19,1
30	38,9	38,2	37,5	38,2
40	74,9	77,2	75,6	75,9

Lebo performed the experiment to determine the effect of concentration of HCℓ on the rate of reaction between Mg and HCℓ.

Concentration of HCℓ ($mol.dm^{-3}$)	Volume of hydrogen(cm^3) collected in 20 s			
	Reading 1	Reading 2	Reading 3	Average
0,5	20,2	20,2	20,2	20,2
1,0	40,0	39,9	40,1	40,0
1,5	59,9	60,0	60,1	60,0
2,0	80,1	80,1	80,1	80,1

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Eldonna performed the experiment to determine the effect of volume of HCℓ on the rate of reaction between Mg and HCℓ.

Volume of HCℓ (cm^3)	Volume of hydrogen (cm^3)collected in 20 s			
	Reading 1	Reading 2	Reading 3	Average
100	50,4	49,9	50,3	50,2
200	50,0	50,0	50,0	50,0
300	50,0	50,6	50,3	50,3
400	49,6	49,8	50,3	49,9

7.1 State the independent variable in **Lebo's** experiment. (1)

7.2 State a suitable conclusion for the experiment conducted by

7.2.1 **Allan** (2)

7.2.2 **Eldonna** (2)

7.3 Write down a hypothesis for **Lebo's** experiment. (2)

7.4 Explain the results of **Allan's** experiment in terms of the collision theory. (2)

7.5 State TWO variables that **Lebo** needs to control in her experiment. (2)

7.6 Each experiment is repeated three times. Why is this important when conduction an experiment? (2)

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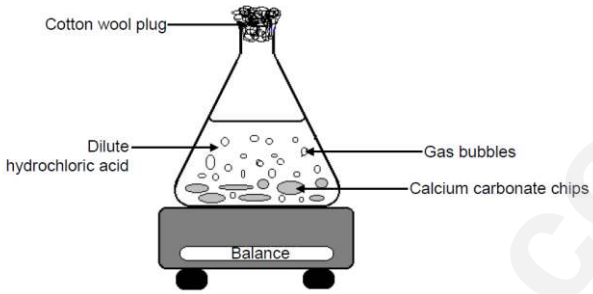
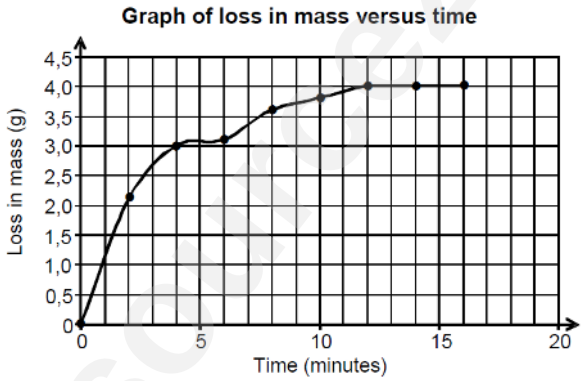
QUESTION 8

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 balanced equation for the reaction that takes place is:

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



8.1 Write down the NAME of the gas that escapes through the cotton wool plug while the reaction takes place. 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. (1)



8.2 From the graph, write down the following:

8.2.1 The coordinates of the point that represents results that were measured incorrectly (1)

8.2.2 How long (in minutes) the reaction lasts (1)

8.2.3 How long (in minutes) it takes 75% (three quarters) of the reaction to occur (1)

8.3 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)

8.4 How would a higher concentration of hydrochloric acid affect the following:
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

8.4.1 Loss in mass per unit time (1)

8.4.2 Total loss in mass (1)

8.4.3 Time for the reaction to reach completion (1)

8.5 Apart from concentration and temperature changes, write down TWO other changes that can be made to increase the rate of this reaction. (2)

8.6 Calculate the mass of calcium carbonate used when the reaction is completed. Assume that all the gas that was formed, escaped from the flask. (5)

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CHEMICAL EQUILIBRIUM

Chemical Reaction Systems

A reaction system refers to reactants and products ONLY in our discussion

Chemical reactions systems are divided into two systems, namely:

1. Open system

2. Closed system

Open System

An **open system** is a system which shares mass with the surroundings

This means some of the products may escape the reaction vessel as a result of that the total mass of the system will decrease.

This happens when one of the product is a gas and is not stored

However, the mass lost by the system will be gained by surroundings.

Hence, the law of conservation of mass is obeyed.

Also, some reactants may come from surroundings to the system

Effectively the mass of the system would increase, and then the mass of surrounding would decrease.

This is usually possible to reactants that may react with atmosphere i.e. oxygen and moisture

Closed System

In contrast to that, a **closed system** is a reaction system that doesn't share mass with surroundings

This means neither reactants nor products may join or leave the system.

Chemical equilibrium / Dynamic Equilibrium

Chemical equilibrium is used to describe the reactions that do not go to completion.

However, they reach a stage with which the concentration of both reactants and products remain constant.

Therefore, these reactions are also termed **reversible** i.e. reactants are converted to products;

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also products decompose back to reactants

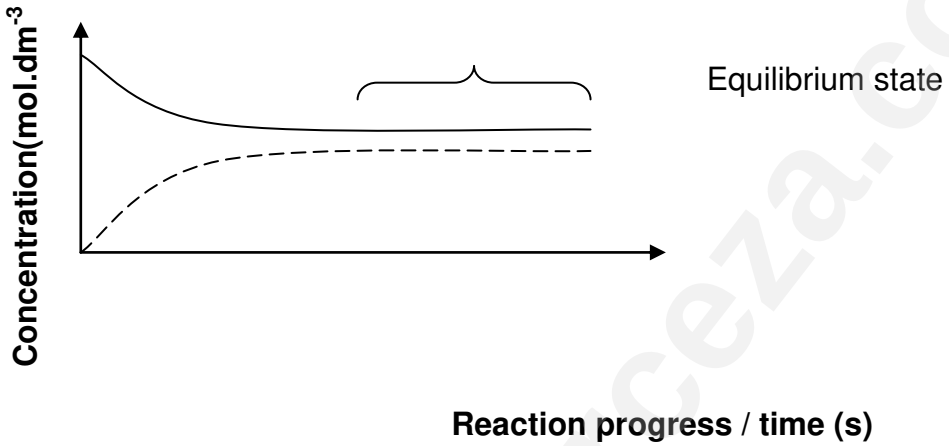
Chemical equilibrium is defined as the state of dynamic equilibrium where the **rate of forward reaction is equal to the rate of reverse**.

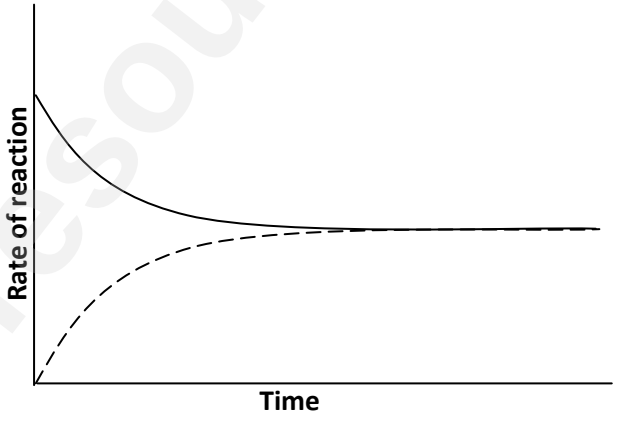
A reaction that has reached equilibrium maybe written as follows:

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

Where; a double arrow illustrates that both forward and reverse reactions are taking place.

Graphically equilibrium is shown as follows





- Industrially a reaction at equilibrium could result in a loss of profit, since there won't be change in the amount of products.
- However, the aim of industrial Chemistry is to increase productivity at minimal cost both financially and time
- Then French Chemist **Henry Louis Le Chatelier** discovered that if some reaction conditions

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are changed, then the reaction could respond in a manner that opposes the change.

- **Le Chatelier's principle** states when the reaction in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will opposes the disturbance.

Factors Affection Equilibrium Position

There are three factors that affect the Equilibrium position, namely:

1. Concentration
2. Pressure
3. Temperature

Concentration (Solutions)

- Concentration is defined as the amount of particles per unit volume. It only applies to solutions.
- Given the following hypothetical reaction equation we shall try to apply Le Chatelier's principle.

$$A + B \rightleftharpoons C + D$$

- From the above reaction the concentration of any of the reactants/products (A/B/C/D) of a reaction system could be altered, thus forcing shifting of equilibrium position. If any of the reactants/products is increased that will force the reaction at equilibrium to shift away from the increased reactants/products in order to decrease it. Furthermore, if any of the reaction reactants/products is decreased, then that will force the reaction at equilibrium to shift towards the decreased reactants/products in order to increase it.

Now, it is decided that [A] is added as stress to the system.

- The increase in [A] will increase effective collision between [A] and [B]; thus that will force the reaction at equilibrium to produce more [C] and [D]. Therefore, we could say after the addition of [A] would force the reaction to shift towards [C] and [D] **or** addition of [A] would force the reaction to favour formation of [C] and [D] to re-establish equilibrium.
- Any other change could be done on the reaction at equilibrium then the reaction will act against the change in order to minimize it.
- Graphically the above scenario is shown as follows.

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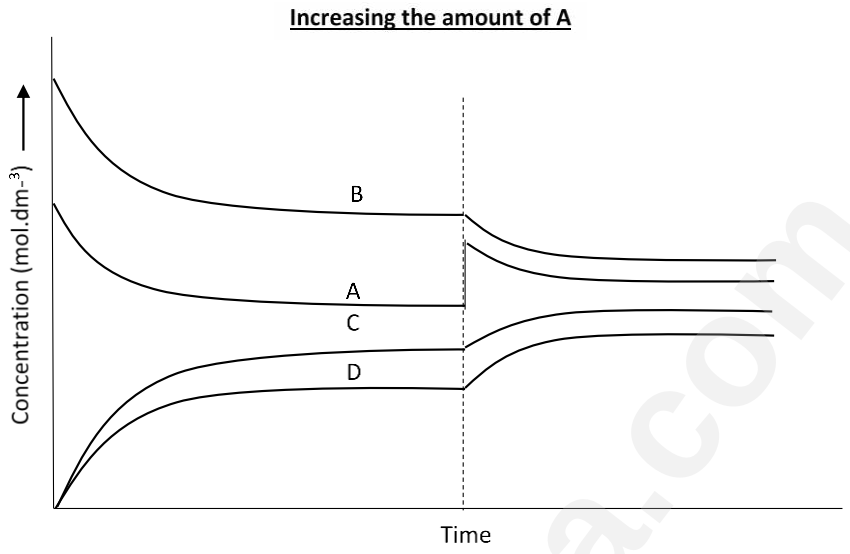
Graph : Shows the effect of increase in reactants of the above reaction



- Since the pressure is inversely proportional to the volume from Boyle's law, the change in pressure also affects volume.
- If the pressure of the system is changed (by changing volume or amount of gas), the sum of stoichiometric coefficients of both reactants and products will decide the direction of equilibrium shifting.
- An increase in pressure forces the reaction at equilibrium to shift towards the side with least moles.
- A decrease in pressure forces the reaction at equilibrium to shift towards the side with most moles.

EXAMPLE

- Given the Haber process then Le Chatelier's principle will be in action.

	$N_{2(g)}$ +	$3H_{2(g)}$ ⇌	$2NH_{3(g)}$
• Mole count	1 +	3	2
	4		2
	Reactants		Products

- From the above equation it is evident that products have least moles, whereas reactants have most moles.
- Then, if in this reaction the pressure is increased, the concentration of all gases will increase, the side with the higher mole is initially favoured, and hence the equilibrium will shift towards (**favours**) the side with least moles (products).
- Also if the pressure is decreased, then the reaction will shift towards (**favours**) most moles (reactants).

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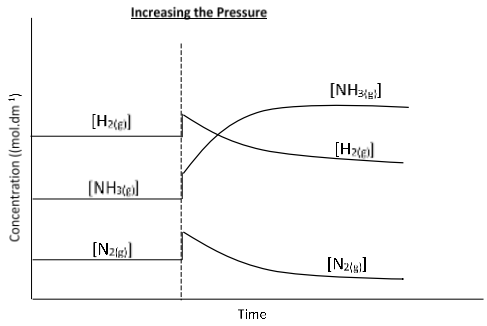
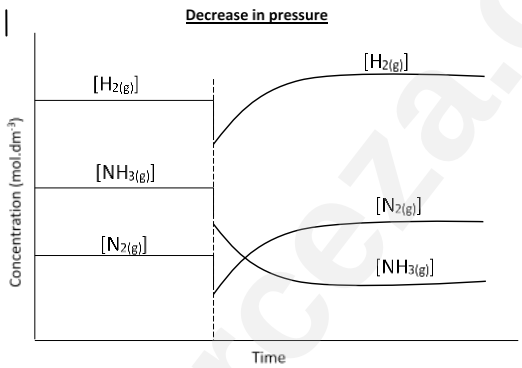
Graphically the above scenario is shown as follows:

Graph : Showing the effect of increase in pressure in Haber Process



Graph : Showing the effect of decrease in pressure in Haber Process



Temperature

When considering the change in temperature, firstly the type of reaction must be identified, whether it is endothermic or exothermic.

This is because the heat is absorbed in an endothermic reaction, then released in an exothermic reaction

- When considering the change in temperature, firstly the type of reaction must be identified, whether it is endothermic or exothermic.

  Given the following hypothetical reaction equation

  $A + B \rightleftharpoons C, \ \Delta H < 0$
- What would happen in this reaction if temperature is decreased?
- Since the reaction has an enthalpy less than zero that means the forward reaction is exothermic.
- Hence, by decreasing temperature of an exothermic reaction that will force the reaction at equilibrium to shift towards (favours) products (C), then it will re-establish equilibrium.
- Also, if temperature could be increased the reaction at equilibrium will shift towards (favours) reactants (A and B).

  Graphically the above could be shown as follows.

  Graph : Shows the effect of increase in temperature in an exothermic reaction

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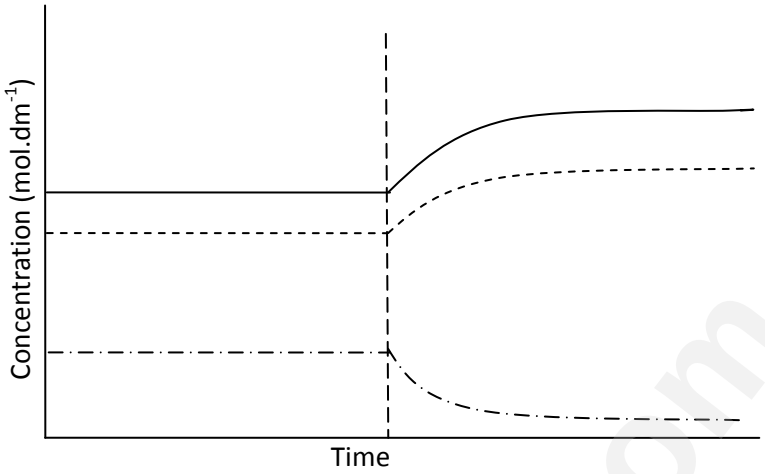
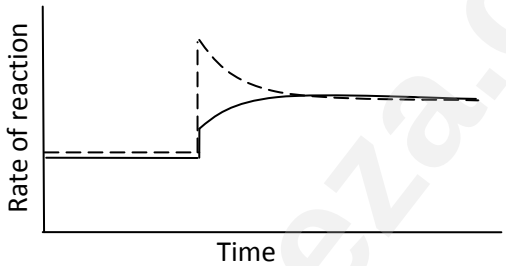


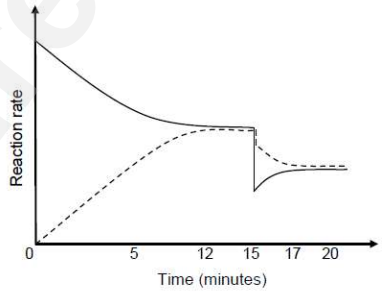


Pure hydrogen iodide, sealed in a 2 dm^3 container at 721 K, decomposes according to the following balanced equation:

$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ $\Delta H = +26$ kJ·mol^{-1}

The graph below shows how reaction rate changes with time for this reversible reaction.

QUESTION 1 (DBE MARCH 2015)



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

1.2 How does the concentration of the reactant change between the 12th and the 15th minute? Write down only INCREASES, DECREASES or NO CHANGE. (1)

1.3 The rates of both the forward and the reverse reactions suddenly change at t = 15 minutes.

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1.3.1 Give a reason for the sudden change in reaction rate. (1)
1.3.2 Fully explain how you arrived at the answer to QUESTION 1.3.1. (3)
The equilibrium constant (Kc) for the forward reaction is 0,02 at 721 K.
1.4 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)
1.5 Calculate the equilibrium constant for the reverse reaction. (1)
1.6 The temperature is now increased to 800 K. How will the value of the equilibrium constant (Kc) for the forward reaction change? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

QUESTION 2 (DBE MARCH 2014)

The reaction of methane gas (CH_4) with steam (H_2O) produces hydrogen gas. The equation for the reaction is shown below.

$CH_{4(g)} + 2H_2O_{(g)} \rightleftharpoons CO_{2(g)} + 4H_{2(g)}$

2.1 Briefly explain why the CO_2 gas may be harmful to the environment. (2)
Initially, 1 mol of methane and 2 mol of steam are sealed in a 5,0 dm^3 container. When equilibrium is established at temperature T_1, the mixture contains 0,3 mol of $CO_2(g)$.
2.2 Define the term chemical equilibrium. (2)
2.3 Calculate the equilibrium constant (K_C) at T_1. (7)
2.4 A new equilibrium is now established at a higher temperature T_2. The value of the equilibrium constant (K_C) at this new temperature is 0,01.
Is this reaction exothermic or endothermic? Use Le Chatelier's principle and the value of K_C at T_1 and T_2 to explain the answer.

QUESTION 3 (DBE NOV 2014)

A certain amount of nitrogen dioxide gas (NO_2) is sealed in a gas syringe at 25 °C. When equilibrium is reached, the volume occupied by the reaction mixture in the gas syringe is 80 cm^3. The balanced chemical equation for the reaction taking place is:

$$\underset{\text{(dark brown)}}{2NO_2(g)} \rightleftharpoons \underset{\text{(colourless)}}{N_2O_4(g)} \qquad \Delta H < 0$$

3.1 Define the term chemical equilibrium. (2)

3.2 At equilibrium the concentration of the $NO_{2(g)}$ is 0,2 $mol \cdot dm^{-3}$. The equilibrium constant for the reaction is 171 at 25 °C.
Calculate the initial number of moles of $NO_2(g)$ placed in the gas syringe. (8)

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3.3The diagram below shows the reaction mixture in the gas syringe after equilibrium is established.

The pressure is now increased by decreasing the volume of the gas syringe at constant temperature as illustrated in the diagram below.

3.3.1IMMEDIATELY after increasing the pressure, the colour of the reaction mixture in the gas syringe appears darker than before. Give a reason for this observation. (1)

3.3.2 After a while a new equilibrium is established as illustrated below. The colour of the reaction mixture in the gas syringe now appears lighter than the initial colour.

Use Le Chatelier's principle to explain the colour change observed in the gas syringe. (3)

3.4 The temperature of the reaction mixture in the gas syringe is now increased and a new equilibrium is established. How will each of the following be affected?

3.4.1 Colour of the reaction mixture
Write down only DARKER, LIGHTER or REMAINS THE SAME. (1)

3.4.2 Value of the equilibrium constant (Kc)
Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

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QUESTION 4 (Gauteng Prep exam 2014)

When a number of moles of X_2 (g) and Y_2 (g) are placed in an empty, closed 2 dm^3 container at 800 °C , a reaction takes place and eventually reaches equilibrium according to the following equation:

$X_2(g) + 3Y_2(g) \rightleftharpoons 2XY_3(g)$

At equilibrium there is 0,4 $mol \cdot dm^{-3}$ of Y_2 and XY_3 present.

You are also given the following information for the reaction:

Temperature °C	Kc
400	0,8
600	2,5
800	4,0

4.1 Calculate the initial number of moles of X2 and Y2 placed in the container. (9)

4.2 Is the forward reaction endothermic or exothermic? (1)

4.3 Explain your answer to QUESTION 4.2. (2)

4.4. What effect will adding more Y2 (g) at 800°C have on the following?

Answer only INCREASE, DECREASE OR STAY THE SAME.

4.4.1The rate of the reverse reaction (1)

4.4.2 Concentration of X_2 (g) (1)

4.5 Which ONE of the following gases XY_3 or X_2 would be present in a higher concentration in the equilibrium mixture at 400°C? (1)

4.6 Explain your answer to QUESTION 4.5. (2)

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QUESTION 5 (Western Cape prep exam 2014)

A solution of potassium chromate is yellow in colour. The addition of a few drops of concentrated nitric acid results in the formation of orange dichromate ions. An equilibrium is established as follows:

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftarrows Cr_2O_7^{2-}(aq) + H_2O(l)$$

yellow orange

5.1 What is meant by "an equilibrium is established"? (2)

5.2 The yellow chromate solution turned orange when <u>concentrated</u> nitric acid was added. Explain why it is necessary for the acid to be concentrated. (2)

5.3 Several changes are made – each time to a new sample of the system in equilibrium.

Complete the table below to indicate what observations are made for the changes indicated. Write down the question numbers and only:

turns more yellow / turns more orange / no change.

change	**observation**
Water is added	**5.3.1**
The pH of the system is decreased	**5.3.2**
A few pellets of sodium hydroxide are added	**5.3.3**

(6)

5.4 Use Le Chatelier's Principle and explain your answer to 5.3.3. (3)

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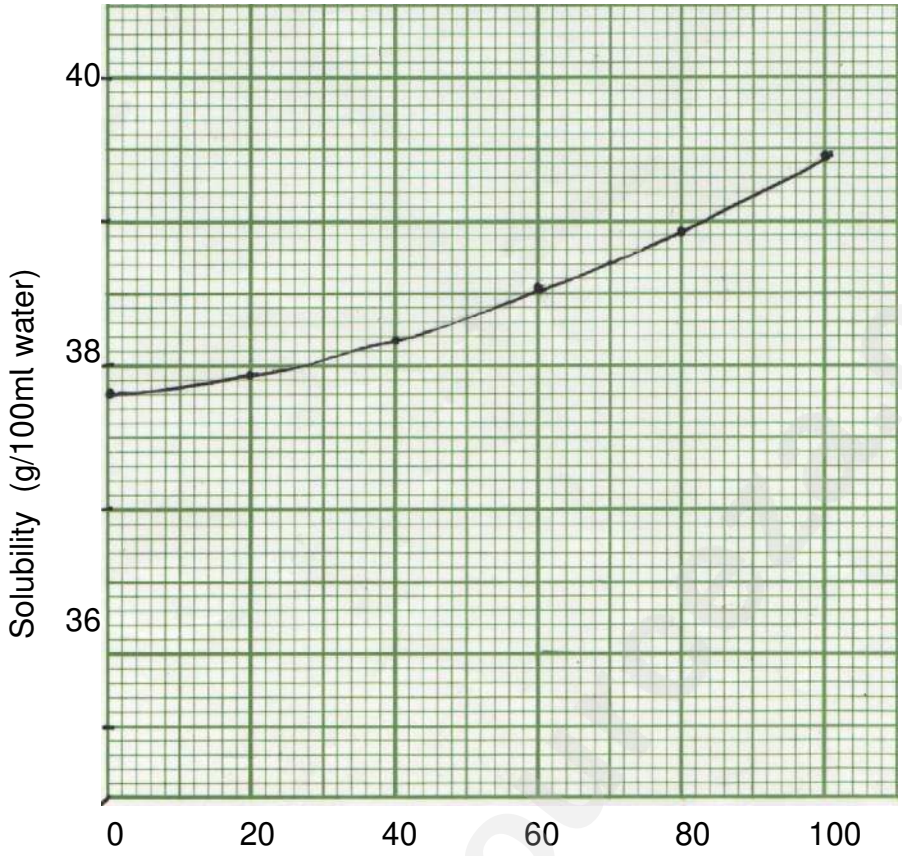
QUESTION 6

The graph below shows the solubility of sodium chloride in g/100ml water at various temperatures.



Consider the equilibrium in a saturated solution of sodium chloride:

$$NaCl(s) \rightleftarrows Na^{+}(aq) + Cl^{-}(aq)$$

6.1 Is the dissolution of NaCl *exothermic* or *endothermic*? (1)

6.2 At 25°C, the solubility of sodium chloride is 35,9g/100ml water.

Calculate the equilibrium constant for the system. (6)

6.3 What can be done to increase the value of Kc at for this system? Explain. (4)

6.4 At the same temperature, the equilibrium constant of a saturated solution of

Silver chloride is 1,8x10^{-10}. Is silver chloride *more soluble* or *less soluble* than Sodium chloride at 25 ^{O}C? (1)

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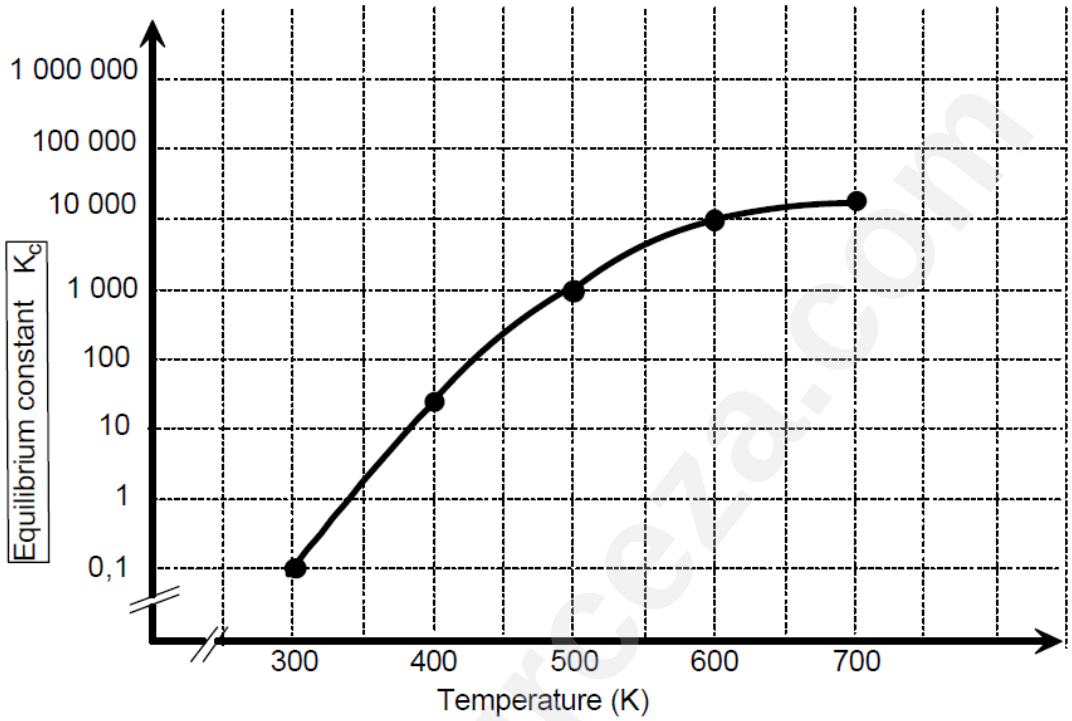
QUESTION 7 DOE FEB/MARCH HG 2007

7.1 The graph below shows the effect of a temperature change on the value of K_c for the following reaction taking place in a closed container:
$N_2O_4(g)$? $2NO_2(g)$



7.1.1 What effect does an increase in temperature have on the value of Kc? (1)
7.1.2 Which reaction was favoured due to an increase in temperature?
Write only FORWARD or REVERSE. (1)
7.1.3 Using Le Chatelier's principle, explain whether the forward reaction is exothermic or endothermic. (4)
7.1.4 Write down two factors, other than temperature, that can be used to increase the rate of the forward reaction at 500 K. (2)

7.2 The equilibrium constant Kc is 360 at 298 K for the reaction:
AgCl(s) + Br-(aq) ? AgBr(s) + Cl-(aq)

If a 0,2 mol.dm-3 solution of Br-(aq) is added to solid AgCl, what will the equilibrium concentrations of Br-(aq) and Cl-(aq) at 298 K be? Your calculation must be accurate to three decimal places. (8)

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QUESTION 8 DOE HG NOV 2006

6.1 Two (2) moles of nitrogen dioxide gas (NO_2) and 2 moles of sulphur dioxide gas (SO_2) are allowed to react in a closed container of volume 2 dm^3 and at a temperature of 700 °C. After t seconds an analysis of the mixture showed that 0,75 moles of SO_3 were present in the container. At 700 °C K_c = 9. The equation for the equilibrium reaction is: (9)

$$NO_2(g) + SO_2(g) \rightleftharpoons SO_3(g) + NO(g)$$

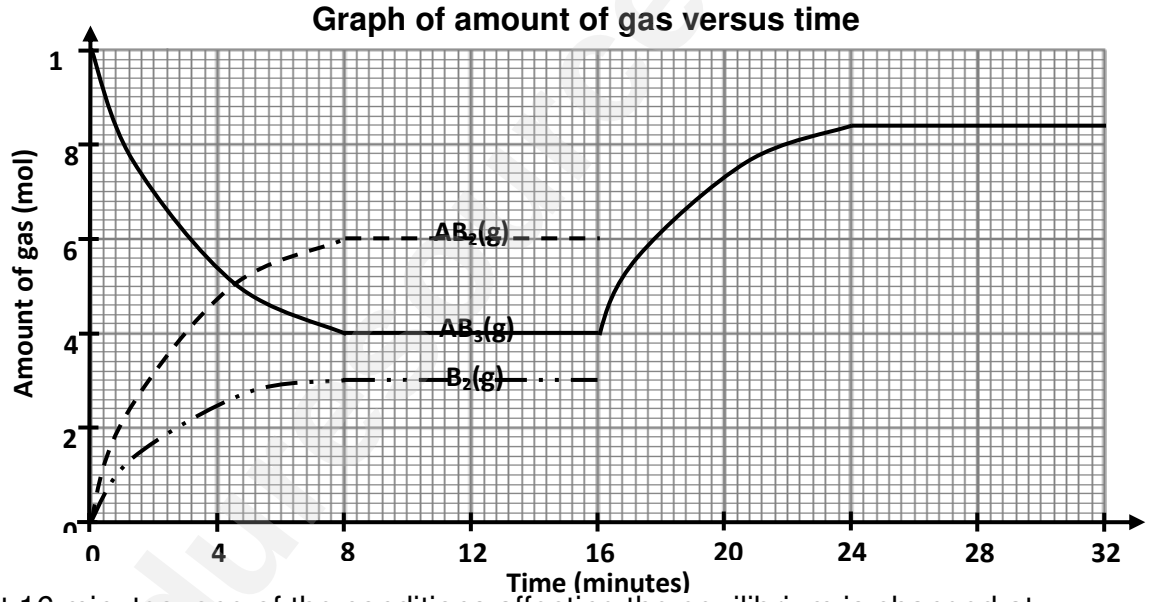
Is the reaction in equilibrium at t seconds? Clearly show how you arrived at your answer.

6.2 After a period of time the temperature is increased and an analysis showed that the K_c value has increased to 12. Make use of Le Chatelier's principle to determine whether the forward reaction is exothermic or endothermic. (4)

QUESTION 7 KZN PREP 2015

The following equation represents a hypothetical reaction that reaches equilibrium in a 2 dm^3 closed container at 500 °C after 8 minutes.

$$2AB_3(g) \rightleftharpoons 2AB_2(g) + B_2(g) \qquad \Delta H < 0$$



7.1 At 16 minutes, one of the conditions affecting the equilibrium is changed at constant volume and a new equilibrium is thereafter established.
Calculate, the K_c value at the new equilibrium. (8)

7.2 Which condition, CONCENTRATION or TEMPERATURE was changed? (2)

7.3 Was the condition identified in QUESTION 6.2 INCREASED or DECREASED? (1)

7.4 Use Le Chatelier's principle to explain the answer to QUESTION 7.3. (3)

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7.5 How does the equilibrium constant, K_c, between t = 8 minutes and t = 16 minutes compare to that between t = 24 minutes and t = 32 minutes? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

7.6 How will the K_c value be affected if the volume of the container, is decreased from 2 dm^3 to 1 dm^3 after 32 minutes, while keeping the temperature constant. (1)

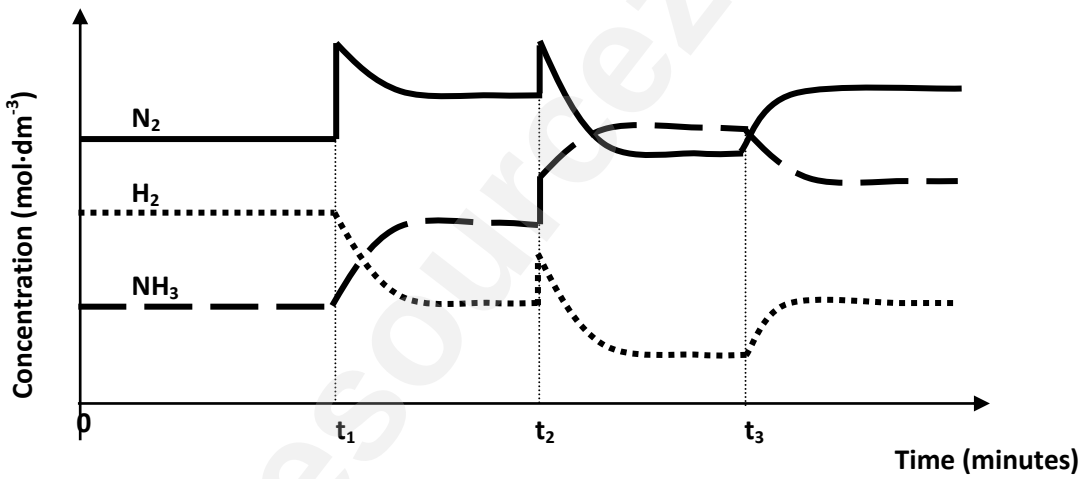
QUESTION 8

A fertiliser company produces ammonia on a large scale at a temperature of 450 °C. The balanced equation below represents the reaction that takes place in a sealed container.

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

To meet an increased demand for fertiliser, the management of the company instructs their engineer to make the necessary adjustments to increase the yield of ammonia.

In a trial run on a small scale in the laboratory, the engineer makes adjustments to the TEMPERATURE, PRESSURE and CONCENTRATION of the equilibrium mixture. The graphs below represent the results obtained.



8.1 Identify and explain the changes made to the equilibrium mixture using Le Chatelier's Principle at each of the following times:

8.1.1 t_1 (3)

8.1.2 t_2 (3)

8.1.3 t_3 (3)

7.5 At which of the above time(s) did the change made to the reaction mixture lead to a higher yield of ammonia? Write down only $\mathbf{t_1}$ and/or $\mathbf{t_2}$ and/or $\mathbf{t_3}$. (2)

7.6 The engineer now injects 5 mol N_2 and 5 mol H_2 into a 5 dm^3 sealed empty container. Equilibrium is reached at 450 °C. Upon analysis of the equilibrium mixture, he finds that the mass of NH_3 is 20,4 g.

Calculate the value of the equilibrium constant (K_c) at 450 °C. (9)

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ACIDS AND BASES

- Acids and bases are chemicals that exhibit their chemical behaviour when dissolved in water. Hence, when dealing with them the word aqueous will be repeatedly used, so is in the chemical equation for acids and bases. Acids and bases produces ions when dissolved in water; therefore, are called **electrolytes**.
- An electrolyte is an **ionic** solution that is able to conduct electricity.
- There are different types of acids and bases that occur naturally; however, there also others which are derived in the laboratory
- Acids and bases are defined based on two theories i.e. Lowry-Bronsted and Arrhenius

Table1: Illustrates acid and base definition using different theories.

Definition	**Acid**	**Base**
Lowry-Bronsted theory	An acid is a proton donor (H^+)	A base is a proton acceptor (H^+)
	$HCl + H_2O \leftrightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$	$NH_3 + H_20 \leftrightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$
Arrhenius theory	An acid liberates hydrogen ions (H^+) in aqueous solutions	A base liberates hydroxyl ions (OH^-) in aqueous solutions
	$HCl \leftrightarrow H^+_{(aq)} + Cl^-_{(aq)}$	$NaOH \leftrightarrow Na^+_{(aq)} + OH^-_{(aq)}$

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Table 2: Illustrate properties of acids and bases

Acid	**Base**
1. Sour taste	1. Bitter taste
2. Corrosive	2. Caustic
3. have pH lower than 7	3. Have pH greater than 7
4. As pH decreases the acidity increases	4. As pH increases the basicity increases.

Ampholyte					
	An **ampholyte** is a substance that can act as a base and as an acid				
e.g.					
	HSO_4^-	$+ H_2O$	$\rightarrow H_2SO_4$	$+ OH^-$	:HSO_4^- acts as a base
	HSO_4^-	$+ H_2O$	$\rightarrow SO_4^{2-}$	$+ H_3O^+$	:HSO_4^- acts as an acid

Activity 1

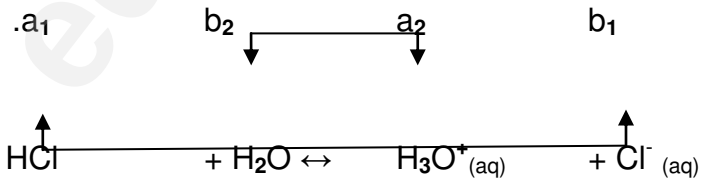
1. With the use of relevant Equations show that water is an Ampholyte.

1.1. $H_2PO_3^-$

1.2. H_2O

Conjugate Acid- base pairs

e.g.



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Activity 2

1. Write down the equation and identify conjugate acid-base pairs using the following:

1.1. H_2SO_4 dissolved in H_2O

1.2. NH_3 dissolved in H_2O

IONIC STRENGTH of Acids and Bases

Table 4 : Illustrates the difference between a strong acid and a weak acid

Strong Acid(HCl,H_2SO_4,HNO_3)	**Weak Acid(CH_3COOH)**
1. Ionises completely in water to form high concentration of hydronium ions	1. Ionises partially in water to form low concentration of hydroxide ions
2. Has a lower pH value	2. Has pH value closer to 7
3. has bigger K_a	3. Has smaller K_a
4. Stronger electrolytes, high conductivity	4. Weak electrolytes, lower conductivity

Table 5 : Illustrates the difference between a strong base and a weak base

Strong bases(NaOH,KOH)	**Weak bases**
1. dissociates completely in water	1. dissociates partially in water
2. Has a pH value closer to 14	2. Has pH value closer to 7
3. has bigger K_b	3. Has smaller K_b
4. Stronger electrolytes, high conductivity	4. Weak electrolytes, lower conductivity

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Auto-ionisation of water

- Water has tendency to ionise itself by transferring a proton (H+) from one water molecule to the other. This ionisation is shown in the equation below:

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

- Since, the above reaction shows an equilibrium nature, then one can write the equilibrium constant expression for water auto-ionisation as follows:

$$K_w = \frac{[H_3O^+][OH^-]}{[H_2O]^2}$$

- However, concentration of liquid water at room temperature remains constant as 1

  mol.dm^{-3}. Therefore K_w maybe written as

  $K_w = [H_3O^+][OH^-]$

- But $K_w = 1{,}0 \times 10^{-14}$

  $K_w = 1{,}0 \times 10^{-14} = [H^+][OH^-]$

Indicators

- An indicator is a chemical substance that changes colour when the solution has a specific pH
- There are three indicators that are of concern for grade 12 discussion i.e. methyl orange, Phenolphthalein and Bromothymol blue
- Indicators are used in titration (neutralisation reactions) to determine an **equivalence point** or an end point
- An equivalence point is a stage whereby an ***acid***/**base** has completely reacted with an ***base***/**Acid**. Therefore, in solution there is only salt, water

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and an indicator available

- Although, there are three different indicators available for use in grade 12, it is important that one is able to determine the suitable indicator based on combination of acid and base available.

Table 3 : Illustrates the selection of a suitable indicator

Combination	Indicator	pH range	Expected colour
Strong Acid + Weak base	Methyl Orange	3,1 – 4,4	Yellow / orange
Strong acid + Strong base	Bromothymol blue	6,0 – 7,6	Blue / dark blue
Weak acid + strong base	Phenolphthalein	8,3 – 10	Pink / red

Activity 3

1. Which indicator would you use if solutions of the following acid and base were titrated against one another?

1.1. HNO_3 and NaOH

1.2. CH_3COOH and $Ca(OH)_2$

1.3. H_2SO_4 and $CaCO_3$

pH

- pH is a measure of concentration of H^+ ions in a solution.
- pH is mathematically defined as pH = -log[H^+] or pH = -log[H_3O^+]
- pH is measured with a pH meter; for grade 12, pH meter ranges from 0 to 14
  - Acidic pH is less than 7
  - Neutral pH is equal to 7

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◦ Basic / Alkaline pH is greater than 7

- Also, pH could be calculated using stoichiometry and hydrolysis of substance to determine the concentration of H^+ ions

Determination of pH for Acids

Example 1: Calculate the pH of 0.01mol.dm^{-3} HNO_3 (aq) solution.

Solution 1:

Step 1: Ionise HNO_3 to get H^+ ions

$HNO_3 \rightarrow H^+ + NO_3^-$

Step 2: Determine stoichiometric ratio of an acid to proton

1 mol of HNO_3 : 1 mol of H^+

Step 3: Determine the concentration of H^+

$HNO_3 \rightarrow H^+ + NO_3^-$

0,01 0,01

Step 4: Determine pH using calculation

pH = $-\log[H_3O^+]$

pH = $-\log(0,01)$

pH = 2

Activity 4

1. Determine the pH of the following solutions

1.1. 0,05 mol.dm^{-3} of HCl

1.2. 0,05mol.dm^{-3} of H_2SO_4

1.3. 0,030 mol.dm^{-3} of H_3PO_4

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Determination of pH for Bases

- The problem with bases is that they don't produce H^+ ions during hydrolysis.

  Therefore, when pH of a base is calculated, it is important to first determine the concentration of H^+ before committing to the mathematical definition of pH.

- K_w of pure water is $1x10^{-14}$:

  However, water is a product of H^+ (acid) and OH^-(base).

  Hence, the above statement could be mathematically written as

  $[H^+][OH^-] = 1x10^{-14}$

  Therefore, concentration of an acid

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

Example 2: Determine the pH of 0,001 $mol.dm^{-3}$ NaOH

Solution 2:

Step 1: Dissociate the base to produce hydroxide ions

$NaOH \rightarrow Na^+ + OH^-$

Step 2: Determine the Stoichiometric ratio of a base is to hydroxide ions

1mol of NaOH = 1mol OH^-

Step 3: Determine the concentration of OH^-

$[OH^-] = 0,01\ mol.dm^{-3}$

Step 4: Determine the concentration of H_3O^+

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

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$$[H_3O^+] = \frac{1 \times 10^{-14}}{0,01}$$

$$[H_3O^+] = 1,0\times10^{-12}\ mol.dm^{-3}$$

Step 5: Determine pH of a base

pH = $-\log[H_3O^+]$

pH = $-\log(1,0\times10^{-12})$

pH = 12

Activity 5

1. Determine the pH for the following solutions

1.1. 0,02 $mol.dm^{-3}$ KOH

1.2. 0,02 $mol.dm^{-3}$ $Ba(OH)_2$

1.3. 0,015 $mol.dm^{-3}$ $Al(OH)_3$

Types of reactions of acids

1. Acid + Metal → Salt + Hydrogen gas

$HCl + Mg \rightarrow MgCl_2 + H_2$

2. Acid + Metal oxide → Salt + water

$HCl + MgO \rightarrow MgCl_2 + H_2O$

3. Acid + Carbonate → Salt + water + carbon dioxide

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$

4 Acid + Metal hydroxide (Base) → Salt + water

$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$

Reaction 2, 3 and 4 are called neutralization reaction, this is mere to the fact that one of the products formed is pure water (distilled water) which is a neutral substance.

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Neutralisation Reactions

- The above reactions are also called protolysis, because there is proton transfer.
- Also, neutralisation produce heat i.e. are exothermic

Concentration

- Concentration is the measure of amount of solute in a solution.
- Solutions are divided into two in terms of concentration i.e. dilute and concentrated solution.
- Concentration is measured in $mol.dm^{-3}$, sometimes denoted as **M** which means molarity. However, for our discussion the focus is on the former.
- Concentration is quantitatively calculated using the following equations:

$$c = \frac{n}{v}$$

$$c = \frac{m}{Mv}$$

Where:

c = concentration ($mol.dm^{-3}$)

n = number of moles (mol)

v = volume of solution (dm^{-3})

m = mass (g)

M = Molar mass ($g.mol^{-1}$)

Example 1: Calculate the concentration of 0,025 mol of NaOH in 250 ml solution.

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Solution 1:

Step 1 : Collect data

n = 0,025 mol

v = 250 / 1000 = 0,250 dm^3

c = ?

Step 2 : Selection of suitable equation

$$c = \frac{n}{v}$$

Step 3 : Substitute and leave an answer with correct units

$$c = \frac{n}{v}$$

$$c = \frac{0{,}025}{0{,}250}$$

$$c = 0{,}10\ mol.dm^{-3}$$

Acid - Base Titration

- For any titration to be done, there must be two solutions, a standard solution and an unknown solution.
- A standard solution is a solution of precisely known concentration. This solution is prepared before titration starts.

Steps required to prepare a standard solution:

- **Step 1:** Calculate the mass required and weigh it on a digital balance
- **Step 2:** Pour the solid substance into a known volume volumetric flask.
- **Step 3:** Slowly add water with constant swirling to speed up dissolution rate.
- **Step 4:** Add water drop wise until it reaches the mark.

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Stoichiometric calculations for determination of unknown solution

$$\frac{c_a V_a}{c_b V_b} = \frac{n_a}{n_b}$$

Where:

c_a = concentration of an acid

Va = volume of an acid

n_a = number of moles of an acid

C_b = concentration of a base

V_b = volume of a base

N_b = number of moles of a base

Example 1: Titration

A 20 cm^3 of 0,012 $mol.dm^{-3}$ solution of sulphuric acid is titrated against an unknown concentration of NaOH; at the end point 30 cm^3 of unknown concentration solution was used. Calculate the concentration of unknown solution.

Step 1: Write a balanced chemical reaction (if given check and balance it)

$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + 2\ H_2O$

Step 2: Ratio of acid to base (Stoichiometry)

1 mol of H_2SO_4 : 2mol of NaOH

Step 3 Collect data

n_a = 1 mol

N_b = 2 mol

c_a = 0,012 $mol.dm^{-3}$

C_b= ?

V_a = 20 /1000 = 0,020 dm^3

V_b = 30 /1000 = 0,030 dm^3

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Step 4: Select a suitable formula and substitute

$$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$

$$\frac{1}{2} = \frac{0{,}012 \times 0{,}020}{c_b 0{,}030}$$

c_b = 0,016 mol.dm^{-3}

TYPICAL EXAM QUESTIONS

QUESTION 1 – 30 minutes (***Taken from IEB Nov 2007 Paper 2 HG***)

1. When 0,1 mol.dm^{-3} ethanoic acid is dissolved in water, the following equilibrium is established

$CH_3COOH_{(aq)} + H_2O_{(l)} \rightarrow CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$

The pH of the solution is measured to be 3.

1.1. What is the **concentration** of the H_3O^+(aq) ions in the solution? (4)

1.2. Calculate the equilibrium constant (K_c) for the reaction at the prevailing Temperature. (5)

1.3 Using the answer calculated above, explain why ethanoic acid is classified as a weak acid. (4)

1.4. 1,713 g of $Ba(OH)_2$ is added to 100 cm^3 of the 0,1 mol.dm^{-3} ethanoic acid solution without changing the volume. The balanced chemical reaction is represented as follows:

$2CH_3COOH + Ba(OH)_2 \rightarrow Ba(CH_3COO)_2 + 2H_2O$

1.4.1. Calculate the number of moles of CH_3COOH present in

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100 cm^3 solution of the ethanoic acid (3)

1.4.2. Calculate the number of moles of $Ba(OH)_2$ present in.

1,713 g barium hydroxide (4)

1.4.3. Determine which of CH_3COOH or $Ba(OH)_2$, is in **excess**

and by how many moles (4)

1.4.4. Using this information, what will be the final pH of the

solution? (5)

[29]

QUESTION 1

1.1 Which ONE of the following solutions has the HIGHEST pH value?

A 0,1 mol•dm^{-3} $Mg(OH)_2$

B 0,1 mol•dm^{-3} NH_3

C 0,1 mol•dm^{-3} HCl

D 0,1 mol•dm^{-3} H_2SO_4

1.2 Which ONE of the following represents the products formed during the hydrolysis of calcium carbonate?

A H_30^+(aq) and $C0_3^{2-}$(aq)

B OH^-(aq) and HCO_3^-(aq)

C Ca^{2+}(aq) and $C0_3^{2-}$(aq)

D Ca^{2+}(aq) and OH^-(aq)

1.3 Ammonium sulphate is dissolved in water. Which ONE of the following statements regarding the solution which is formed, is CORRECT?

A pH = 7

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B $[H_3O^+]\cdot[OH^-] < 1 \times 10^{-14}$

C $[H_3O^+] > [OH^-]$

D $[H_3O^+] < [OH-]$

1.4. Which ONE of the following solutions has the HIGHEST conductivity?

A 0,1 $mol.dm^{-3}$ H_2C0_3

B 0,1 $mol.dm^{-3}$ $(C00H)_2$

C 0,1 $mol.dm^{-3}$ HNO_3

D 0,1 $mol.dm^{-3}$ CH_3COOH (2)

1.5 Which ONE of the solutions below is acidic?

A KCl (aq)

B Na_2SO_4

C NH_4Cl

D $CH_3COONa(aq)$ (2)

1.6 Consider the ionization reaction below:

$$NH_3 + H_2O \rightleftarrows NH_4^+ + OH^-$$

A conjugate acid-base pair is...

A NH_3 ; NH_4^+

B NH_3 ; H_2O

C H_2O ; NH_4^+

D NH_3 ; OH^- (2)

1.7 A 1 $mol.dm^{-3}$ solution of each of a number of acids is prepared. Which solution will have the lowest pH?

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A HCl

B H_2SO_4

C CH_3COOH

(2)

D NH_4OH (2)

1.8 Water undergoes auto-ionisation. During this process ...

A a proton is transferred from one water molecule to another.

B water molecules act as proton donors only.

C water molecules act as proton acceptors only.

D the pH of water will decrease. (2)

1.9 A small quantity of concentrated hydrochloric acid is gradually added to 1 dm^{-3} of distilled water at 25 °C. After testing the resultant solution, it is found that the value of K_w, $[H_3O^+]$ and $[OH^-]$ in $mol{\cdot}dm^{-3}$ are:

A	$K_w = 10^{-14}$	$[H_3O^+] < 10^{-7}$	$[OH^-] > 10^{-7}$
B	$Kw < 10^{-14}$	$[H_3O^+] < 10^{-7}$	$[OH^-] < 10^{-7}$
C	$Kw = 10^{-14}$	$[H_3O^+] > 10^{-7}$	$[OH^-] < 10^{-7}$
D	$K_w = 10^{-14}$	$[H_3O^+] = 10^{-7}$	$[OH^-] = 10^{-7}$

QUESTION 2 (GP PREP 2015)

2.1 Define a *Bronsted-Lowry base.* (2)

2.2.1 Calculate the pH of a 0,12 $mol.dm^{-3}$ HCl? solution. (3)

2.2.2 Write down the FORMULA for the conjugate base of HCl. (I)

2.3.1 Why is HSO_4^- regarded as an ampholyte? (1)

2.3.2 Write down an equation for the reaction of HSO_4^- with water to form the hydronium ion. (3)

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2.4 Bongiwe and Sam plan to do a titration. Prior to the titration each of them prepares a burette using the method given in the table below.

Bongiwe	Sam
She rinses the burette with the acid before filling it to the mark with acid.	He rinses the burette with water before filling to the mark with acid.

Explain why Sam used an **INCORRECT** method. (1)

2.5 A solution of potassium hydroxide is made by dissolving 8,0 g of potassium hydroxide in 250 cm^3 of distilled water.

2.5.1 Calculate the concentration of the potassium hydroxide solution.)

2.5.2 25,0 cm^3 of this solution prepared as above is titrated and neutralised against 40,0 cm^3 of a DILUTE sulphuric acid solution.

The reaction is as follows:

$$H_2SO_4\ (aq) + 2KOH\ (aq) \longrightarrow K_2SO_4(aq) + 2\ H_2O(l)$$

Calculate the concentration of the DILUTE acid. (4)

2.5.3 The dilute sulphuric acid solution in QUESTION 2.5.2 was prepared by adding 10,0 cm^3 of concentrated sulphuric acid to 490,0 cm^3 of distilled water.

Calculate the concentration of the CONCENTRATED acid. (4)

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QUESTION 3 : (MP PREP 2015)

3.1 A bottle in a laboratory contains dilute sulphuric acid of unknown concentration.

Learners wish to determine the concentration of the sulphuric acid solution. To do this they titrate the sulphuric acid against a standard potassium hydroxide solution.

The balanced equation for the reaction taking place is; $2KOH + H_2S0_4$

$\rightarrow K_2S0_4 + 2H_20$

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. (2)

INDICATOR	pH
Methyl orange	7.9 — 4.0
Methyl red	4.4 — 6.0
Bromothymol blue	8.0 — 10.0
Phenolphthalein	8.3 — 10.0

3.1.5 During the titration the learners finds that 15 cm^3 of the KOH solution neutralises 20 cm^3 of the H_2S0_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 $mol{\bullet}dm^{-3}$ $KMnO_4$.

The net reaction is...

$$2Mn0_4 + 5C_20_4^{2-} + 16H^+ \rightarrow 2Mn^{2+}\ 10CO_2 + 8H_20$$

Calculate the percentage purity of the CaC_2O_4 in the original sample. (6)

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QUESTION 4 (WCED PREP 2014)

You are tasked to determine the percentage ethanoic acid (CH_3COOH) in vinegar.
7,5g of commercial vinegar is dissolved in $100cm^3$ water . $25cm^3$ of this solution is neutralised by $28,5cm^3$ of a sodium hydroxide (NaOH) solution of concentration $0,11mol•dm^{-3}$. The balanced equation for the reaction is

$$NaOH\ (aq) + CH_3COOH\ (aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

4.1 Calculate the pH of the sodium hydroxide solution. (5)
4.2 Calculate the number of moles sodium hydroxide used to neutralise the $25cm^3$ of acid. (2)
4.3 Calculate the percentage ethanoic acid in the vinegar. (5)

QUESTION 5 (EC PREP 2014)

5.1 Define a *strong acid*. (2)
5.2 A solution of an unknown, monoprotic acid has a concentration of 0, 01 $mol·dm^{-3}$ and a pH of 3.
5.2.1 Calculate the concentration of the hydrogen ions in this solution. (2)
5.2.2 How will the strength of this unknown acid compare to that of hydrochloric acid of the same concentration?
Write down only STRONGER THAN, WEAKER THAN or EQUAL TO (1)
5.2.3 Give a reason for your answer in QUESTION 5.2.2. (2)
5.3 Ammonium chloride is an example of a salt that can undergo <u>hydrolysis.</u>
5.3.1 Define the underlined term. (2)
5.3.7. Write an equation to show the hydrolysis of ammonium chloride. (3)
5.3.3 Methyl orange is red in an acidic medium and yellow in an alkaline medium. What will the colour of methyl orange be in an ammonium chloride solution? (2)
5.4 A learner adds a sample of calcium carbonate to 50, 0 cm^3 of sulphuric acid. The sulphuric acid is in excess and has a concentration of 1, 0 $mol·dm^{-3}$. The balanced equation for the reaction that takes place is:

$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$ 1

The reaction is allowed to proceed until all the $CaCO_3$ is used up.

The H_2SO_4 **left over** from REACTION 1 is now neutralised by 28, 0 cm^3 of a 0,5 $mol·dm^{-3}$ sodium hydroxide solution.

The balanced equation for this reaction is:

$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$ 2

Calculate the **mass** of calcium carbonate in the sample used in REACTION 1. (10)

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QUESTION 6 DOE FEB/MARCH 2007

A learner determined the pH of a number of solutions at 25 °C. She obtained the following results:

Solution	Battery acid	Orange juice	Bicarbonate of soda
pH	1	4,2	12

6.1 Which solution contains the highest concentration of hydrogen ions? (2)
6.2 Calculate the concentration of hydroxide ions in orange juice. (5)
6.3 How will the pH of battery acid change when …
(Only write INCREASES, DECREASES or STAYS THE SAME.)
6.3.1 distilled water is added to it? (2)
6.3.2 some of the bicarbonate of soda solution is added to it? (2)

QUESTION 7 DOE HG FEB/MARCH 2006

7.1 Consider separate solutions of two substances HX and HY and the information supplied on their pH, [OH-] and [H+].

	$[OH^-]$	$[H^+]$	pH
HX	10^{-11}	7.1.1	7.1.2
HY	7.1.3	7.1.4	10

Complete the table by writing down the numbers 7.1.1 to 7.1.4 and next to each number the correct answer. (8)

7.2 A 5,3 g sample of sodium carbonate (Na_2CO_3) is dissolved in pure water.
7.2.1 Write down the equation for the hydrolysis of the carbonate ion in water. (3)
7.2.2 Write down the conjugate acid-base pairs in QUESTION 7.2.1. (4)
7.2.3 The sodium carbonate solution is now neutralised by 200 cm3 of a solution of an acid HZ according to the equation:

$$Na_2CO_3(g) + 2HZ(g) \longrightarrow 2NaZ(aq) + CO_2(g) + H_2O(l)$$

Calculate the concentration of the HZ solution. (7)

QUESTION 8 DOE HG NOV 2005

8.1
8.1.1 The meaning of the term **diprotic** acid.
8.1.2 The formula of a **diprotic** acid.
8.2
8.2.1 Calculate the concentration of the hydrochloric acid in the person's stomach.
8.2.2 Will the pH in the stomach **INCREASE, DECREASE** or **STAY THE SAME** after taking in a dose of $Mg(OH)_2$?

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8.2.3 A person takes in a dose of $Mg(OH)_2$. Write down the balanced equation for the reaction that takes place in the stomach.

8.3 A textbook states that calcium sulphate ($CaSO_4$) is slightly soluble in water.

Two learners decided to test the dam water from a local municipality for calcium sulphate. They took a 0,5 dm^3 sample of the dam water and treated it with sodium carbonate solution to precipitate the calcium ions present according to the following equation:

$$CaSO_4(aq) + Na_2CO_3(aq)\ Na_2SO_4(aq) + CaCO_3(s)$$

The precipitate is then dissolved in 30 cm^3 of 0,1 $mol.dm^{-3}$ $HC\ell$ solution which converts the precipitate to aqueous calcium chloride, water and carbon dioxide according to the following equation:

$$CaCO_3 + 2HC\ell\ CaC\ell_2 + CO_2 + H_2O$$

The $HC\ell$ was in excess. They neutralised the excess $HC\ell$ by adding 15,8 cm^3 of a 0,1 $mol.dm^{-3}$ NaOH solution. The equation for the reaction is:

$$HC\ell + NaOH\ NaC\ell + H_2O$$

Calculate the mass of calcium sulphate that was present in the sample of dam water. (10)

QUESTION 9 DOE HG NOV 2005

A learner is provided with 50 cm^3 of dilute sulphuric acid with a concentration of 0,2 $mol.dm^{-3}$. Assume complete ionisation of the acid.

9.1 What is meant by a dilute acid solution? (2)

9.2 The learner uses X grams of potassium hydroxide to prepare a 100 cm^3 potassium hydroxide solution in a conical flask. She then adds all the sulphuric acid solution to the conical flask containing potassium hydroxide at 25 °C.
The pH of the resulting solution is 12,8.

9.2.1 Which of the ions, OH^- or H^+, is in excess in the resulting solution? (1)

9.2.2 Calculate the number of moles of ions in excess in the resulting solution. (7)

9.2.3 Determine the mass X of the potassium hydroxide used. (8)

9.3 A few crystals of ammonium nitrate are added to distilled water in a test tube and a solution is formed.

9.3.1 Is the solution ACIDIC, BASIC or NEUTRAL? (2)

9.3.2 Write down an ionic equation that will explain the answer to QUESTION 9.3.1. (3)

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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

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. In addition to this, loss of electrons leads to an increase in an oxidation number (charge) whereas gaining of electrons leads to the decrease of an oxidation number (charge).

Reduction and oxidation reactions are two concurrent reactions that are mothers of electrochemical cell. These reactions occur simultaneously at the same rate and that means there is a constant change in electrolyte concentration.

Components of any redox reaction are **electrolyte** and **two electrodes**. An *anode* that is being oxidized always shows a decrease in mass, whereas a *cathode* undergoing reduction always shows an increase in mass. Whereby electrolyte is the solution that is able to conduct electricity and electrode are parts that house the redox chemistry.

Reduction reaction

Reduction reaction is defined as gaining of electrons, of which consequentially leads to a decrease in an **oxidation number**. Hence, the term **reduction** was derived from that occurrence. An element that undergoes reduction facilitates the loss of electrons of another element therefore it's called an **oxidizing agent**.

This half reaction is located at an electrode called cathode.
Then reduction reaction is written as follows:

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

Also, if there is an uncertainty of whether the reaction is reduction or not, one must look for the change in charge from reactants to products, if it decreases then that is reduction reaction.

Oxidation reaction

Oxidation reaction is defined as losing of electrons, of which consequentially leads to an increase in an **oxidation number**. Hence, the term oxidation was derived from that occurrence. Historically it was believed that oxidation is only possible in the presence of oxygen. However, later research showed that anything which causes the increase of elemental oxidation number is oxidation. An element that undergoes reduction facilitates the gain of electrons of another element therefore it's

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called a reducing agent. This half reaction is located at an electrode called Anode. Then oxidation half reaction is written as follows:

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

Also if there is an uncertainty of whether the reaction is reduction or not, one must look for the change in charge from reactants to products, if it increases then that is oxidation reaction.

There are two type electrochemical cells

1. Galvanic / Voltaic cell
2. Electrolytic Cell

<u>Galvanic Cell</u>

Galvanic cell is an electrochemical cell that converts chemical energy into electrical energy. This cell must be spontaneous which could be observed by a positive E^o_{cell} being positive. Also it's made up of the following major components: salt bridge, conducting wire, and voltmeter. Salt bridge connects a chamber with a cathode with the one that has an anode. Salt bridge is made up of very stable salt usually KNO_3.

1. The salt bridge is used to:
    a. Complete the circuit
    b. Neutralises solutions by allowing the flow of ions in between solutions.
2. Conducting wire is used to transport electrons that are being transferred.
3. Voltmeter is used to measure the potential difference across the cell.

This cell uses the standard reduction potential tables to determine which substances shall undergo reduction as well as oxidation in a pair. The element with a smaller E value always undergoes oxidation. Which means it must be located on an ANODE which is a negative electrode for this cell. Whereas, an element with a bigger E value will always undergo reduction and that is located on the positive electrode called Cathode for this cell.

e.g. given the following pair Zn / Cu

E value for Zn is -0.76V

E value for Cu is +0.34V

When comparing both values its evident that Zn has a smaller value and that means in this pairing it shall undergo oxidation. Then Cu must undergo reduction to complete redox reaction.

Oxidation half reaction: $Zn \rightarrow Zn^{2+} + 2e^-$

Reduction half reaction: $Cu^{2+} + 2e^- \rightarrow Cu$

Also from the same set of elements the net reaction could be derived. A net reaction is the sum of both half reactions. Before the net reaction could be done there must be an equal amount of electrons for both equations. If they do not balance, they must be balanced before a net reaction is done.

Nett reaction: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

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Also the potential difference of the cell could be calculated based on the pair given. The potential difference is measured by the voltmeter; however, it could also be determined from the E values. Also the potential difference is independent of the number of electrons transferred, but depends upon the elements used in a cell.

$$E_{cell} = E_{reduction} - E_{oxidation}$$
$$= (+0.34) - (-0.76)$$
$$= +1.10V$$

Also this could show using cell notation which is a summary of a Galvanic Cell. In a cell notation anything with a charge must be accompanied by a standard concentration which is 1 $mol.dm^{-3}$. Also in a cell notation electrons transferred aren't shown however, the species of a substance are shown. The cell notation starts with an anode then double vertical lines that represent a salt bridge then a cathode

$Zn / Zn^{2+}(1\ mol.dm^{-3})\ II\ Cu^{2+}(1\ mol.dm^{-3}) / Cu$

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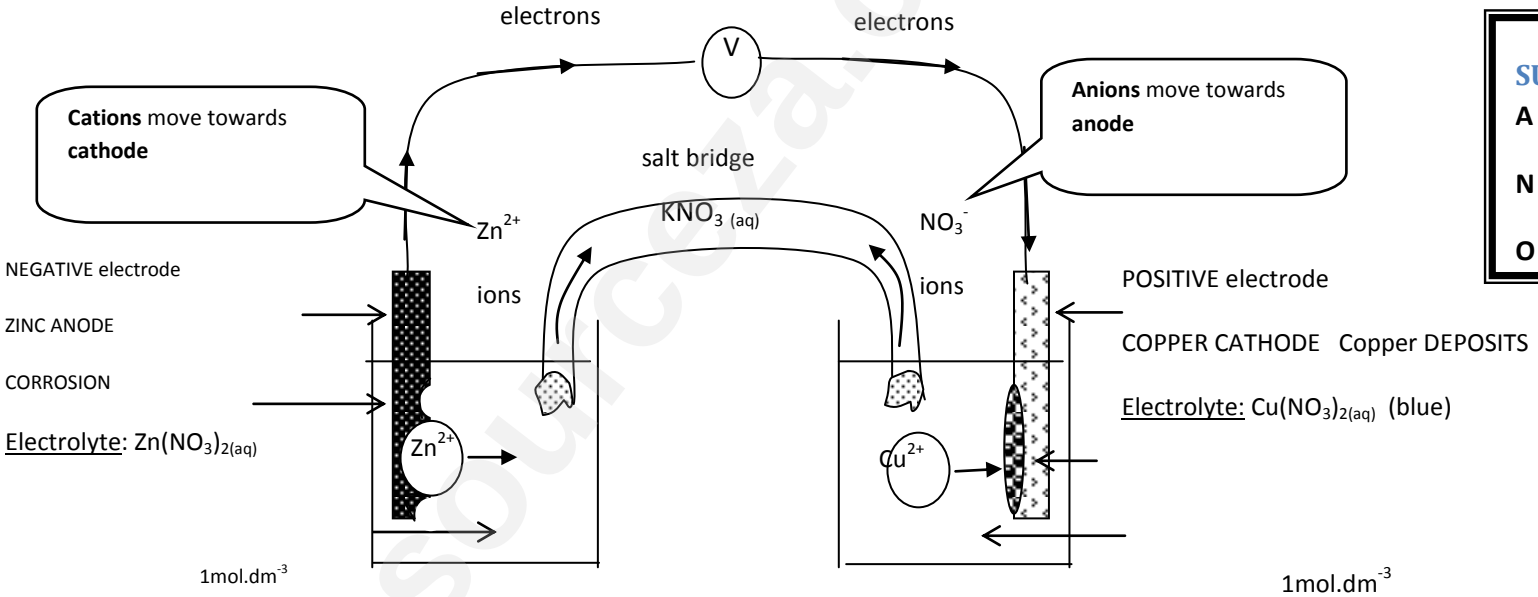
The diagram below shows a standard Galvanic Cell.



SUMMARY

A node

N egative

O xidation

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).

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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 ; 0,5mol.dm^{-3} H_2SO_4*
- H_2 gas at a **pressure of 1 atmosphere** which is bubbled over the electrode
- The temperature of the half cell is kept at **25°C**
- The half cell potential assigned to this electrode is **0,00V**

Using a zinc half cell connected to a hydrogen half cell we find that the voltmeter reads -0,76 V, thus E^o for Zn/Zn^{2+} = - 0,76 V (the negative sign is given to the zinc half cell because when connected to the hydrogen electrode, it will be the source of electrons). Using a copper half-cell connected to the hydrogen electrode the value of E^o = + 0,34 V.

Relationship of current and potential to rate, equilibrium and E^o values

- The faster the reaction rate the greater the current i.e. the rate of flow of charge (current) will increase when the reaction rate increases.
- The E^o values used to calculate cell potential are measured at standard conditions.
- As the cell reaction progresses the concentration of reactant ions decreases and product ions increases causing the **cell potential** to decrease until it **reaches zero**. At this point the **cell reaction is in equilibrium** and there is no nett change in the amount of ions in the system so no electrons flow from anode to cathode. **The cell is flat.**
- The larger the E^o value the further the reaction is from equilibrium.
- Since the cell reaction is a reversible process changes in the reaction conditions can shift the equilibrium position.
    - If a change is made which **favours the forward reaction** then the **emf of the cell will increase** since electrons are transferred at a faster rate.
    - If a change is made that **favours the reverse reaction** then the **emf of the cell will decrease** since electrons are transferred at a slower rate.

Example:

Anode: $Zn \rightarrow Zn^{2+} + 2e^-$ (Oxidation half-reaction)

Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$ (Reduction half-reaction)

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

Note:

- If the reaction in a zinc / copper cell is approaching equilibrium (emf approaching zero) then Cu^{2+} ions could be added to the cathode half cell in order to favour the forward reaction and increase the emf of the cell.
- If Zn^{2+} ions are added to the zinc half cell then the zinc electrode will have less tendency to oxidise, i.e. reverse reaction favoured, therefore less electrons transferred and emf decreases.
- Ions are added to a half cell by adding a soluble salt containing those ions, eg adding $Cu(NO_3)_2$ will add Cu^{2+} ions.

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Worksheet on galvanic cells

*1 Consider a voltaic cell that is set up between **aluminium (Al) and lead (Pb)**.*

1.1 What metal will form the cathode of this cell?

1.2 Name a suitable electrolyte for the lead half-cell.

1.3 Which metal electrode will corrode during the operation of this cell?

1.4 Write the anode, cathode and nett reaction for this cell.

Anode

Cathode

Nett

1.5 Give the cell notation for this cell (include standard conditions).

1.6 Calculate the emf (E^{o}_{cell}) of this cell.

1.7 What will happen to the emf of this cell as the cell reaction approaches equilibrium?

1.8 How will the emf of the cell be affected if the concentration of Al^{3+} ions is increased in the aluminium half cell? Explain.

Electrolytic Cell

Electrolytic cell is an electrochemical cell whereby electrical energy is converted to chemical energy. This is because in the cell the process called electrolysis takes place. **Electrolysis** is breaking down of compounds using electricity. Also this is a non-spontaneous cell because it requires electrical energy before redox reactions could be observed. The electrical energy source for this cell must be DC supply. Being a DC supply means there will be polarisation of electrodes since a DC has a positive electrode and a negative electrode. In this regard an anode is always connected to a positive terminal and that influences its polarity thus becomes a positive electrode; and this is in contrast with a Galvanic cell. Furthermore a cathode is always connected to a negative terminal; thus its polarity becomes negative. There are few type of electrolytic cells; however, for chemical change will only discuss Electroplating, electro-refining and aluminium extraction.

Electro-plating

Electro-plating is the process whereby material that corrodes easily is coated with material does not corrode easily. Then the reason behind this is to mix useful properties from different substances to meet the needs of people. For example iron is a strong greyish metal which can be used to make artefacts like spoon; however, iron has a dull colour which is not so attractive also it is susceptible to oxidation by atmosphere. Therefore one might decide to coat it with Silver which provides the silver and attractive colour. Also it will not be available for oxidation in air because it's now covered with silver. The metals that are used for electroplating are unreactive (inert) metals like Ag,Cr, Au, Sn to name the few. In any electroplating an anode and electrolyte are made up of

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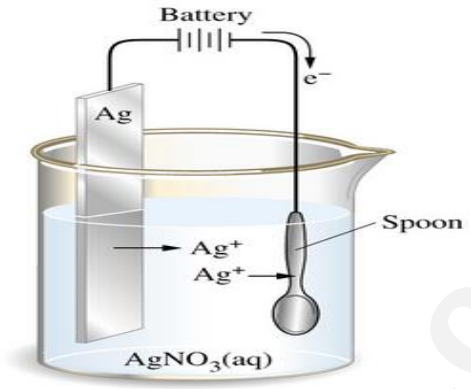
the same metal then an artefact to be coated is always a cathode. As the processes is continuing the artefact being coated changes colour to the colour of the metal used for coating. In this cell both oxidation and reduction is from only one metal.

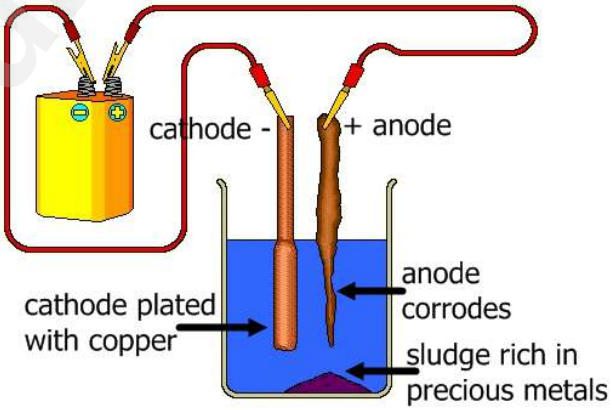
The diagram below shows a simple electroplating cell



<u>Anode:</u> $Ag \rightarrow Ag^+ + e^-$ (silver metal is oxidised to Ag^+ ions ∴anode corrodes)
<u>Cathode</u>: $Ag^+ + e^- \rightarrow Ag$ (silver ions are reduced to silver metal which deposits on spoon)
<u>NOTE:</u> The concentration of the electrolyte remains the same during electroplating process.

<u>Electro-refining</u>

Electro-refining is the process whereby metals are purified from their ores. An ore (impure metal) is mined composite of other atoms bonded with a metal of interest. Then electro-refining is used to extract that metal from others. In this cell both electrodes i.e. pure and impure electrodes and an electrolyte they are made up of the same metal (Cu). However, one of these electrodes is an ore (impure). In electro-refining an impure electrode is always an anode then a pure electrode is always a cathode.
Diagram below shows a simplified Cu purification cell.



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Anode (impure copper): $Cu \rightarrow Cu^{2+} + 2e^-$

Cathode (pure copper): $Cu^{2+} + 2e^- \rightarrow Cu$

Precious metals such as silver and gold are not oxidised (since they have higher positive reduction potentials, E^o, than copper) and sink to the bottom with other impurities where they form sludge.

THE CHLOR-ALKALI INDUSTRY

Chlorine is manufactured by the electrolysis of brine (saturated sodium chloride solution).

The overall reaction is:

$$\mathbf{2NaC\ell(aq) + 2H_2O(\ell) \rightarrow C\ell_2(g) + H_2(g) + 2NaOH(aq)}$$

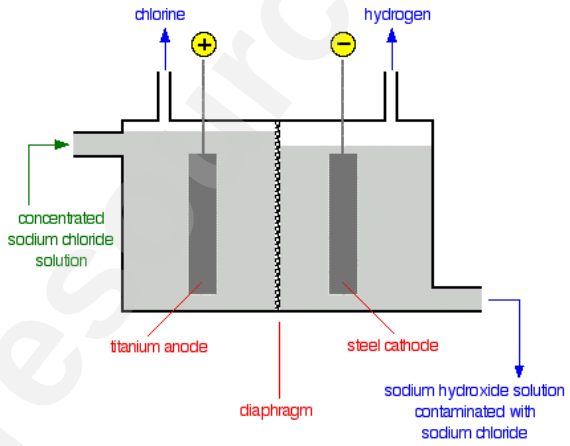
There are three different cells:

- Mercury cell
- Diaphragm cell
- Membrane cell

The mercury cell uses the least energy of the three cells but it has the lowest yield of chlorine. Mercury is also harmful to the environment.

The diaphragm cell produces a dilute sodium hydroxide solution and it uses an asbestos diaphragm, which is also harmful to the environment.

The membrane cell: LEARN WELL!!!



The membrane used is a polymer, which is quite expensive to make but it has no harmful environmental issues. This method produces very pure sodium hydroxide.

NITROGEN GAS

Nitrogen occurs naturally in the atmosphere. It forms 78% of the air. Pure nitrogen is obtained by from the fractional distillation of liquid air.

HYDROGEN GAS

Hydrogen gas is produced at Sasol from steam and coal by the process of gasification. These are heated together with oxygen at very high temperatures and pressure.

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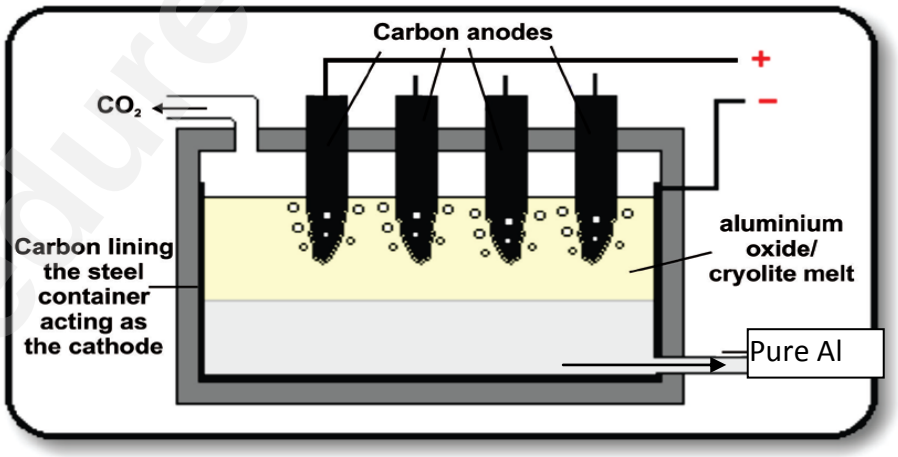
Aluminium Extraction

Aluminium is mine 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 bauxite has to be made molten before it can start conducting electricity. However, Al_2O_3 melts at 2050˚C which requires a lot of energy that is generated from electricity. These temperatures consume lot of energy and that may lead to less profit being obtained. Therefore, alumina is dissolved is cryolite (Na_3AlF_6) which reduces the melting point temperature of alumina to 900 – 1000 ˚C. This invention is cost effective because the amount of electricity used is reduced by more than half. Also this help in reduction of CO_2 on electricity production of which it's also an environmental saving measure. Since CO_2 is a greenhouse gas. The aluminium extraction cell uses carbon electrodes (both anode and Cathode). After alumina has been electrolyzed it produces Al^{3+} and O^{2-}; of which Al^{3+} is attracted by a negative electrode which is a cathode and it undergoes reduction there. Whereas O^{2-} is attracted by a positive electrode which is an 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 anode may need to be replaced.
The diagram below shows the simple representation of aluminium extraction cell.



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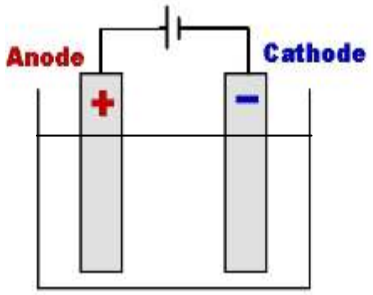
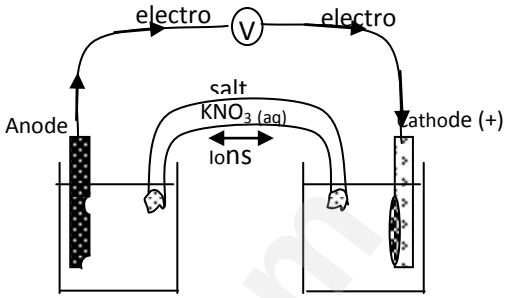
SUMMARY OF ELECTROLYTIC CELL VS VOLTAIC (GALVANIC) CELL

	ELECTROLYTIC	VOLTAIC (GALVANIC)
Appearance of simple form of cell	 • Must have 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)

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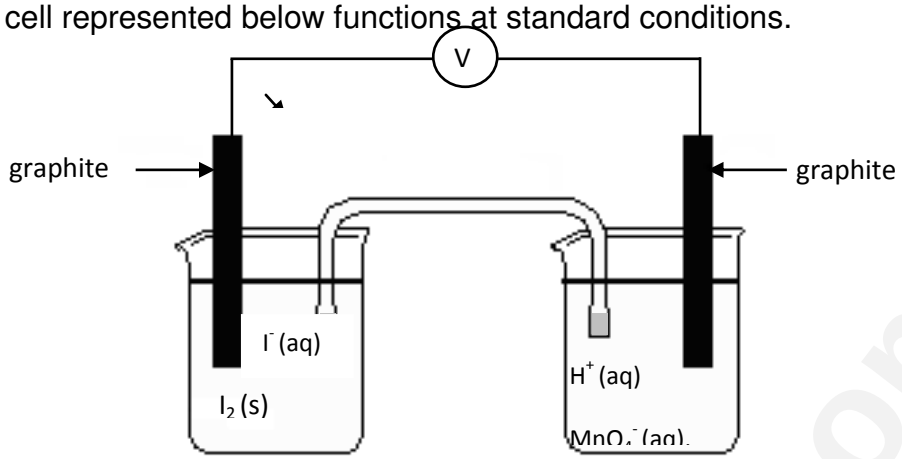
QUESTION 1: ***DBE Exemplar 2014***

The voltaic cell represented below functions at standard conditions.



1.1 Write down the concentration of H^+ (aq) in the one half-cell. (1)

1.2 Solids present in half-cells are usually used as electrodes. Give a reason why I_2(s) is not suitable to be used as an electrode. (1)

1.3 Write down TWO properties of graphite, other than being a solid, that makes it suitable for use as electrodes in the above voltaic cell. (2)

1.4 For the above voltaic cell, write down the :

1.4.1 NAME of the oxidizing agent. (1)

1.4.2 Net cell reaction (3)

1.4.3 Cell notation (3)

1.5 Calculate the cell potential of the above cell. (4)

1.6 How will the reading on the voltmeter be affected if the concentration of MnO_4^- decreases? Only write down INCREASES, DECREASES or NO EFFECT. (1)

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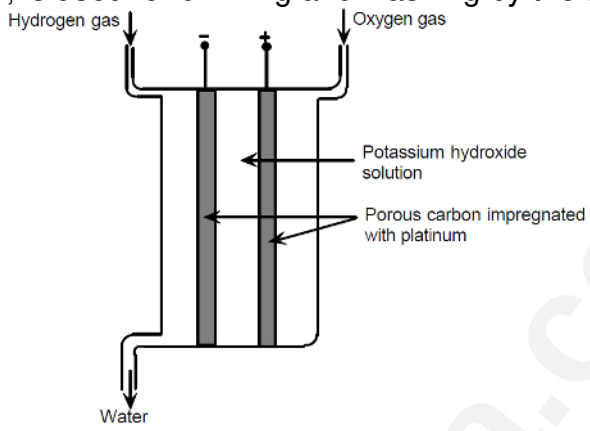
QUESTION 2 DOE MARCH 2007 HG

2.1 An oxygen-hydrogen fuel cell is used to provide electricity for a manned space vehicle. A simplified diagram of a fuel cell is shown below. The hydrogen and oxygen gases are passed over platinum electrodes immersed in potassium hydroxide. The water that is produced when the cell is in operation, is used for drinking and washing by the astronauts.



In the fuel cell, the hydrogen gas reacts according to the equation:

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

2.1.1 Is the hydrogen half reaction occurring at the anode or the cathode? Give a reason for your answer. (3)

2.1.2 Write down an equation for the half-reaction that the oxygen undergoes. (2)

2.1.3 Write down a balanced equation for the overall reaction in the fuel cell. (2)

2.1.4 Calculate the *emf* of this fuel cell. (4)

2.1.5 In the fuel cell, the mass of the anode remains constant whereas in the Zn-Cu cell, the mass of the anode decreases. Write down a reason for this observation. (2)

2.2 The following chemicals are available in the school laboratory:
$SO_2(g)$ $H_2S(g)$ concentrated $HNO_3(l)$

2.2.1 Select one of the chemicals that could be used to convert Fe^{2+} to Fe^{3+}. (2)

2.2.2 Refer to the relative strengths of oxidising and reducing agents and give a reason for the answer in QUESTION 2.2.1. (2)

2.2.3 Write down a balanced ionic equation for the reaction between the chemical mentioned in QUESTION 2.2.1 and Fe2+. Make use of the Table of Standard Reduction Potentials. (3)

QUESTION 3

3.1 Define *reduction* in terms of electron transfer. (2)

3.2 Manganese dioxide (MnO2) reacts with hot concentrated hydrochloric acid (HCl) to produce chlorine. Use the Table of Standard Reduction Potentials to write down:

3.2.1 The equation for the reduction half-reaction (2)

3.2.2 The balanced net ionic equation for the preparation of chlorine gas (3)

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3.3 A learner constructs an electrochemical cell using an aluminium rod as the anode.

3.3.1 Name the other electrode that the learner should use in the cell to obtain an emf of 0,9 V. Show how you arrived at the answer. (6)

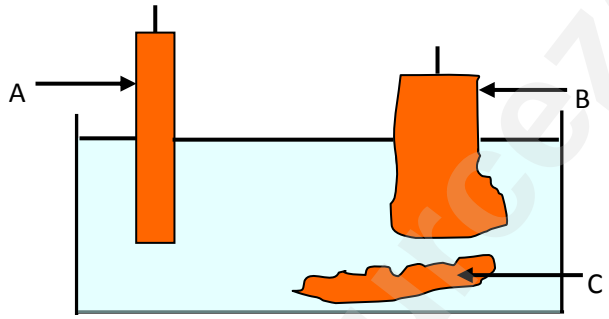
3.3.2 Write down the equation for the half-reaction that takes place at the Cathode. (2)

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

3.4 A laboratory has zinc and copper containers available. Which one of them can be used to store an aqueous solution of a tin (Sn2+) compound? Use the Table of Standard Reduction Potentials to explain the answer. (5)

QUESTION 4 KZN JUNE 2011

Copper is a good conductor of electricity when it is almost 100% pure. Small amounts of impurities cut down conductivity quite noticeably. Impure copper is rich in precious metals. To ensure a high level of purity, newly extracted copper is purified by electrolysis. The diagram below shows an electrolytic cell used for the purification of copper.



4.1 Electrode B consists of impure copper. What is the polarity of electrode B when the cell is in operation? Write only POSITIVE or NEGATIVE. (1)

4.2 Give a reason for your answer to QUESTION 4.1. (2)

4.3 Write down the half reaction that will take place at electrode A. (2)

4.4 In which direction will electrons flow in the external circuit? Write only from A to B OR from B to A. (1)

4.5 Substance C is a by-product that forms during the above electrolysis. Why is substance C of economic importance? (1)

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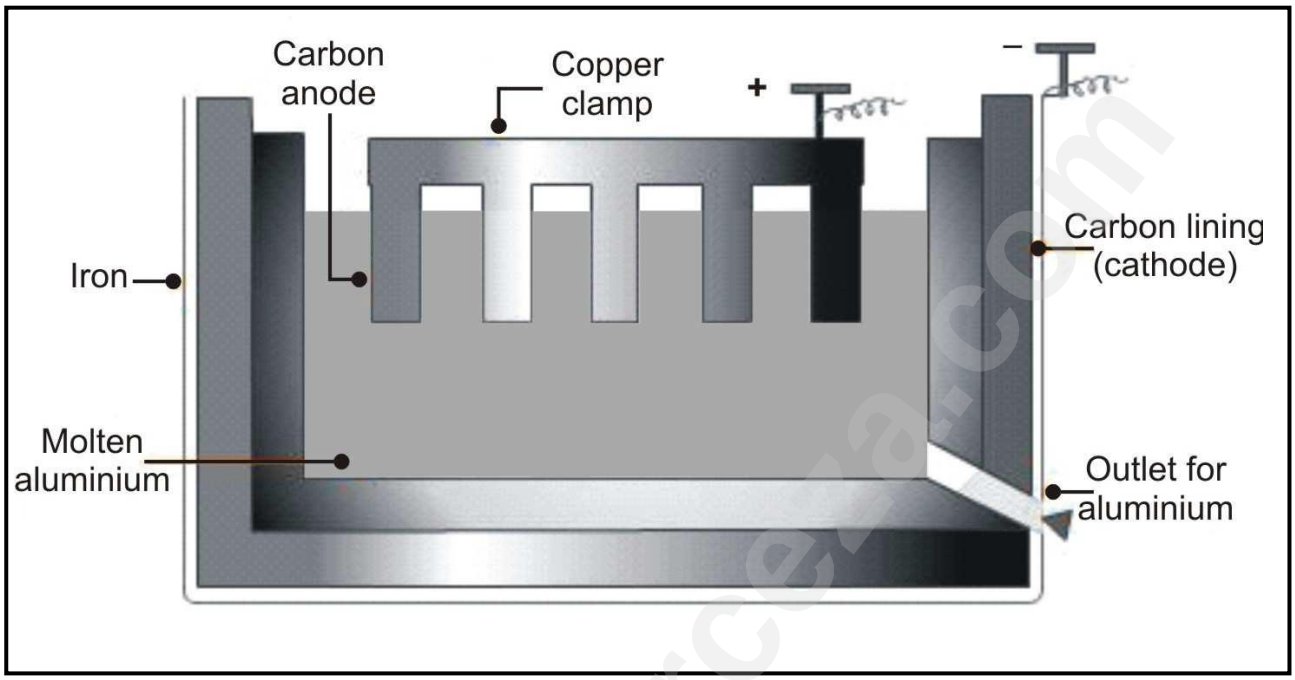
QUESTION 5 KZN JUNE 2012

The Hall-Heroult process is used to manufacture aluminium from its ore, bauxite. The ore is processed and purified. Alumina (Al_2O_3) is produced from the ore and this is fed into the cell where it undergoes a chemical change to produce aluminium.



5.1 Is this process Galvanic or electrolytic? Explain. (2)

5.2 At which electrode (ANODE or CATHODE) is aluminium formed? (1)

5.3 Write down the half-reaction for the formation of aluminium. (2)

5.4 Explain why graphite is used as the anode. (2)

5.5 Why do the carbon anodes need frequent replacement in this process? (2)

5.6 Environmentalists in South Africa have been arguing that the production of aluminium in this country ought to be stopped. Assume that you agree with environmentalists. Use your understanding of the aluminium manufacturing process to argue your position and state TWO negative considerations in your answer. You may answer in point form. (2)

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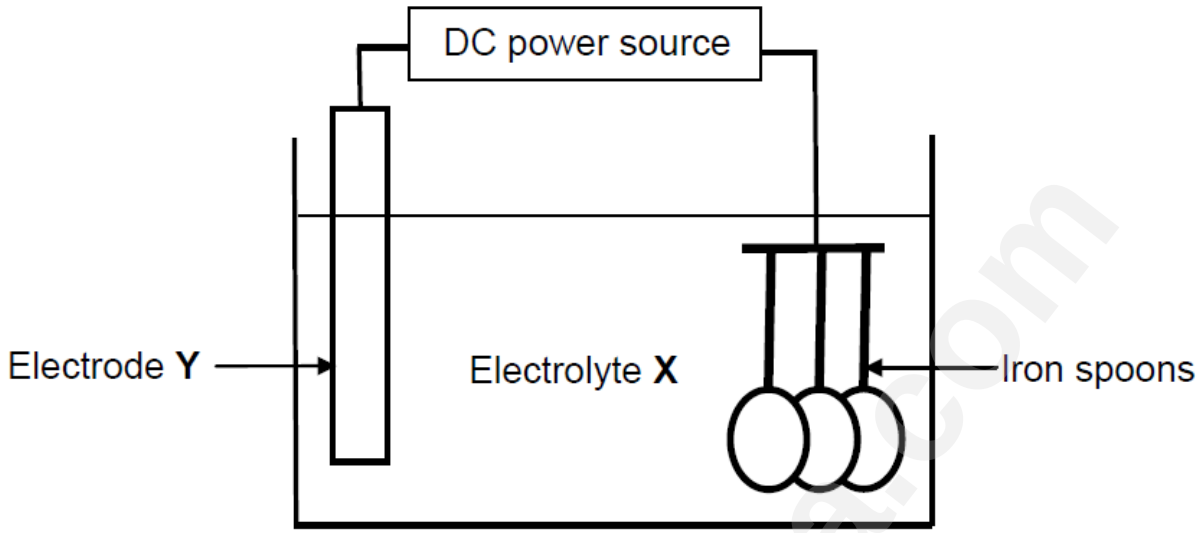
QUESTION 6

The simplified diagram below shows an electrolytic cell used at an electroplating company to coat iron spoons with silver.



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

6.2 Direct current (DC) is used in this process. Give a reason why alternating current (AC) is NOT used. (1)

6.3 Which type of reaction (OXIDATION or REDUCTION) takes place at the spoons? (1)

6.4 Write down the:

6.4.1 Equation for the half-reaction that takes place at electrode **Y** (2)

6.4.2 NAME or FORMULA of electrolyte X (1)

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

6.6 Apart from the income generated, write down ONE major reason why the company electroplates the spoons. (1)

6.7 Write down the TWO major expenses for the company during the process. (2)

QUESTION 7

The chlor-alkali industry began in the late 19th century. This industrial process is based on the electrolysis of brine for the production of chlorine, hydrogen and sodium hydroxide (caustic soda). It made the production of these chemicals a relatively inexpensive process. It helps sustain the high demand of these substances in order to create soaps, detergents and other household substances. This process has a very high energy consumption - (The second highest energy consumer of all electrolytic industries.) The chemical reaction can be represented by the following equation:

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

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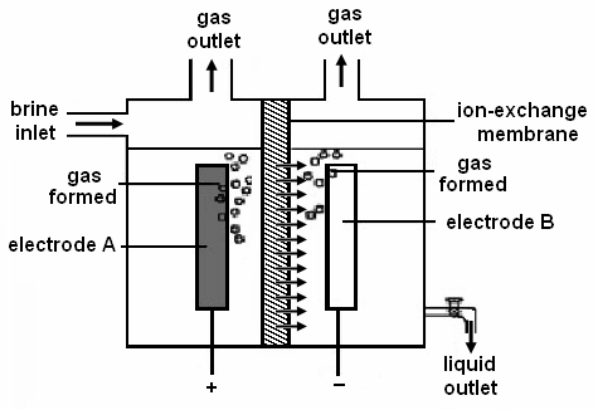

7.1 Name the raw materials used in this process. (2)
7.2 Which gas is produced at electrode A? (1)
7.3 Name the liquid used to fill the right hand half cell. (1)
7.4 The ion exchange membrane divides the cell into two different compartments. Why is it necessary to use this membrane? (3)
7.5 Which ion moves through the membrane? (1)
7.6 Write down the name of the oxidising agent in the reaction that takes place (1)
7.7 Explain why hydrogen is formed at one of the electrodes and not sodium (2)
7.8 Write down the half reaction that occurs at the anode. (2)
7.9 Write down the half reaction that occurs at the cathode. (2)
7.10 Chlorine can be produced by using the membrane cell, the diaphragm cell and the mercury cell. Why is the membrane cell the preferred cell for the production of chlorine? Give two reasons. (2)

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