



**Department of Education
REPUBLIC OF SOUTH AFRICA**

Education

KwaZulu-Natal

CURRICULUM DIRECTORATE

LEARNER ASSISTANCE REVISION

DOCUMENT

GRADE 12 - 2020

PHYSICAL SCIENCES

PREAMBLE

This supporting document is meant to assist learners to understand basic concepts in this subject. It focuses mainly on levels 1 and 2; and a bit of level 3 questions/ activities. When studied well, the document can help learners to do just about enough to get a pass mark during examinations. If a learner wishes to get even better marks, however, he or she is advised to work on levels 4 questions/ activities (the so-called high order questions). Unfortunately those challenging questions/ activities are not contained herein.

TIPS FOR EXAM PREPARATIONS

In preparing for your final exams work through as many past examination papers as you can. Remember, your success in the final exam will depend on how much extra time you put into preparing.

Top 10 study tips

1. Have all your materials ready before you begin studying – pencils, pens, highlighters, paper, calculator and information sheets
2. Be positive. Set yourself short term goals that are SMART (Specific, Measureable, Achievable, Realistic and include a Timeframe). For example, complete making a summary of Fertiliser Industries by tomorrow at 5pm. As a self-test, draw a flow chart of the process to make ammonium based fertilisers correctly.
3. Break up your learning sections into manageable parts. Trying to learn too much at one time will only result in a tired, unfocused and anxious brain.
4. Keep your study sessions short (Between 45 min and 50 min) but effective and reward yourself with short, constructive breaks of no more than 10 minutes. For example, take a short walk outside. A change of scenery will stimulate your learning. You'll be surprised at how much more you take in after being outside in the fresh air.
5. Use the Exam Guidelines as a checklist for each section. Break your study up into sessions that include summarising, practising questions and self-testing.
6. Teach your concepts to anyone who will listen. It might feel strange at first, but it is definitely worth reading your revision notes aloud. You can make voice notes and share them with your friends.
7. Your brain learns well with colours and pictures. Try to use them whenever you can. Repetition is the key to retaining information you have to learn. Keep going – don't give up!
8. Form a study group that meets once or twice a week. Keep these group study sessions short. No more than 2 hours. Spend 30 minutes on each topic. Use these to do teach backs, ask questions and solve previous exam questions together under exam conditions. Time yourselves and try to answer at a rate of less than 1 mark per minute. This means you must try to answer a 5 mark question in under 5 minutes.

9. Sleeping at least 8 hours every night, eating properly and drinking plenty of water are all important things you need to do for your brain. Studying for exams is like strenuous exercise, so you must be physically prepared.
10. Include some physical activity in your study routine. Exercising your body helps you to think more clearly. It doesn't matter what you do. You can speed walk, run, swim, cycle, dance or a gym routine (situps, pushups, lunges, star jumps). You must try to raise your pulse rate for at least 20 min a day. One session shouldn't last longer than 45 minutes. Do this regularly.

STUDY SKILLS TO BOOST YOUR LEARNING

Mobile notes

Mobile notes are excellent tools for learning all the key concepts in the study guide. Mobile notes are easy to make and you can take them with you wherever you go:

1. Fold a blank piece of paper in half. Fold it in half again. Fold it again.
2. Open the paper. It will now be divided into 8 parts.
3. Cut or tear neatly along the folded lines.
4. On one side of each of these 8 bits of paper, write the name of the basic concept you need to learn e.g Newton's 2nd Law
5. On the other side, write the meaning or the explanation of the basic concept. Check that this is correct by referring to the Exam Guidelines.
6. Use different colours and add pictures to help you remember.
7. Take these mobile notes with you wherever you go and look at them whenever you can.
8. As you learn, place the cards in 3 different piles:
 - I know this information well.
 - I'm getting there.
 - I need more practice.
9. The more you learn them, the better you will remember them.
10. Use these notes to play as a game with your study group.

Mnemonics

A mnemonic code is a useful technique for learning information that is difficult to remember. This is an example of a word mnemonic using the word BALANCE where each letter of the word stands for something else:

B – Best – doing your best is more important than being the best.

A – Attitude – always have a positive attitude.

L – Load – spread the load so you don't leave everything to the last minute. Use a study timetable to plan.

A – Attention – pay attention to detail. Only answer what is required.

N – Never give up! Try, try and try again!

C – Calm – stay calm even when the questions seem difficult.

E – Early – sleep early the night before your exam. If you prepare well you will not need to cram the night before.

Mnemonics are code information and make it easier to remember. The more creative you are and the more you link your 'codes' to familiar things, the more helpful your mnemonics will be.

In Chemistry we use the following Mnemonics in Redox reactions:

OIL - Oxidation Is Loss of electrons
RIG - Reduction Is Gain of electrons

Mind maps

Mind maps work because they show information that we have to learn in the same way that our brains 'see' information. As you study, add pictures to each of the branches to help you remember the content. Make your own mind maps as you finish each section.

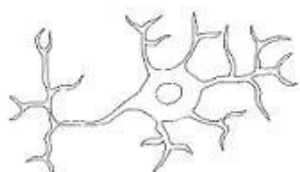


Figure 1: Brain cell or neuron

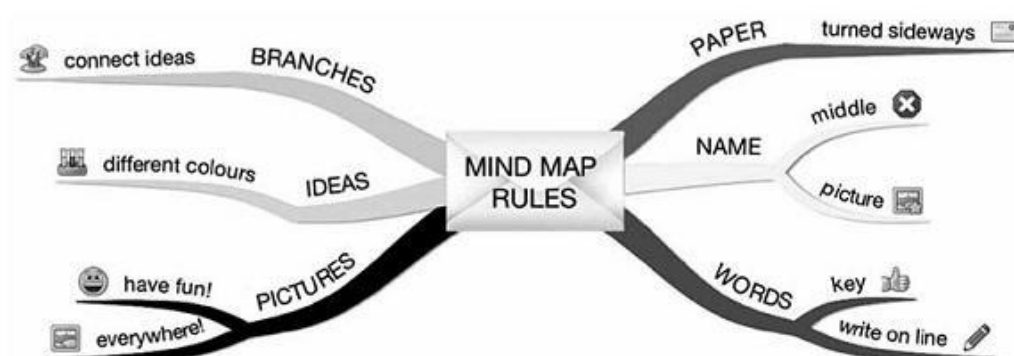


Figure 2: Mind map rules

How to make your own mind maps:

1. Turn your paper sideways so your brain has space to spread out in all directions.
2. Decide on a name for your mind map that summarises the information you are going to put on it.
3. Write the name in the middle and draw a circle, bubble or picture around it.
4. Write only key words on your branches, not whole sentences. Keep it short and simple.
5. Each branch should show a different idea. Use a different colour for each idea. Connect the information that belongs together. This will help build your understanding of the learning areas.

6. Have fun adding pictures wherever you can. It does not matter if you can't draw well.

General Tips for Physical Sciences

1. Learn your Laws and definitions very well. These are listed in the Exam Guidelines. You must know them as they are written. Every word is important.
2. Link your Laws and definitions to an equation on the Information sheet.
3. Learn what each symbol on the information sheet means and also learn the S.I unit for that quantity. Highlight all vector quantities and remember these need directions in their answers. Write note on a copy of the information sheet.
4. For Chemistry, make sure you know the names of the elements. Use the Periodic Table to help you write chemical formula. Use the Redox Tables for polyatomic ions, like sulphate and nitrate. You must learn ammonium is NH_4^+ .

ON THE DAY OF THE EXAM

1. Make sure you have all the necessary stationery for your exam, i.e. pens, pencils, eraser and calculator (with new batteries). Make sure you bring your ID document and examination admission letter.
2. Make sure you have something to eat before your exam. Don't eat too much. It's better to eat protein (e.g eggs, fish or meat) than too much starch.
3. Arrive on time, at least one hour before the start of the exam.
4. Go to the toilet before entering the exam room. You don't want to waste valuable time going to the toilet during the exam.
5. Use the 10 minutes reading time to read the instructions carefully. This helps to 'open' the information in your brain. All questions are compulsory in the Physical Sciences papers. Skim through the multiple choice questions as quickly as you can and identify which sections the questions come from. Next skim through the longer questions. If there is time go to the section you know the best and re-read this question. Re-read the multiple choice if you have time. Do a rough calculation of how much time you will allocate to each big question. This must be less than a mark per minute.
6. Do not start your paper with multiple choice. Always start answering the questions from the section or topic you know best. Take time to read your questions carefully. Check the instructions too.
7. Make sure you number all questions exactly as they are in the question paper.
8. Break the questions down to make sure you understand what is being asked. If you don't answer the question properly you won't get any marks for it. Look for the key words in the question to know how to answer it.
9. Try all the questions. Each question has some easy marks in it so make sure that you do all the questions in the exam.
10. Manage your time properly. Don't waste time on questions you are unsure of. Move on and come back if time allows.

11. Check weighting – how many marks have been allocated for your answer? Do not give more or less information than is required. You do not need to write essays in Physical Sciences. Keep your explanations short. (less than 5 lines)
12. Write big and bold and clearly. You will get more marks if the marker can read your answer clearly. Leave space between each question.
13. Remember to start each new question on a new page. It's even better if you start on a new double page. All your answers for a question will then be together. This makes it easier to mark

TIPS ON HOW TO USE THIS BOOKLET

1. Use the checklists at the start of each topic to make sure you have revised all the work you need to know for the examinations. These checklists have been adapted from the Exam Guidelines.
2. Take note of the specific study tips that address common errors for each topic.
4. Do the previous exam questions without referring to your notes. Time yourself and make sure you answer in less than a mark a minute.
5. Compare your answer to the answer in the solutions provided. Don't just check the answer, check the method too. If you have got the answer wrong, try to again in a few days and see if you get it correct the 2nd time.

Force and Newton's Laws

CORE CONCEPTS AND DEFINITIONS

TYPES OF FORCES

1. A **force** is a push or pull upon an object resulting from the object's interaction with another object.
2. **Gravitational force (F_g)** is the force of attraction that objects exert on other objects in virtue of having mass. It is the force that makes all things fall and causes tides in the ocean. The greater the mass of an object, the greater its gravitational pull.
3. **Applied force (F_A)** is a force that is applied to an object by a person or another object.
4. **Tension force (T)**, the force that is transmitted through a rope, string or wire when pulled by forces acting from opposite sides. The tension force is directed over the length of the wire and pulls energy equally on the bodies at the ends.
5. The **normal force (F_N)** is a perpendicular force that a surface exerts on an object with which it is in contact.
6. **Frictional force**, f or f_f , as the force that opposes the motion of an object and which acts parallel to the surface.
7. **Static frictional force**, f_s , as the force that opposes the tendency of motion of a stationary object relative to a surface.
8. **Kinetic frictional force**, f_k , as the force that opposes the motion of a moving object relative to a surface.
9. **Coefficient of kinetic friction, μ_k** , constant of proportionality between the force of friction and the normal force in the processes of sliding friction,
10. The **resultant (net) force, (F_{net})** acting on an object is the vector sum of all the forces acting on the object. The vector sum is the sum of all vectors (all the forces added up, taking their directions into account).

LAWS

Inertia is the property of an object to resist any attempt to change its state of motion. The mass of an object is a measure of its inertia.

1. **Newton's First Law of Motion:** An object will remain at rest or continue moving at a constant velocity (or at constant speed in a straight line) unless acted upon by a non-zero external resultant force.
2. **Newton's Second Law of Motion:** If a resultant (net) force acts on an object, the object will accelerate in the direction of the resultant force. The acceleration is directly proportional to the resultant force and inversely proportional to the mass of the object.
3. **Newton's Third Law of Motion:** When object A exerts a force on object B, object B simultaneously exerts a force on object A, which is of equal magnitude but opposite in direction.
4. **Newton's Law of Universal Gravitation:** A force of gravitational attraction exists between any two particles or objects anywhere in the universe. The magnitude of this force is directly proportional to the product of the objects' masses and is inversely proportional to the square of the distance between their centres.

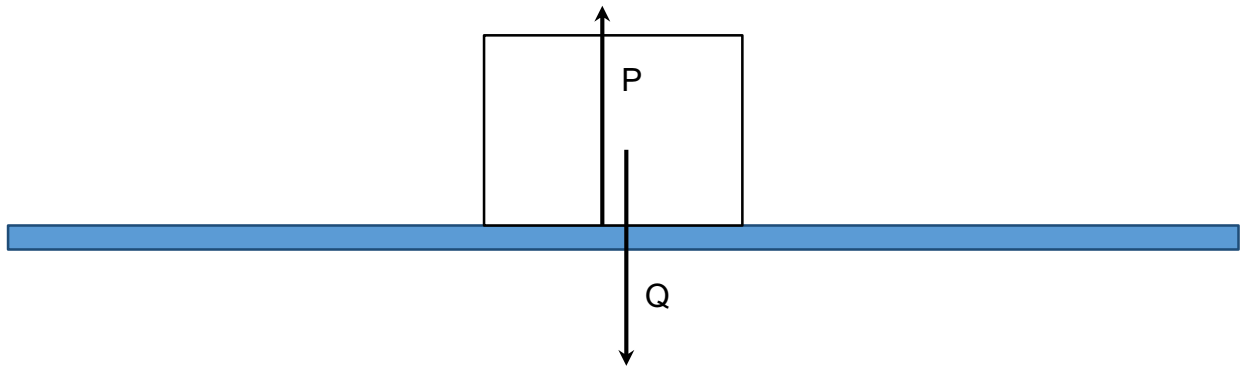
CLASSWORK EXERCISE

1. The table given below lists the different types of forces that can act on an object.

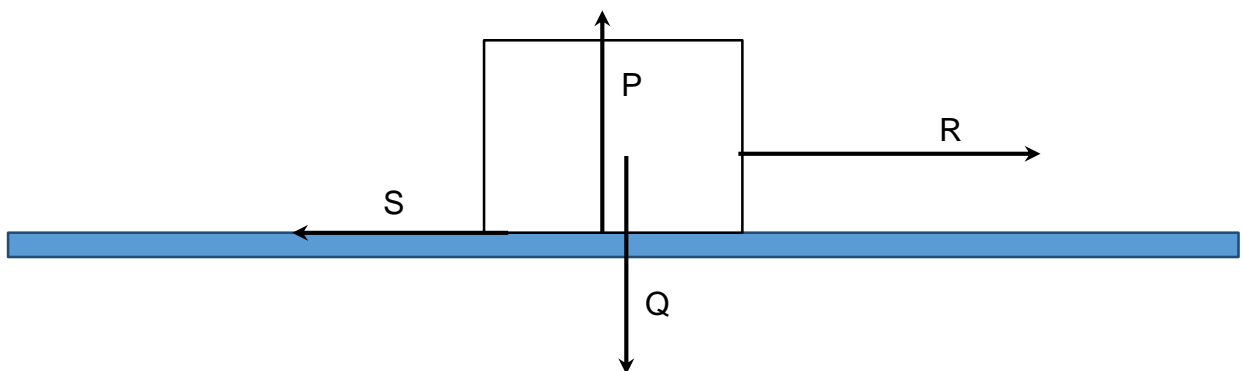
Kinetic frictional force
Resultant (net)force
Gravitational force
Applied force
Tension force
Normal Force
Frictional force
Static frictional force

Using the table, identify the various forces acting on the objects below

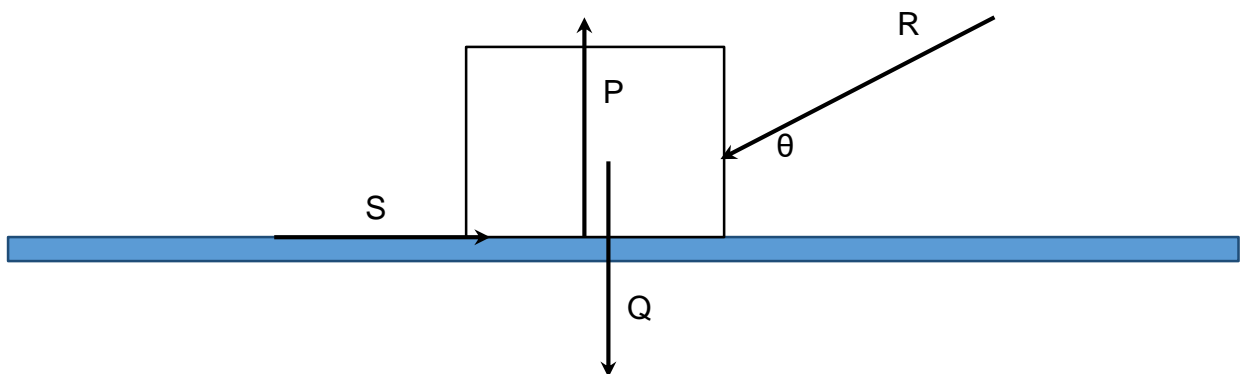
a) An object lies motionless on a surface.



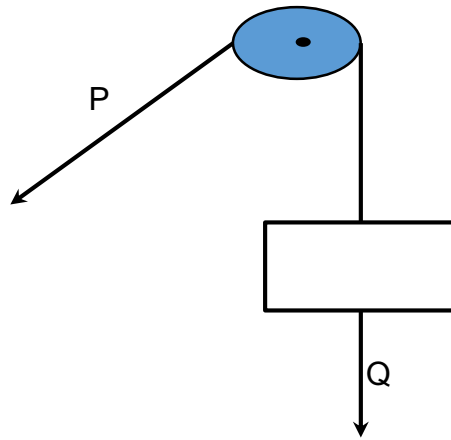
b) An object is pulled by a force parallel to the surface. The surface is rough or has friction.



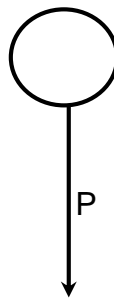
d) The object is pushed by a force at an angle θ to the surface. The surface is rough.



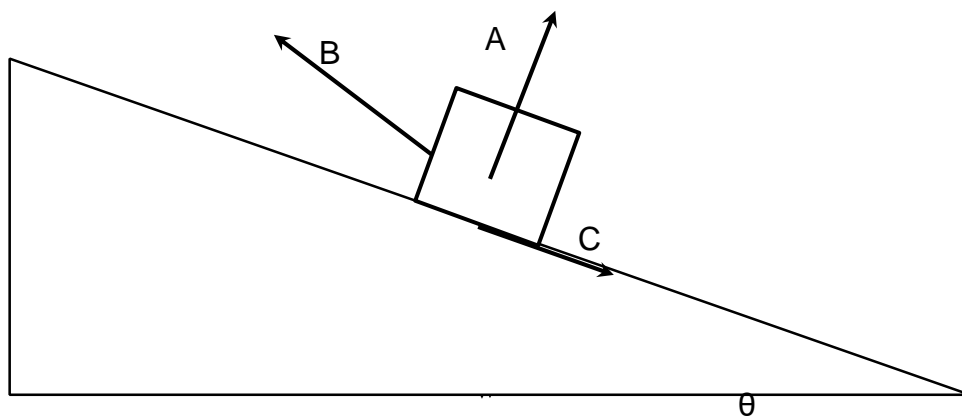
e) The object is pulled upward at constant speed.



f) An object in freefall



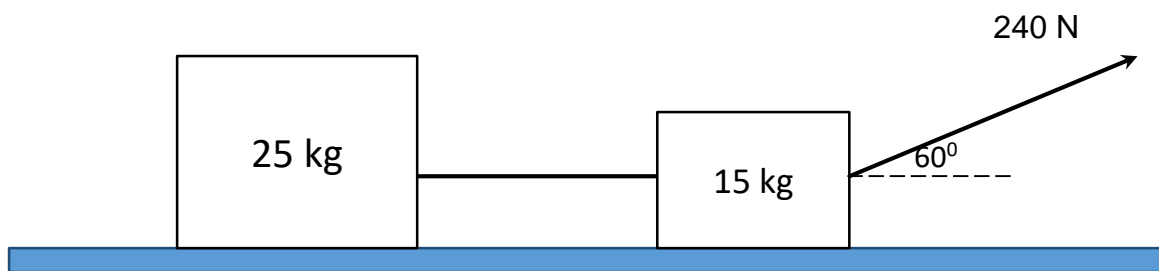
g) An object is pulled up a rough inclined plane



A **FREE BODY** diagram is a vector diagram that shows all the forces acting on a body from at a common point.

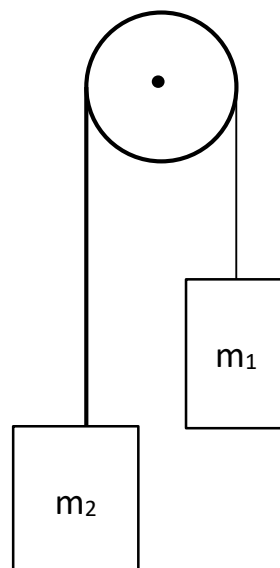
Homework Exercise :

1. Two blocks of 25 kg and 15 kg are connected by a light string on a horizontal surface. Assume that the string cannot stretch. A force of magnitude 240 N is applied to the block of 15 kg forming an angle of 60° with the horizontal as shown in the sketch below. The coefficient of kinetic friction is 0,20.



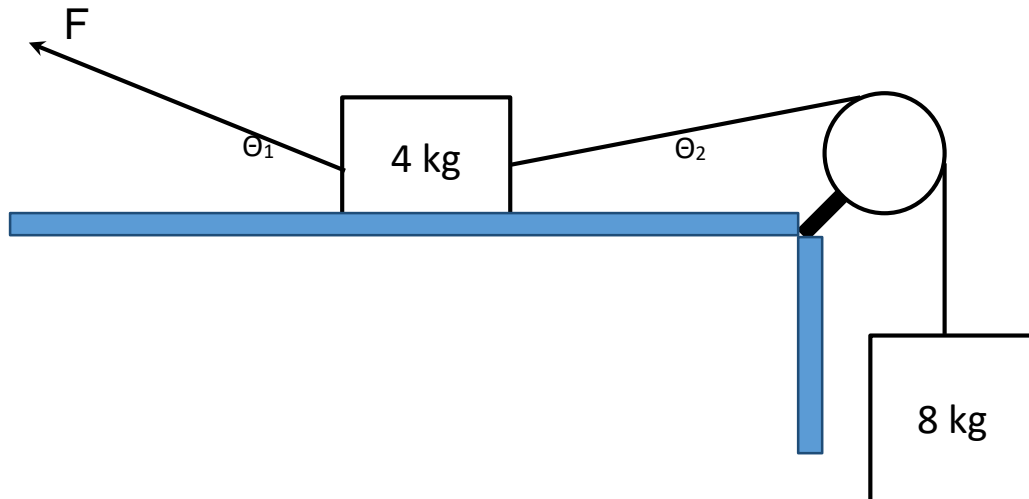
Draw a free body diagram of all the forces acting on both blocks

2. The sketch below shows two blocks connected by a string of negligible mass that passes over a frictionless pulley also of negligible mass.



Draw a free body diagram of all the forces acting on each block.

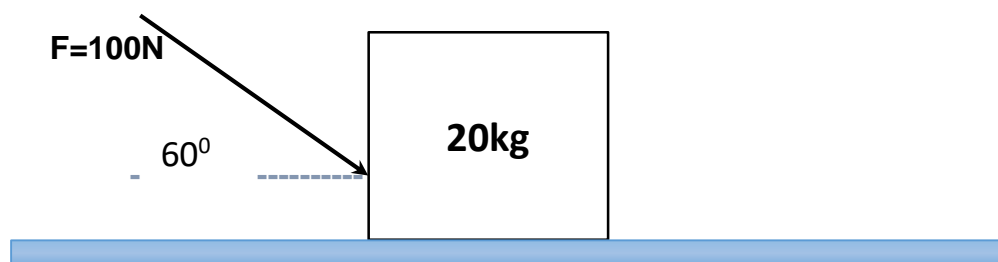
3. A 4 kg block on a horizontal, rough surface is connected to a 8 kg block by a light string that passes over a frictionless pulley as shown below. A force F is applied to the 4 kg block and the system accelerates to the left. Assume that the string cannot stretch. The coefficient of kinetic (dynamic) friction between the block of 4 kg and the surface is 0,6.



Draw a free body diagram of all the forces acting on each block

ACTIVITIES

1. A crate with a mass of 20 kg is pushed from rest across a horizontal rough surface with a force of 100 N acting at an angle of 60° to the horizontal. The friction between the crate and the surface is 12 N.



Calculate:

- 1.1 the acceleration of the crate. (4)
 1.2 coefficient of kinetic friction. (4)
 1.3 the distance that it moves in 10 seconds if the force remains constant. (3)

[11]

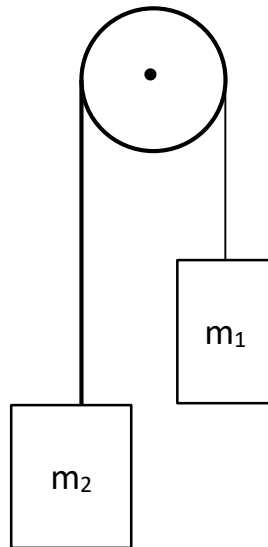
2. A crate of mass 500 kg is lifted vertically upward by a cable attached to a helicopter. Ignore the mass of the cable and determine the tension in the cable if the crate:

2.1 moves upwards at a constant velocity; and (3)

2.2 accelerates upwards at $2 \text{ m}\cdot\text{s}^{-2}$. (3)

[6]

3. Two objects, P and Q, with masses 3 kg and 2 kg respectively, are tied to opposite ends of a light string. The string is suspended over a frictionless pulley system. The mass of the string is negligible.



Calculate:

3.1 the acceleration of the system; and (4)

3.2 the magnitude of the tension in the string. (4)

[8]

4. A man stands on a scale in a lift. His mass is 80 kg. The scale is calibrated in Newton's. Calculate the reading on the scale when the lift:

4.1 accelerates upwards at $2 \text{ m}\cdot\text{s}^{-2}$; (3)

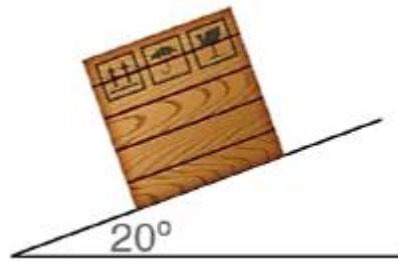
4.2 accelerates downwards at $2 \text{ m}\cdot\text{s}^{-2}$; (2)

4.3 moves at constant velocity of $2 \text{ m}\cdot\text{s}^{-1}$ downwards; and (2)

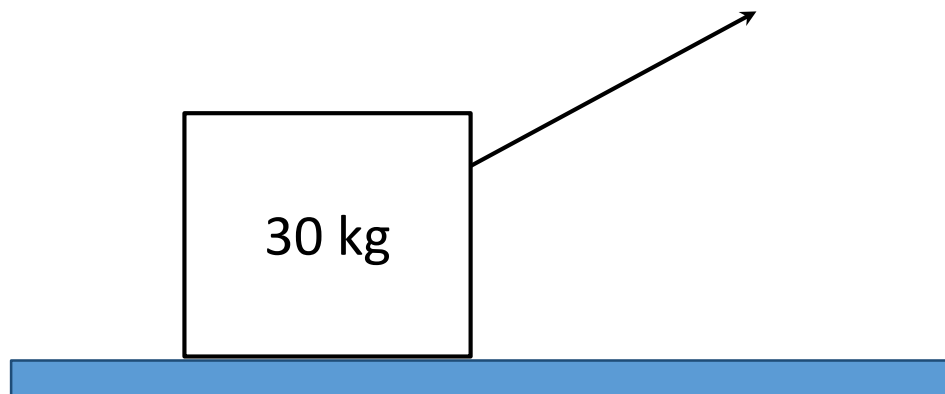
4.4 falls freely (2)

[9]

5. A crate with a mass of 50 kg, slides down a rough slope at constant velocity as indicated in the diagram.



- 5.1 Determine the friction between the surface and the crate. (4)
5.2 Calculate the coefficient of kinetic friction. (3)
6. Peter drags a crate across a smooth surface as shown in the diagram. [7]



Calculate:

- 6.1 the acceleration of the crate.
6.2 the acceleration if there is a frictional force of 24 N.
6.3 μ_k if the pulling force is reduced to 100 N and the crate continues to move.

VERTICAL PROJECTILE MOTION

Relevant concepts:

- **Projectile** is an object upon which the only force acting is the force of gravity.
- **Free-fall** is a motion on which the only force acting is the force of gravity.

EQUATIONS OF MOTION IN A VERTICAL PLANE

1. $v_f^2 = v_i^2 + 2a\Delta y$
2. $\Delta y = v_i\Delta t + \frac{1}{2}g\Delta t^2$
3. $v_f = v_i + a\Delta t$
4. $v_f^2 = v_i^2 + 2a\Delta y$

Remember:

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

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

The following procedure summarizes the problem-solving approach.

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

VERTICAL PROJECTILES GRAPHS

Velocity vs time graph

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

Displacement/position vs time graph

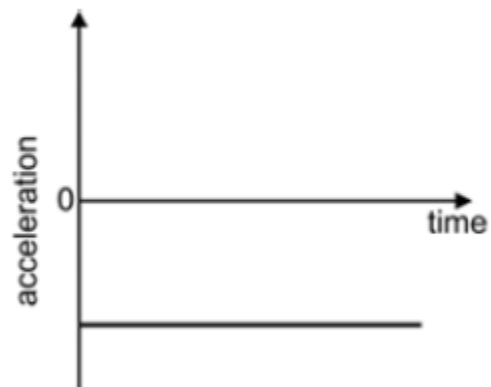
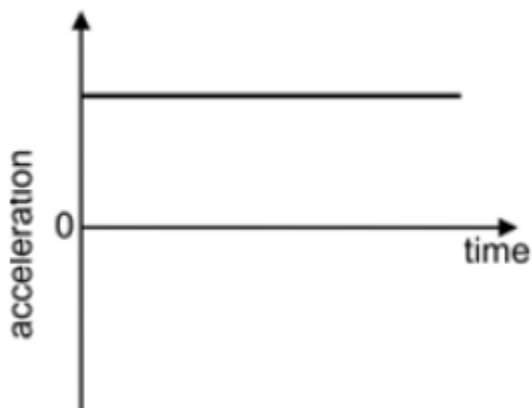
The position vs time graph is best described by the formula $\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$, this equation can be written mathematically this is in the form $y = ax^2 + bx + c$ which is a parabola, so the graph of position vs time will always be a parabola or combinations of parabolic shape in case of a bouncing object. So a graph can be a full parabolic shape or a part of depending on the question. Teachers must assist in this regard



Acceleration vs time graph

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

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



Activity 1

A ball is thrown vertically upwards at $4 \text{ m}\cdot\text{s}^{-1}$ and returns to the thrower's hand.

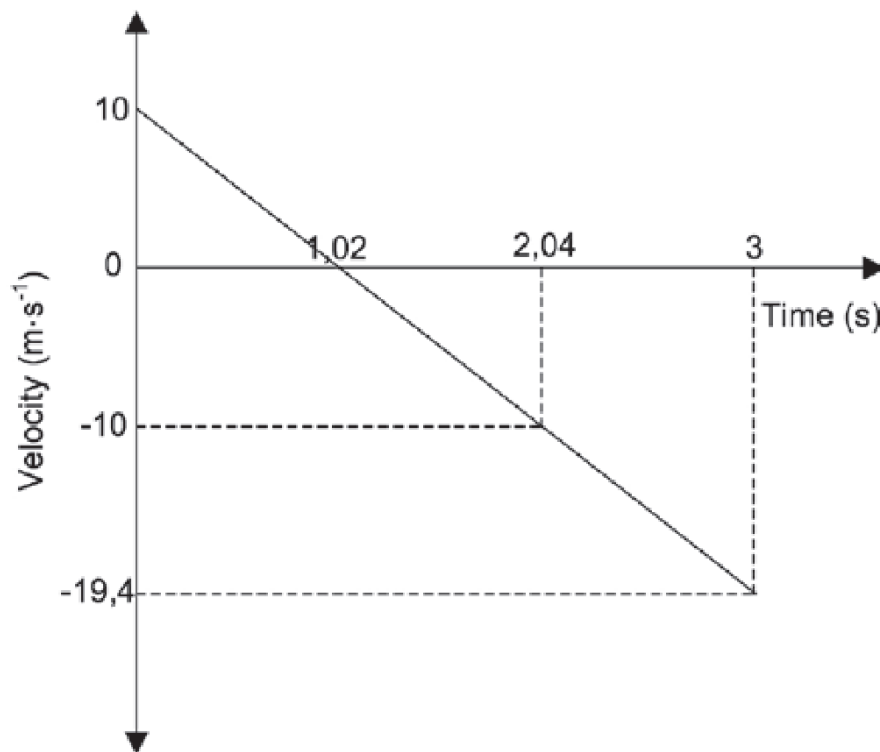
Calculate:

1. The maximum height reached by the ball. (4)
2. The time taken for the ball to reach the highest point in its trajectory. (5)
3. The total time that the ball is in the air. (3)
4. The ball's total displacement during the motion. (1)

[13]

Activity 2

Lerato throws a stone vertically into the air from the top of a cliff. The stone strikes the ground below after 3 s. The velocity vs. time graph below shows the motion of the stone. Ignore the effect of air resistance.

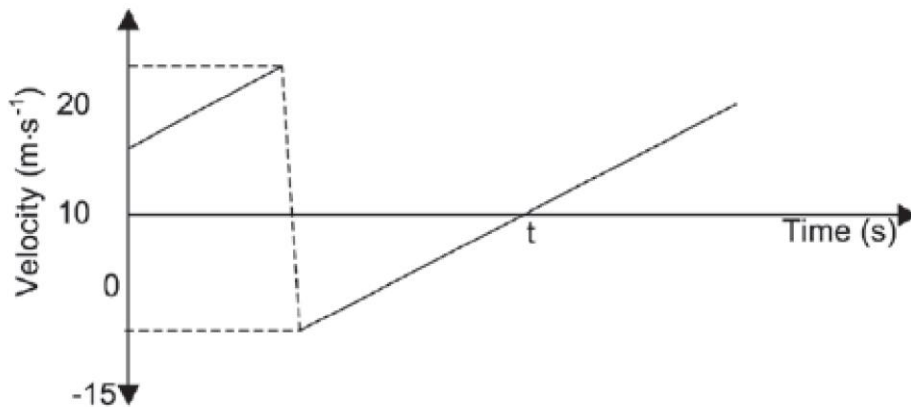


- 1.1. How long does the stone take to fall from the height of the cliff to the ground below? (2)
- 1.2. What is the maximum height that the stone reaches above the ground? (Hint: calculate the height the stone reaches above the cliff, then calculate the height of the cliff, and add these two numbers). (4)
- 1.3. Draw a graph of position versus time. Use upwards as negative. (6)

[12]

Activity 3

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.



- 1.1. From the graph, write down the magnitude of the velocity at which the ball bounces off the floor. (1)
- 1.2. Is the collision of the ball with the floor ELASTIC or INELASTIC? Refer to the data on the graph to explain the answer. (2)
(Note: This question links to momentum)
- 1.3. Calculate the:
 - 1.3.1. Height from which the ball is thrown. (3)
 - 1.3.2. Size of the displacement of the ball from the moment it is thrown until time t . (5)
- 1.4. Sketch a position versus time graph for the motion of the ball from the moment it is thrown until it reaches its maximum height after the bounce.

USE THE FLOOR AS THE ZERO POSITION.

Indicate the following on the graph:

- The height from which the ball is thrown
- Time t (4)

[15]

Activity 4 Multiple Choice Questions

- 4.1 A 30 kg iron sphere and a 10 kg aluminum sphere with the same diameter falls freely from the roof of a tall building. Ignore the effects of friction. When the spheres are 5 m above the ground, they have the same ...
- A. momentum.
 - B. acceleration
 - C. kinetic energy
 - D. potential energy
- (2)
- 4.2. An object is thrown vertically into the air at $12 \text{ m}\cdot\text{s}^{-1}$ in the absence of air friction. When the object is at the highest point, the velocity of the object in $\text{m}\cdot\text{s}^{-1}$ is?
- A. 0
 - B. 9,8 downwards
 - C. 9,8 upwards
 - D. 12
- (2)
- 4.3. An object is projected vertically upwards and then falls back to the ground level. The acceleration of the object is
- A. Directed upwards throughout its movement.
 - B. Zero at the greatest height.
 - C. Directed downwards throughout its movement.
 - D. Directed upwards and then downwards.
- (2)

[6]

MOMENTUM

Momentum:

Momentum is the product of an object's velocity and mass. It is a vector quantity.

$$p = mv$$

The symbol for momentum is p and the SI unit is $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$

Impulse:

Impulse is the product of the net force acting on an object and the time that the force is applied to an object. (Impulse = $F\Delta t$).

Newton's second law of motion in terms of momentum:

The net (resultant) force acting on an object is equal to the object's rate of change of momentum. In a formula: $F_{\text{net}} = \frac{\Delta p}{\Delta t}$

The law of conservation of linear momentum:

The total linear momentum of an isolated (closed) system remains.

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

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

OR

$$m_A v_{1A} + m_B v_{1B} = m_A v_{2A} + m_B v_{2B}$$

- ✓ **Isolated/closed system:** a system on which the resultant/ net external force is zero.
- ✓ **External forces:** Forces outside of the system.
- ✓ **System:** A set number of objects and their interactions with each other.

Elastic Collision and Inelastic Collision

- ✓ **Elastic collision** : a collision in which both momentum and kinetic energy are conserved.
- ✓ **Inelastic collision** : a collision in which momentum is conserved and kinetic energy is not conserved.
 - To prove that a collision is elastic, we only have to prove that total kinetic energy is conserved.
 - Kinetic energy can be calculated using the mass and velocity of an object:

$$\triangleright E_k = \frac{1}{2}mv^2$$

Where:

E_k = kinetic energy in Joules (J)

m = mass (kg)

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

Elastic collision: $\sum E_k(\text{before}) = \sum E_k(\text{after})$

Inelastic collision: $\sum E_k(\text{before}) \neq \sum E_k(\text{after})$

(some energy is lost as sound or heat)

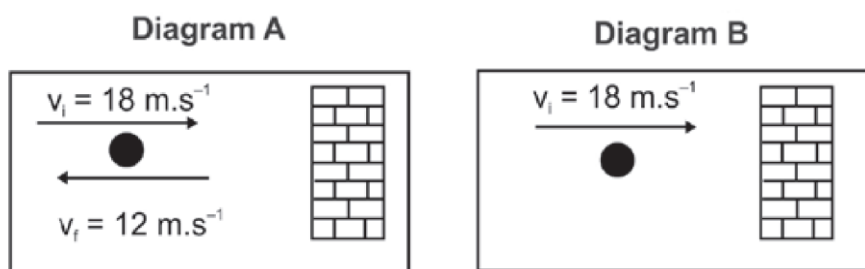
Activity 1

Define the following terms in words

- 1.1. Momentum (2)
 - 1.2. Impulse (2)
 - 1.3. Elastic collision (2)
 - 1.4. Inelastic collision (2)
 - 1.5 Principle of conservation of linear momentum (2)
 - 1.6 Isolated system in Physics (2)
- (10)**

Activity 2

Study the diagrams below showing the movement of a 150 g baseball thrown at a wall at right angles.



- 1.1 Calculate the initial momentum of the baseball as it strikes the wall in Diagram A. (3)
- 1.2 Calculate the final momentum of the baseball as it leaves the wall in Diagram A. (3)
- 1.3. Calculate the change in momentum during the collision in Diagram A. (3)
- 1.4. Calculate the force exerted by the wall on the baseball in Diagram A and in Diagram B, if each collision lasts 0,1 s. (6)
- 1.5. Draw a vector diagram to illustrate the relationship between the INITIAL MOMENTUM, FINAL MOMENTUM and CHANGE IN MOMENTUM for the baseball in Diagram A. (6)

[21]

Activity 3

A cricket ball of mass 175 g is thrown horizontally towards a player at $12 \text{ m}\cdot\text{s}^{-1}$. It is hit back in the opposite direction with a velocity of $30 \text{ m}\cdot\text{s}^{-1}$. The ball is in contact with the bat for a period of 0,05 s. Calculate:

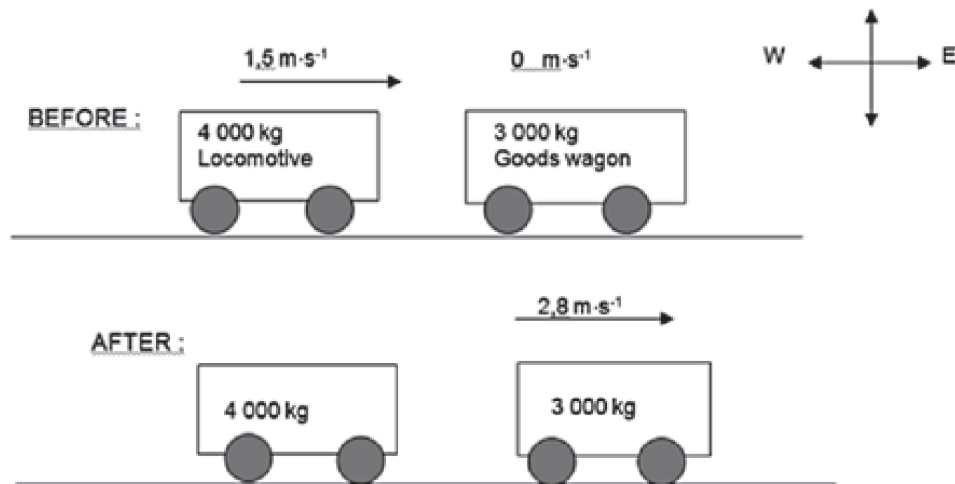
- 1.1 The impulse of the ball. (4)
- 1.2 The force exerted on the ball by the bat. (3)

[7]

Activity 4

- 1.1 Define an isolated system as used in Physics. (2)

1.2 In a railway shunting yard, a locomotive (train engine) of mass 4 000 kg, travels due east at a velocity of $1,5 \text{ m}\cdot\text{s}^{-1}$. The train driver tries to link it to a stationary wagon of mass 3 000 kg by letting them collide. Instead, the wagon moves due east with a velocity of $2,8 \text{ m}\cdot\text{s}^{-1}$.



Calculate the magnitude and direction of the velocity of the locomotive immediately after the collision. (5)

1.3 Is the above collision elastic or inelastic? Use calculations to justify your answer. (5)

[12]

WORK ENERGY AND POWER

Work

Define the work done on an object by a constant force F as $F \cdot \Delta x \cos\theta$, 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.**)

At the end of this section, learners should be able to do the following:

- 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: $W = \Delta K = K_f - K_i$

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

Calculate the power involved when work is done.

Perform calculations using $P_{av} = F \times v_{av}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.

Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

HINTS:

Know that in a free body diagram, the object of interest is drawn as a dot and all the forces acting on it are drawn as arrows pointing away from the dot. All the forces acting on an object must be labelled using appropriate symbols.

Know that a force diagram is a picture of the object(s) of interest with all the forces acting on it drawn in as arrows. (i.e the weight should be drawn from the centre of the body and the normal force should be from the surface.

Revise and emphasise trigonometric ratios.

Energy conversion when calculating power should be emphasised.

All the definitions, principles and laws should be stated as they are in the CAPS document.

All the equations should be copied as they are from the data sheet.

Activity 1

Define the following terms

- 1.1 Work – Energy theorem. (2)
- 1.2 Conservative force. (2)
- 1.3 Non – Conservative force. (2)
- 1.4 Isolated system. (2)
- 1.5 Principle of Mechanical energy conservation. (2)
- 1.6 Power (2)
- 1.7 Kinetic energy (2)
- 1.8 Gravitational potential energy (2)

[16]

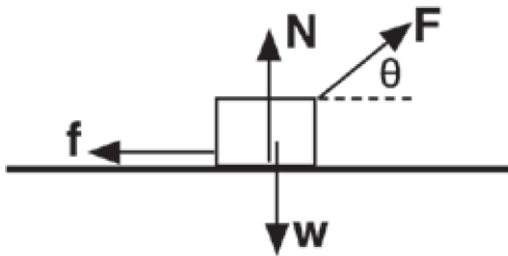
Activity 2

Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Write only the letter (A–D) next to the question number (1.1 – 1.2).

1. An object moves in a straight line on a ROUGH horizontal surface. If the net work done on the object is zero, then

- A. the object has zero kinetic energy.
- B. the object moves at a constant speed.
- C. the object moves at constant acceleration.
- D. there is no frictional force acting on the object. (2)

2. An object is pulled along a straight horizontal road to the right without being lifted. The force diagram below shows all the forces acting on the object.



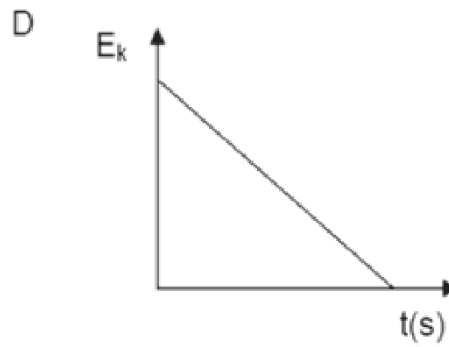
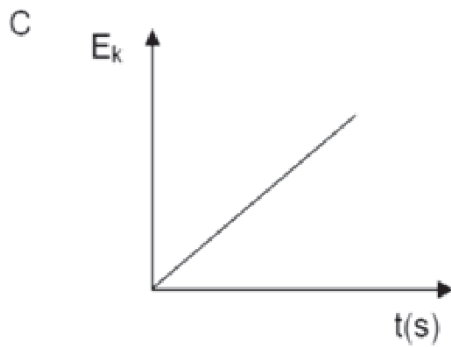
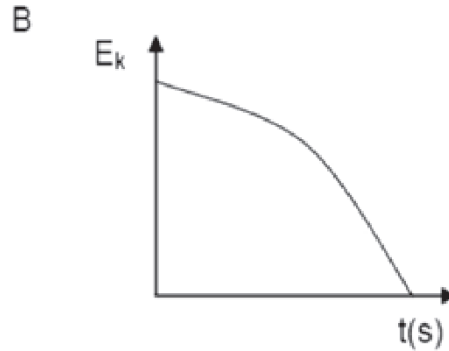
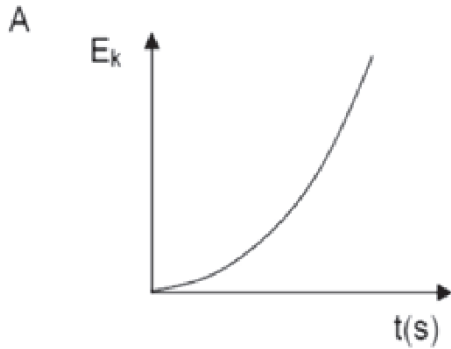
Which ONE of the above forces does POSITIVE WORK on the object?

- A. W
- B. N
- C. f
- D. component F (2)

3. The kinetic energy of a car moving at a constant velocity v is K . The velocity of the car changes to $2v$. What is the new kinetic energy of the car?

- A. $0,25 K$
- B. $0,5 K$
- C. $2 K$
- D. $4 K$ (2)

4. A stone is dropped from the edge of a cliff. Which ONE of the following graphs best represents the change in kinetic energy of the stone during its fall?



(2)

5. Power is defined as the rate....

- A. of change in velocity.
- B. at which work is done.
- C. of change of momentum.
- D. of change of displacement.

(2)

6. Which ONE of the following physical quantities is equal to the product of force and average velocity?

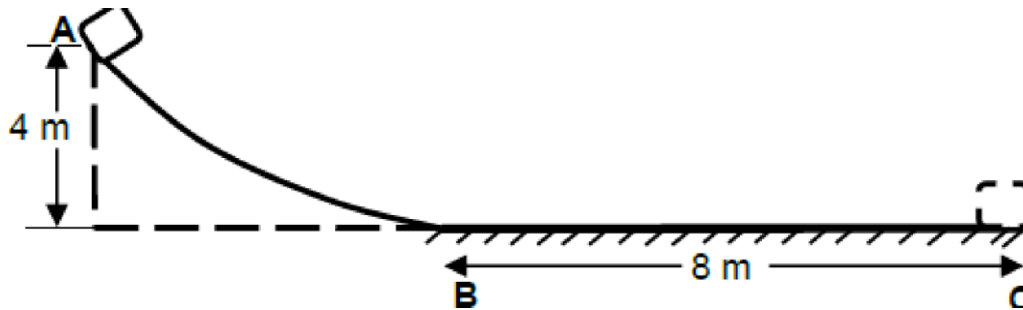
- A. Work
- B. Average power
- C. Energy
- D. Average acceleration

(2)

[12]

Activity 3

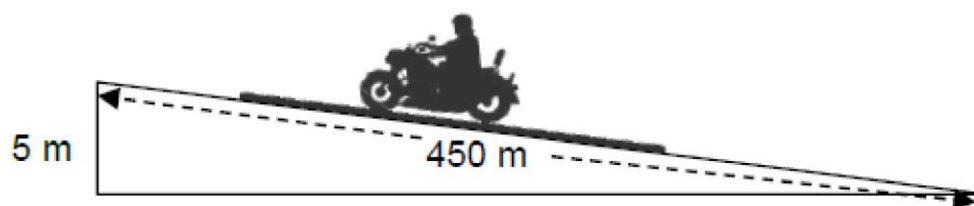
1. The diagram below shows a track, **ABC**. The curved section, **AB**, is frictionless. The rough horizontal section, **BC**, is 8 m long.



An object of mass 10 kg is released from point A which is 4 m above the ground. It slides down the track and comes to rest at point C.

- 3.1 State the principle of conservation of mechanical energy in words. (2)
- 3.2 Is mechanical energy conserved as the object slides from A to C? Write only YES or NO. (1)
- 3.3 Draw a free-body diagram, representing all the forces that act on the object as it moves along BC. (3)

3.4 A person practices on the motorbike on a track with an incline. Starting from rest, the person rides a distance of 450 m up the incline which has a vertical height of 5 m, as shown.

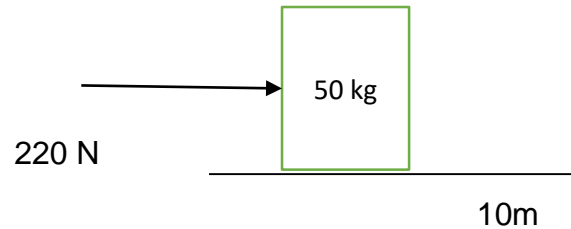


The total frictional force acting on the motorbike is 294 N. The combined mass of rider and motorbike is 300 kg. The average driving force on the motorbike as it moves up the incline is 350 N. Consider the motorbike and rider as a single system.

- 3.4.1 Draw a labelled free-body diagram for the motorbike-rider on the incline. (4)
- 3.4.2 State the WORK-ENERGY theorem in words. (2)
- 3.4.3 Friction is a non-conservative force. What is meant by the term non-conservative force? (2)

Activity 4

A 220 N force is applied horizontally to a box of mass 50 kg which rests on a rough horizontal surface and the box moves 10 m. The kinetic friction between the surface and the box is 40 N. Calculate:



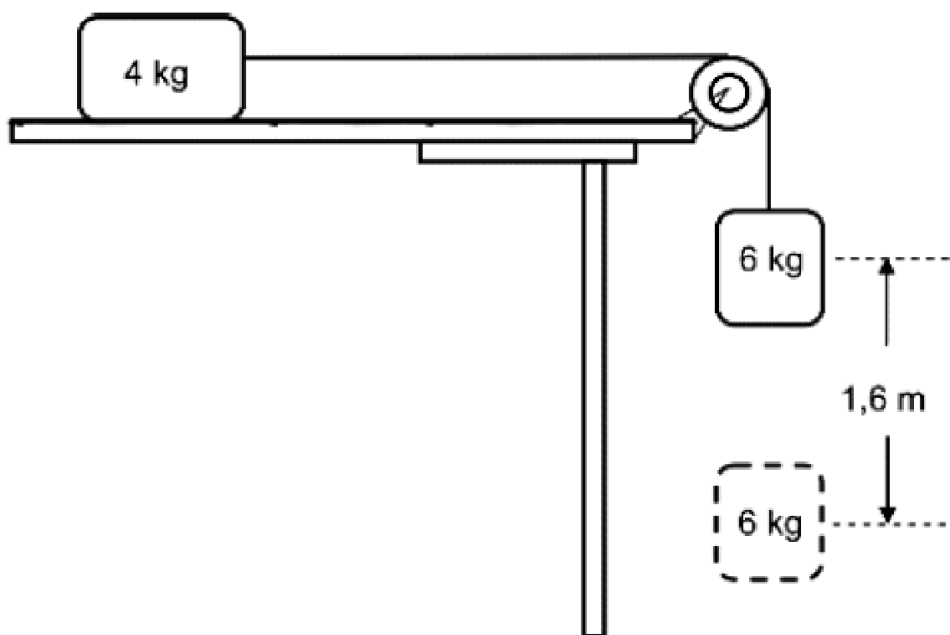
Calculate the following:

- 4.1 The work done on the box by the applied force. (3)
- 4.2 The work done on the box by the normal force. (3)
- 4.3 The work done on the box by the friction. (3)
- 4.4 The net work done on the box. (3)

[12]

Activity 5

In the diagram below, a 4 kg block lying on a rough horizontal surface is connected to a 6 kg block by a light inextensible string passing over a light frictionless pulley. Initially the blocks are HELD AT REST.



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

When the blocks are released, the 6 kg block falls through a vertical distance of 1,6m.

5.2 Draw a labelled free-body diagram for the 6 kg block. (2)

5.3 Calculate the work done by the gravitational force on the 6 kg block. (3)

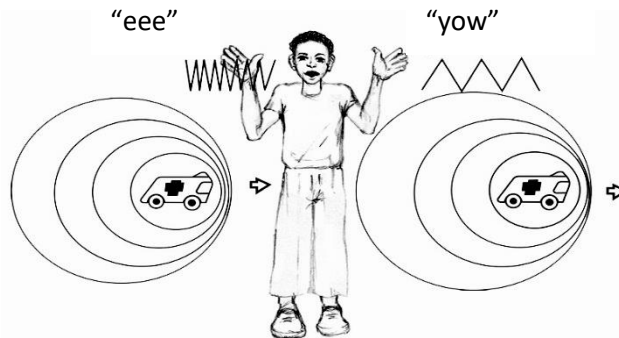
The coefficient of kinetic friction between the 4 kg block and the horizontal surface is 0,4. Ignore the effects of air resistance.

5.4 Use energy principles to calculate the speed of the 6 kg block when it falls through 1,6 m while still attached to the 4 kg block. (5)

[12]

Waves, sound and light: The Doppler Effect

Have you ever heard an approaching fire engine (or ambulance) and noticed the distinct change in the sound of the siren as it passes? The effect is similar to what you get when you put together the two syllables “eee” and “yow” to produce “eee-yow.” While the vehicle approaches, the pitch of the siren is relatively high (“eee”), but as it passes and moves away, the pitch suddenly drops (“yow”). Something similar, but less familiar, occurs when an observer moves towards or away from a stationary source of sound.



This phenomenon is called the Doppler Effect.

Change in observed frequency

An insect moving its legs and bobbing up and down in the middle of a quiet puddle, while staying in the same position, causes water waves in concentric circles, as illustrated in Figure 1. Waves arrive at Point A as frequently as they arrive at Point B – the frequency of the waves is the same at Points A and B, or anywhere in the vicinity of the insect. This wave frequency is the same as the bobbing frequency of the insect.

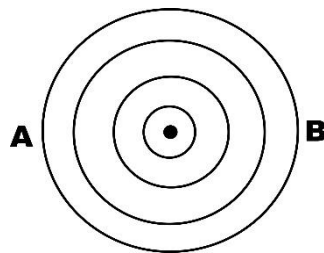


Figure 1: Water waves produced by a stationary insect moving its legs

Suppose the insect moves across the water at a speed less than the speed of the water waves. In effect, the insect chases part of the waves it has produced. The wave pattern is distorted and no longer consists of concentric circles, as illustrated in Figure 2.

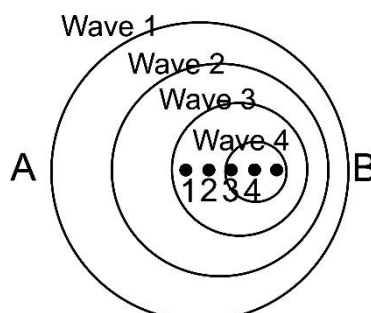


Figure 2: Distorted wave pattern when insect moves forward

The centre of the outer wave was made when the insect was at the centre of that circle. The centre of the next smaller wave was made when the bug was at the centre of that circle, and so forth. The centres of the circular waves move in the direction of the swimming insect.

Although the insect maintains the same bobbing frequency as before, an observer at B would see the waves coming more often. The observer would measure a **higher frequency**. This is because each successive wave has a shorter distance to travel and therefore arrives at B more frequently than if the insect weren't moving toward B. An observer at A, on the other hand, would measure a **lower frequency** because of the longer time between wave-crest arrivals. This is because, in order to reach A, each crest has to travel further than the one ahead of it because of the movement of the insect.

What is the Doppler Effect?

The change in observed frequency due to the relative motion between a source and an observer (or listener), is called the **Doppler Effect**. Such phenomena were first identified in 1842 by the Austrian physicist Christian Doppler (1803 – 1853) and are collectively referred to as the Doppler Effect.

The Doppler Effect and sound waves

When a police car (sound source) approaches a listener (the boy in Figure 3), the waves in front of the source are crowded together so the listener receives more waves per unit time and thus detects a higher pitch than when there is no movement.

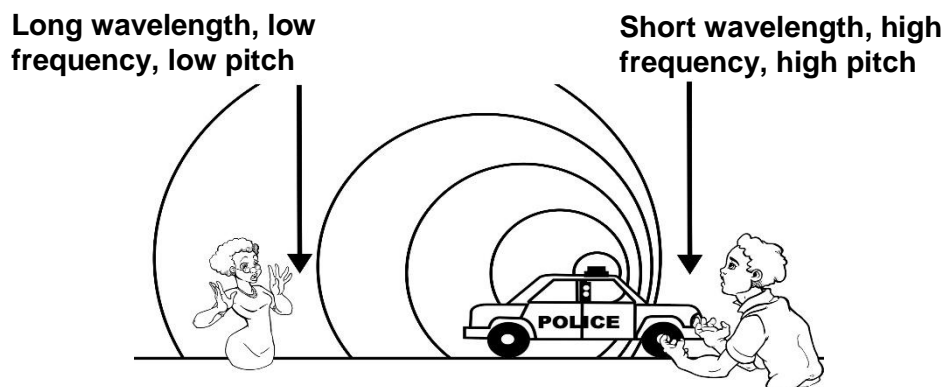
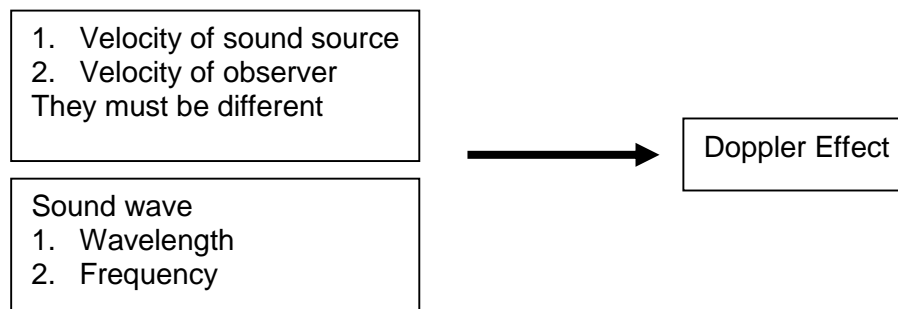


Figure 3: The Doppler Effect for a moving sound source

When the sound source moves away from the listener (the girl in Figure 3), the reverse is true and the pitch is lower. This is an example of the Doppler Effect with sound waves. The Doppler Effect is the change in the observed frequency (pitch) due to the relative motion between the police car (source) and the observers (boy and girl).

When does the Doppler Effect take place for sound waves?

The Doppler Effect takes place when a object creating waves, called the source, moves relative to a listener (observer). The flow diagram below summarises the concepts needed to describe the Doppler Effect:



Different scenarios resulting in the Doppler Effect are described below. It is assumed that the source and the listener move either directly towards or directly away from each other, at speeds less than the speed of sound.

1. Moving source, stationary listener (observer)

Consider the sound emitted by a siren on a stationary fire engine, as illustrated in Figure 4. Like the fire engine, the air is assumed to be stationary with respect to the earth. Each solid arc in the drawing represents a compression (crest) of a sound wave. Since the sound pattern is symmetrical, listener L_1 standing in front of the truck and listener L_2 standing behind the truck detect the same number of compressions per second and, as a result, hear the same frequency.

In Figure 4, the wavelength of the sound waves is given as λ and the speed of the sound waves in air as v . The frequency of the sound waves is given as f_s . Both listeners will hear the frequency f_s when the sound source is stationary.

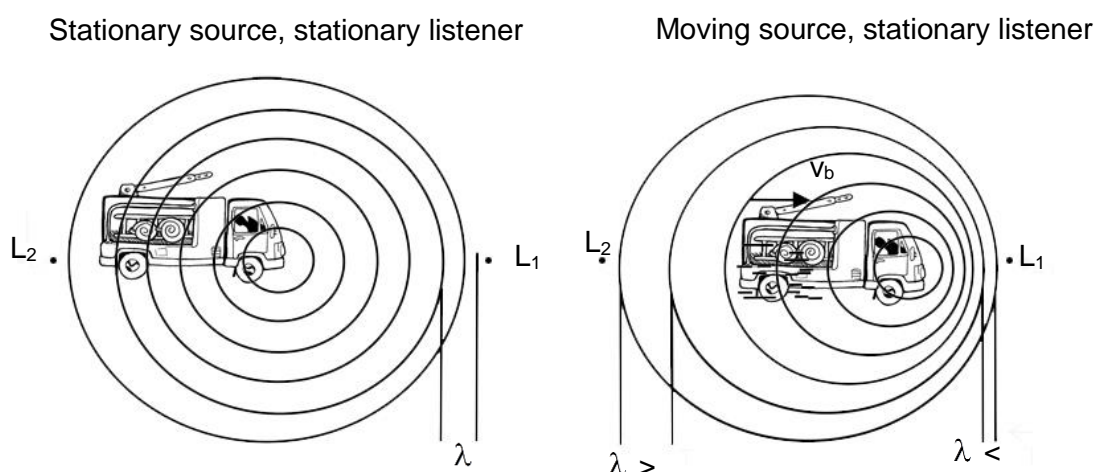


Figure 4: The Doppler Effect for a moving source and stationary listener

Source approaching listener L₁: The diagram to the right of Figure 4 shows the truck moving to the right at velocity v_s while emitting sound at the same frequency f_s as before. Ahead of the truck, due to the velocity v_s of the truck, the compressions are now closer together, resulting in a **decrease in wavelength** of the observed sound. This ‘bunching-up’ occurs because the moving truck ‘gains ground’ on a previously emitted compression before emitting the next one. Since the compressions are closer together, listener L₁ senses more of them arriving per second than she does when the truck is stationary. The increased rate of arrival corresponds to a greater sound frequency, which the listener hears at a higher pitch.

The frequency observed by a stationary listener when the source approaches the listener can be given as:

$$f_L = f_s \frac{v}{v - v_s}$$

f_L : frequency observed by listener
 f_s : frequency emitted by source
 v_s : speed of source
 v : speed of sound in medium

Source moving away from listener L₁: Behind the moving truck, as illustrated in the diagram to the right of Figure 4, the compressions are further apart than they are when the truck is stationary. This increase in wavelength occurs because the truck pulls away from compressions emitted toward the rear. As a result, fewer compressions per second arrive at the ear of listener L₂ behind the truck, corresponding to a smaller sound frequency or lower pitch.

The frequency observed by a stationary listener when the source moves away from the listener can be given as:

$$f_L = f_s \frac{v}{v + v_s}$$

f_L : frequency observed by listener
 f_s : frequency emitted by source
 v_s : speed of source
 v : speed of sound in medium

2. Stationary source, moving listener (observer)

When the listener moves and the source is stationary, the wavelength **does not change**, but the speed at which the listener encounters the waves, **changes**. A moving listener intercepts a different number of wave compressions per second than a stationary listener does, and, therefore detects a different frequency, f_L .

Listener moving toward stationary sound source: A listener moving with a speed v_L toward a stationary source **intercepts more** wave compressions per unit of time than a stationary listener does, as illustrated in Figure 6.

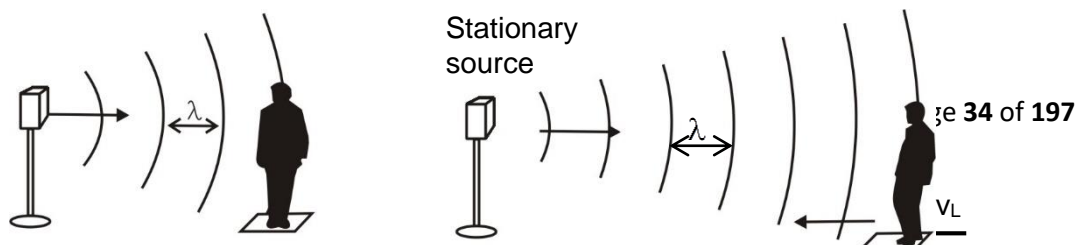


Figure 6: Listener moving towards a stationary sound source

The frequency observed by a listener approaching a stationary source can be given as:

$$f_L = f_s \frac{v + v_L}{v}$$

f_L : frequency observed by listener
 f_s : frequency emitted by source
 v_L : speed of listener
 v : speed of sound in medium

Listener moving away from stationary sound source: A listener moving with a speed v_L away from a stationary source **intercepts fewer** wave compressions per unit of time than a stationary listener does.

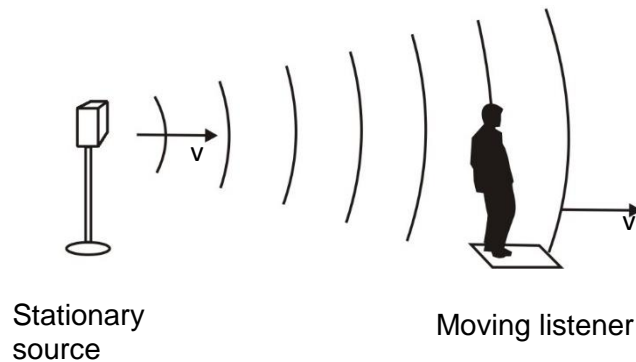


Figure 7: Listener moving away from a stationary sound source

The frequency f_L observed by the listener can be given as follows:

The frequency observed by a listener approaching a stationary source can be given as:

$$f_L = f_s \frac{v - v_L}{v}$$

f_L : frequency observed by listener
 f_s : frequency emitted by source
 v_L : speed of listener
 v : speed of sound in medium

To summarise:

- When a sound source moves and the listener is stationary, the motion of the sound source changes the wavelength of the sound wave and, as a result, the observed frequency changes.
- When the listener moves and the sound source is stationary, the wavelength remains constant, but the rate at which the listener intercepts with the sound waves changes, causing the observed frequency to change.

General Doppler formula

The four formulae derived above can be combined in one formula which is referred to as the general Doppler formula:

$$f_L = f_s \frac{v \pm v_L}{v \pm v_s}$$

f_L : frequency heard by listener
 f_s : frequency emitted by source
 v_L : speed of listener
 v_s : speed of source
 v : speed of sound in medium

In the numerator, the plus sign applies when the listener moves toward the source (higher frequency), and the minus sign applies when the listener moves away from the source (lower frequency).

In the denominator, the minus sign is used when the source moves toward the listener (higher frequency), and the plus sign is used when the source moves away from the listener (lower frequency).

Example 1

An ambulance moving at $35 \text{ m}\cdot\text{s}^{-1}$ and blowing its siren, emits sound waves at a frequency of 400 Hz. Calculate the frequency that will be heard by a stationary boy when the ambulance:

- Is approaching her.
- Moves away from her. (Take the speed of sound in air as $340 \text{ m}\cdot\text{s}^{-1}$.)

Solution:

- The listener is stationary – $v_L = 0$

The source is approaching the listener; therefore a higher frequency will be heard:

$f_L > f_s$ – this implies a minus in the denominator

$$f_L = f_s \frac{v \pm v_L}{v \pm v_s} = (400) \frac{340 \pm 0}{340 - 35} = 445,90 \text{ Hz}$$

- The listener is stationary – $v_L = 0$

The source is moving away from the listener; therefore a lower frequency will be heard:

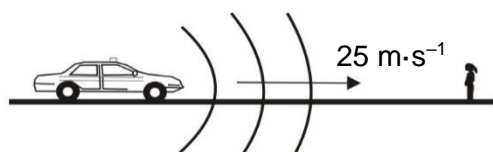
$f_L < f_s$ – this implies a plus in the denominator

$$f_L = f_s \frac{v \pm v_L}{v \pm v_s} = (400) \frac{340 \pm 0}{340 + 35} = 362,67 \text{ Hz}$$

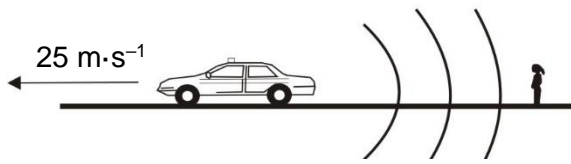
Activity 2: Assignment

Unless otherwise stated, take the speed of sound in air as $340 \text{ m}\cdot\text{s}^{-1}$.

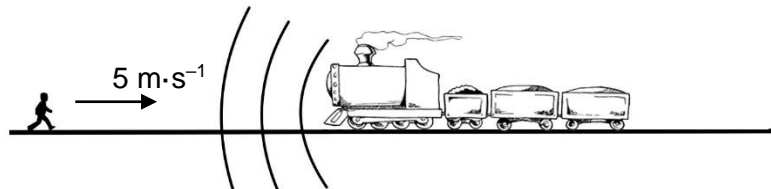
- What is the Doppler Effect?
- The siren of a police car emits waves at a frequency of 350 Hz. Determine the frequency of the sound heard by a stationary listener when the police car is moving:
 - Towards the listener at a speed of $25 \text{ m}\cdot\text{s}^{-1}$.



- Away from the listener at a speed of $25 \text{ m}\cdot\text{s}^{-1}$



3. A railway train parked at the station sounds its siren at 450 Hz before it takes off. A passenger runs towards the train at a velocity of 5 m·s⁻¹.

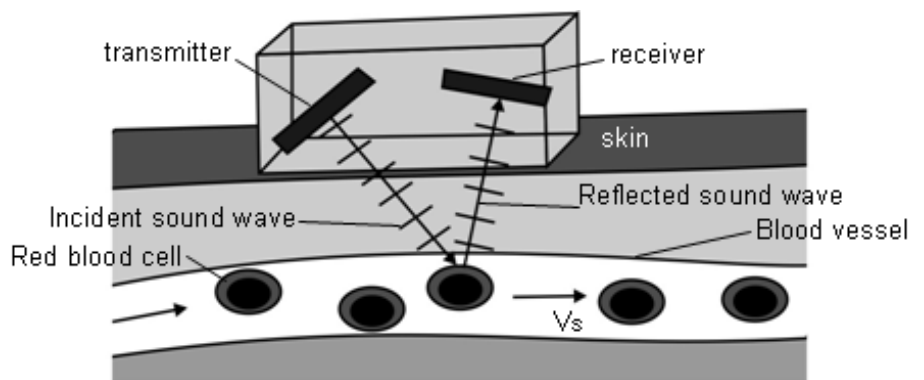


What frequency of sound, will be heard by the passenger?

4. A rocket moves at a speed of 240 m·s⁻¹ toward a stationary pole. The rocket emits a sound wave at a frequency of 1 200 Hz.
- 4.1 Calculated the frequency that will be measured by a detector attached to the pole.
- 4.2 On reaching the pole, some of the sound waves are reflected towards the rocket as an echo. Calculate the frequency that will be detected by a detector placed on the rocket.
5. A moving ambulance blows its siren and emits sound waves at a frequency of 400 Hz. The ambulance approaches a stationary girl with a detector in her hand. The frequency measured by the detector is 450 Hz. Calculate the speed at which the ambulance is moving.

Applications of the Doppler Effect with sound and ultrasound

Doppler flow meter: The Doppler flow meter is a device used in medicine to measure the speed of blood flow. A transmitter, placed on the skin, sends out sound waves at a certain frequency. When the sound is reflected from the moving red blood



cells, its frequency is changed due to the Doppler Effect. From the change in frequency the speed of the blood flow can be determined. Increased blood flow locates regions where the blood vessels have narrowed.

The Doppler flow meter can also be used to detect the motion of a foetal heart as early as 8 – 10 weeks after conception.

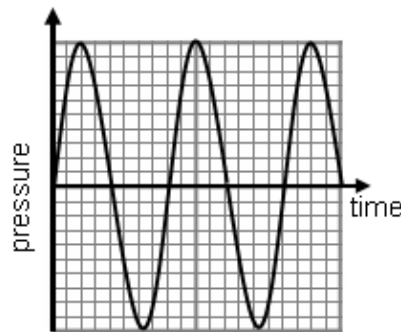
In nature: A bat emits a sound with an ultra-frequency from its nose. When this sound is reflected by insects, the bat can hear some of it. From this sound the bat can work out the position of these insects.

Burglar alarms: A burglar alarm emits ultrasound of a particular frequency. This sound is reflected with the same frequency by stationary objects in the room. If there is any motion in the room, the frequency of the emitted sound will change depending on whether the object is moving towards or away from the alarm. When the electronics in the alarm detect a sound with a frequency different from the original one, the alarm goes off immediately.

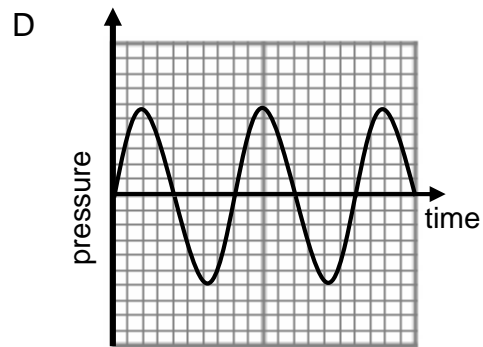
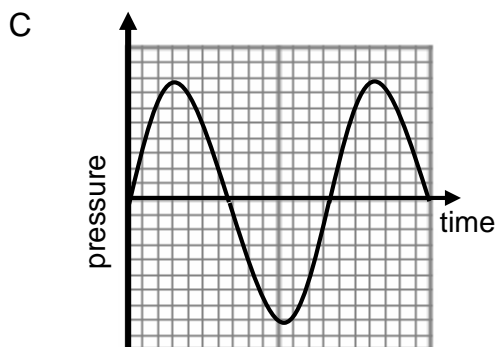
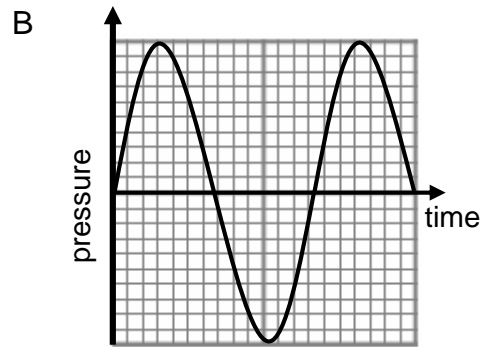
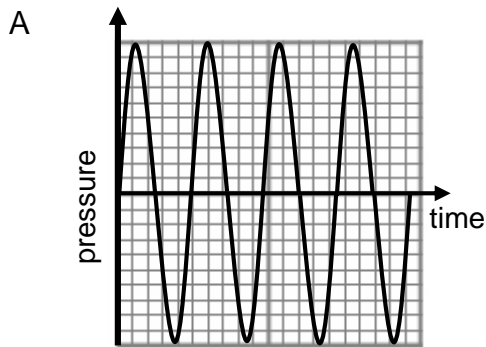
More exercises

1. 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 $20 \text{ m} \cdot \text{s}^{-1}$ towards the rock. Assume that the speed of sound in water is $1\,500 \text{ m} \cdot \text{s}^{-1}$.
 - 1.1 Calculate the frequency of the sound waves detected by a detector on the rock.
 - 1.2 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 1.1? Write down only HIGHER, LOWER or REMAINS THE SAME. Explain your answer.
2. The siren of a police car produces a sound of frequency 420 Hz. A man sitting next to the road notices that the pitch of the sound changes as the car moves towards and then away from him.
 - 2.1 Write down the name of the above phenomenon.
 - 2.2 Assume that the speed of sound in air is $340 \text{ m} \cdot \text{s}^{-1}$. Calculate the frequency of the sound of the siren observed by the man, when the car is moving towards him at a speed of $16 \text{ m} \cdot \text{s}^{-1}$.
 - 2.3 The police car moves away from the man at constant velocity, then slows down and finally comes to rest.
 - 2.3.1 How will the observed frequency **compare** with the original frequency of the siren when the police car moves away from the man at constant velocity? Write only GREATER THAN, SMALLER THAN or EQUAL TO.
 - 2.3.2 How will the observed frequency **change** as the car slows down whilst moving away? Write only INCREASES, DECREASES or REMAINS THE SAME.
3. An ambulance with its siren on, moves at constant velocity away 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 ambulance.
 - 3.1 Name the phenomenon observed.
 - 3.2 If the speed of sound in air is $340 \text{ m} \cdot \text{s}^{-1}$, calculate the speed of the ambulance.

4. A fire truck, with its siren on, is moving at $20 \text{ m}\cdot\text{s}^{-1}$ towards a burning building. A person standing next to the road with a detector, measures the frequency of the sound emitted by the siren to be 450 Hz . The measured frequency is HIGHER than the frequency of the sound emitted by the siren.
- 4.1 Is the fire truck moving toward or away from the person?
- 4.2 Explain why the registered frequency is higher.
- 4.3 Calculate the frequency of the siren if the speed of sound in air is $340 \text{ m}\cdot\text{s}^{-1}$.
5. The pressure versus time graph below represents a sound wave in air emitted by a stationary source.



Which ONE of the following graphs best represents the sound wave, as observed by a stationary observer, if the source is moving towards the observer?



Multiple Choice Questions

1. An ambulance is moving at a speed of $28 \text{ m}\cdot\text{s}^{-1}$ and its siren emits sound waves of frequency 700 Hz . If the speed of the sound in air is $340 \text{ m}\cdot\text{s}^{-1}$, when the ambulance approaches to the hospital, a nurse standing on the entrance of the hospital, hears a sound with a frequency:

- A 644Hz
- B 763Hz
- C 700 Hz
- D 350 Hz

2. A stationary source produces a sound of frequency 400 Hz . A listener is moving towards the source of sound with a constant speed of $20 \text{ m}\cdot\text{s}^{-1}$. If the speed of the sound in air is $340 \text{ m}\cdot\text{s}^{-1}$ the listener hears a sound wave with a frequency of:

- A 400 Hz
- B 376 Hz
- C 424 Hz
- D 800 Hz

Homework Exercise

1. The siren of a police car produces a sound of frequency 420 Hz . A man sitting next to the road notices that the pitch of the sound changes as the car moves towards and then away from him.

1.1 Name and state in words the phenomenon described above.

(3)

1.2 Calculate the frequency of the sound of the siren observed by the man, when the car is moving towards him at a constant speed of $16 \text{ m}\cdot\text{s}^{-1}$.

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

(5)The police car moves away from the man at a constant velocity, then slows down and finally comes to rest.

1.3.1 How will the observed frequency compare with the original frequency of the siren when the police car moves away from the man at constant velocity? Write only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

1.3.2 How will the observed frequency CHANGE if the car moves at a lower speed away from the observer? Write only INCREASES, DECREASES or REMAINS THE SAME. (1)

ELECTROSTATICS

TYPES OF CHARGES:

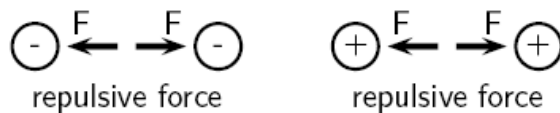
1. **Positive charge** – A positive charge on an object originates with the removal or shortage of electrons
2. **Negative charge** – A negative charge on an object originates with the addition or surplus of electrons.

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

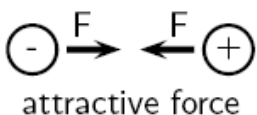
Electrostatic force is the force of attraction or repulsion between two charges.

Charged objects exert forces on each other:

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



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



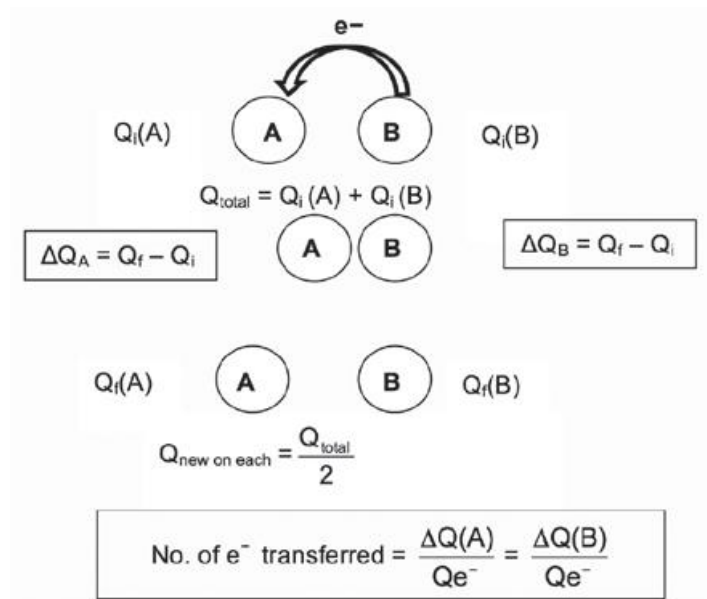
The law of conservation of charge

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

When two charged spheres are brought into contact with each other, electrons flow from the sphere with more electrons to the sphere with fewer electrons.

The symbol for charge is Q .

Q is measured in coulombs



Unit of charge

- Charge is measured in units called coulombs (C).
- A coulomb of charge is a very large charge.
- In electrostatics we therefore often work with charge in micro coulombs

(1 $\mu\text{C} = 1 \times 10^{-6} \text{ C}$) and nano coulombs (1 $\text{nC} = 1 \times 10^{-9} \text{ C}$).

Unit of distance between charges must be in metres.

[1m = 1000mm ($\times 10^{-3}$); 1m = 100cm ($\times 10^{-2}$)]

Coulomb's law

The magnitude of the electrostatic force exerted by one point charge on the other point is directly proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.

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

Where:

F is the force in Newtons (N)

Q₁ and Q₂ are charges in coulombs (C)

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

k is proportionality constant (Coulomb's Law constant) with the value of

$$9 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2}$$

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

Worked Example 1

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

Solution 1

Step 1: Data

$$F =$$

$$Q_1 = +3 \text{ nC} = +3 \times 10^{-9} \text{ C}$$

$$Q_2 = -5 \text{ nC} = -5 \times 10^{-9} \text{ C}$$

$$r = 2 \text{ m}$$

$$k = 9 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2}$$

Step 2: Suitable Equation

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

Step 3: Determine the magnitude of the force

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

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

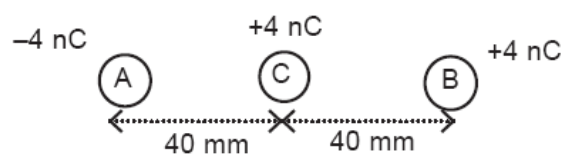
$$= 3,38 \times 10^{-8} \text{ N}$$

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

Worked example 2

Two tiny spheres A and B with charges - 4 nC and +4 nC respectively, are placed as in the sketch. They are fixed while a third charge C of + 4 nC has its centre placed at a distance of 40 mm from the centres of both A and B.

(1 nC = 1 nano coulomb = $1 \times 10^{-9} \text{ C}$.)

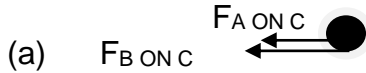


- (a) Draw a free body diagram showing all forces acting on charge C due to the presence of charges A and B.
 (b) Calculate the magnitude of the Coulombic force that exists between charge A of -4 nC and the charge C of $+4 \text{ nC}$ charge.
 (c) In which direction will the sphere C move?

Solution 2

Draw a free body diagram showing the forces on C. For C, take as positive the direction to the left.

Let C react with A first, and then with B



(b)
$$F = \frac{kQ_1Q_2}{r^2} = \frac{9 \times 10^9 (4 \times 10^{-9})(4 \times 10^{-9})}{(40 \times 10^{-3})^2} = 9 \times 10^{-5} \text{ N}$$

(c) $F_{AB} = 9 \times 10^{-5} \text{ N}$ to the left (Repulsive)

ELECTRIC FIELD AROUND CHARGES

Electric field

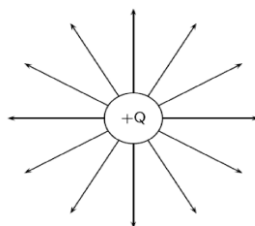
An electric field is a region of space in which an electric charge experiences a force.

Some important points to remember about electric fields:

- Field lines never cross.
- They are directed from positive to negative
- They start from the surface of the sphere.
- All lines must have the direction which is shown by the arrows.
- When drawing a field line, each charge must have a minimal number of field lines.

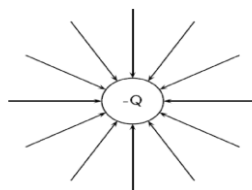
Electric field lines around a positive point charge:

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

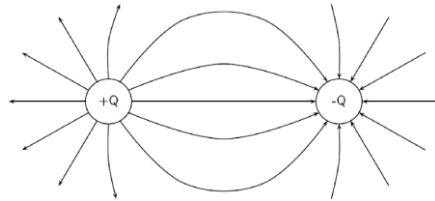


Electric field lines around a negative point charge:

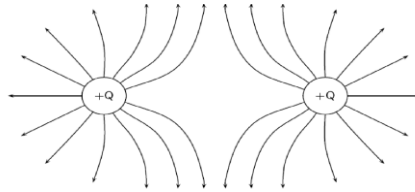
- For a negative charge, field lines are drawn towards the charge.



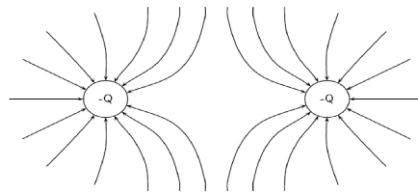
Electric field lines of two equal but opposite charges:



Electric field lines of two equal positive charges:



Electric field lines of two equal negative charges:



Electric field at a point is defined as the electrostatic force experienced per unit positive charge

Strength of an electric field

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

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

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

Unit: if the electrostatic force F acts on the charge in Newton (N), the charge q is in coulomb (C), then the electric field strength (E) is in $N \cdot C^{-1}$ (Newton per Coulomb). As we will see later, the electric field strength can also be measured in Volt per metre ($V \cdot m^{-1}$).

Worked example 3

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

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

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

$$F = 2,1 \times 10^{-2} \text{N}$$

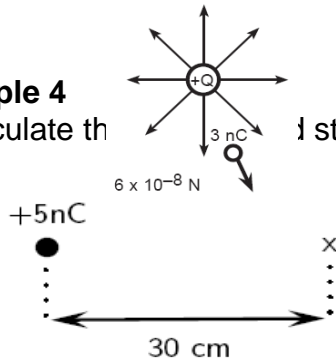
Electric field strength at a point due to a number of point charges

The electric field can be written as

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

Worked Example 4

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



Solution 4

Step 1: Data.

$$\begin{aligned} Q &= +5\text{nc} = +5 \times 10^{-9} \text{ C} \\ r &= 30 \text{ cm} = 0.30 \text{ m} \\ k &= 9 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2} \end{aligned}$$

Step 2: Select a suitable equation

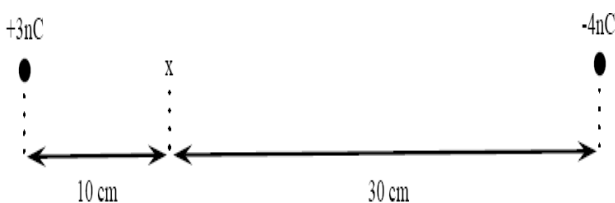
$$E = \frac{kQ}{r^2}$$

Step 3: substitute into equation:

$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{(9 \times 10^9) (5 \times 10^{-9})}{(0,3)^2} \\ &= 5 \times 10^{-16} \text{ N} \cdot \text{C}^{-1} \end{aligned}$$

Worked example 5

R and S are two points in the electric field of a small negatively charged sphere Q, Two charges of $Q_1 = +3\text{nC}$ and $Q_2 = -4\text{nC}$ are separated by a distance of 40cm. What is the electric field strength at a point that is 10cm from Q_1 and 30cm from Q_2 ? The point lies between Q_1 and Q_2 .



Solution 5

Step 1: Determine what is required:

We need to calculate the electric field a distance from two given charges.

Step 2: Determine what is given:

We are given the magnitude of the charges and the distances from the charges.

Step 3: Determine how to approach the problem:

We will use the equation:

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

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

Step 4: Substitute into an equation:

We first calculate E at x due to **Q₁**:

$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{(9 \times 10^9) (3 \times 10^{-9})}{(0, 1)^2} \\ &= 2,70 \times 10^3 \text{ N}\cdot\text{C}^{-1} \end{aligned}$$

Then for **Q₂**:

$$\begin{aligned} E &= \frac{kQ}{r^2} \\ &= \frac{(9 \times 10^9) (4 \times 10^{-9})}{(0,3)^2} \\ &= 4,00 \times 10^2 \text{ N}\cdot\text{C}^{-1} \end{aligned}$$

We need to add the two electric fields because both are in the same direction.

The field is away from **Q₁** and towards **Q₂**.

Therefore,

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

LONG QUESTIONS

QUESTION 1

The diagram below shows two identical spheres R and S carrying charges of $-6\mu\text{C}$ and $+2\mu\text{C}$ respectively placed a distance apart in vacuum.

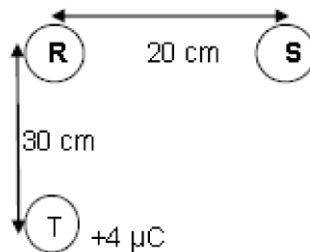


1.1 State *Coulomb's Law* in words

Spheres R and S are brought into contact for a while and then separated by a distance of 20 cm

- 1.2 Calculate the charge on each sphere
- 1.3 Calculate the number of electrons transferred or received during their contact.
- 1.4 Calculate the electrostatic force they exert on each other.

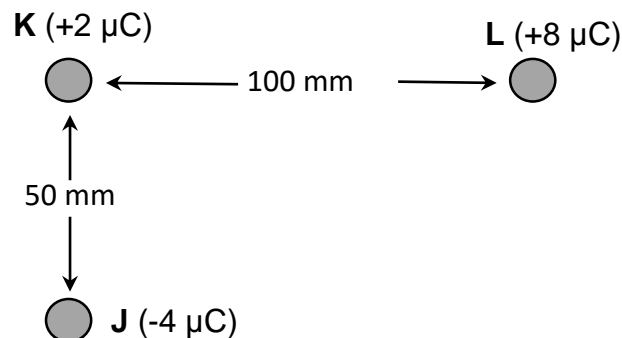
After R and S have touched, a third sphere T, of charge $+4\mu\text{C}$, is placed at a position as shown in the diagram below.



- 1.5 Calculate the net electrostatic force acting on R due to the presence of spheres S.

QUESTION 2

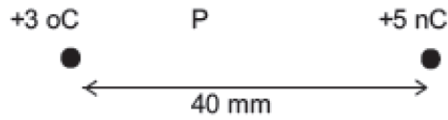
Three charges J, K and L are arranged on a horizontal plane so that angle JKL is a 90° angle. The charges are $-4\ \mu\text{C}$, $+2\ \mu\text{C}$ and $+8\ \mu\text{C}$ respectively. J and K are 50 mm apart and K and L are 100 mm apart. J and L are fixed in position while K is free to move.



- 2.1 State in words, *Coulomb's Law*.
- 2.2 Calculate the magnitude of the electrostatic force between charges J and K.
- 2.3 Draw a free-body diagram showing the electrostatic forces exerted on K due to charges J and L. Also show on the vector diagram how the net force can be determined.
- 2.4 Calculate the magnitude and direction of the net electrostatic force exerted on K due to charges J and L.

QUESTION 3

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



3.1 Define an electric field. (2)

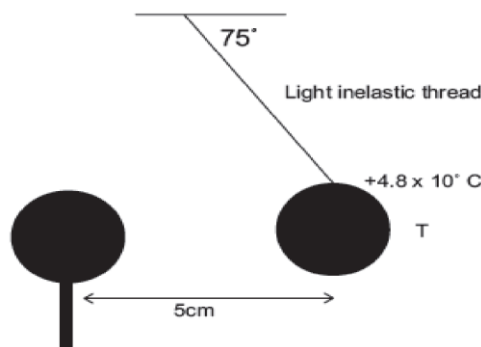
3.2 Draw the electric field that would surround these two small conducting spheres. Show the conducting spheres as small circles. (2)

3.3 Along the line joining the two small spheres, there is a point **P**, which is **10 mm** from the **+3 nC** charge. Show that the magnitude of the resultant or net electric field strength at **P** is **$2,2 \times 10^5 \text{ N.C}^{-1}$** . (8)

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

QUESTION 4

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



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

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

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

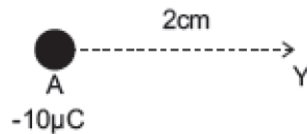
4.4 Draw a free body of the forces acting on sphere **T** (4)

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

4.6 Calculate the electric field strength at S (3)

QUESTION 5

A charged sphere (A) holding a charge of $-10\mu\text{C}$, is held fixed in position on a horizontal, insulated surface.

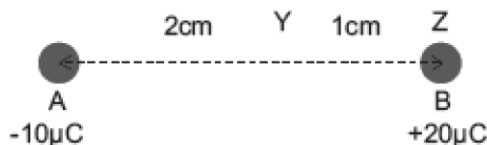


5.1 What is meant by the term 'electric field'? (2)

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

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

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



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

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

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

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

ELECTRIC CIRCUITS

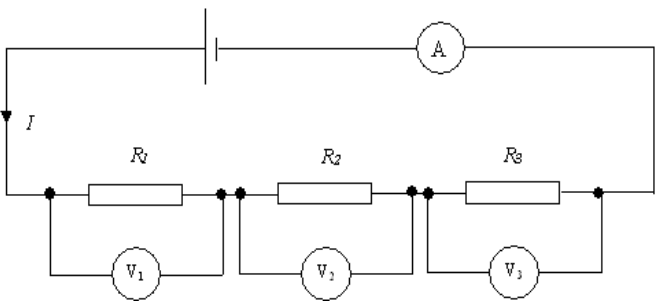
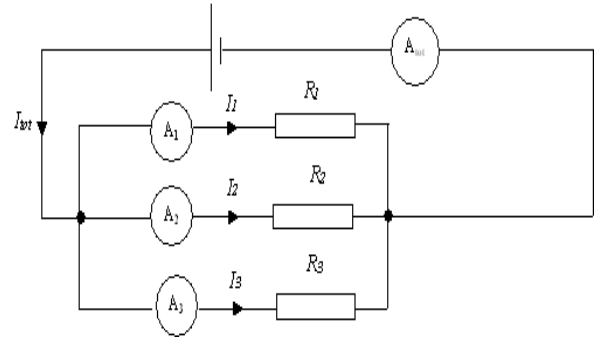
Current is the rate of flow of charge. In symbols: $I = \frac{q}{\Delta t}$

The amount of **energy transferred per coulomb of charge** is called the **potential difference**.

In symbols: $V = \frac{W}{q}$

Ohm's Law: The current (I) **through** a conductor is directly proportional to the potential difference (V) **across** it, provided the temperature remains constant.

In symbols: $R = \frac{V}{I}$

<u>Series Circuits</u>	<u>Parallel Circuits</u>
<p>A series circuit is simply a circuit that has only one pathway. There are no branches in the circuit, and hence the electricity can only travel in one route.</p>	<p>Parallel circuits are circuits which have more than one branch, or pathway which charges can travel through.</p>
	
<ul style="list-style-type: none"> • $V_T = V_1 + V_2 + V_3$ • The total potential difference (voltage) across all resistors will add up to the potential difference (voltage) off the power source, e.g. a battery. 	<ul style="list-style-type: none"> • $V_{tot} = V_1 = V_2 = V_3$ • The potential difference (voltage) in parallel circuits is actually the same for each branch, and equal to the potential difference (voltage) of the power source when the switch is closed.
<ul style="list-style-type: none"> • $I_T = I_1 = I_2 = I_3$ • In a series circuit the current is the same at any particular point in the circuit. The current does not vary as it passes through each individual resistor. 	<ul style="list-style-type: none"> • $I_{tot} = I_1 + I_2 + I_3$ • Current is divided between the various branches. The current in one branch will not be the same as in other branches (unless of course all the resistances are the same). The sum of the current in each individual branch will add up to give the total current of the circuit.

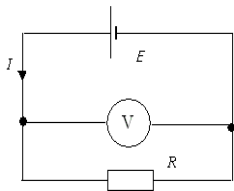
$R_{total} = R_1 + R_2 + R_3 + \dots$	OR	$R = \frac{V}{I}$	OR	$\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	OR	$R = \frac{V}{I}$
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Internal resistance

A battery is said to produce an **emf** (electromotive force). EMF is a **potential difference (voltage)**.

A good working definition of EMF is that it is the **open circuit terminal potential difference (voltage)** of the battery, i.e. **when there is no current in the external circuit**

Suppose we now add a load (component with resistance) as shown in the circuit diagram below. We will assume the wires have **negligible** resistance.



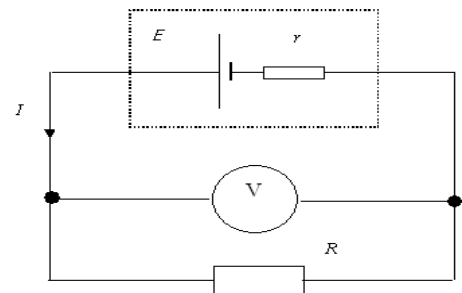
This time we find that the terminal potential difference (voltage) drops from \mathcal{E} to V . Since V is **less** than the EMF, it tells us that not all of the potential difference (voltage) is being transferred to the outside circuit. Some is lost due to the internal resistance of the battery causing the battery to become hot.

EMF = terminal voltage + lost voltage In symbols: $\mathcal{E} = V_{terminal} + V_{lost}$

We can thus represent the circuit as in the accompanying circuit diagram.

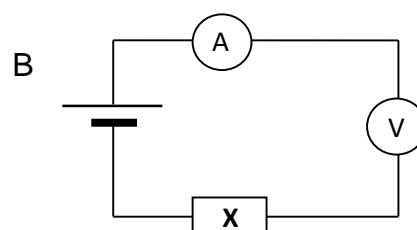
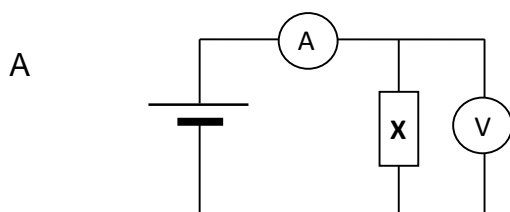
We can now treat this as a simple series circuit and we know that the current, I , will be the same throughout the circuit. We also know the potential difference (voltage)s in a series circuit add up to the battery potential difference (voltage).

Emf = $V(\text{external}) + V(\text{internal})$ In symbols: $\mathcal{E} = IR + Ir = I(R + r)$

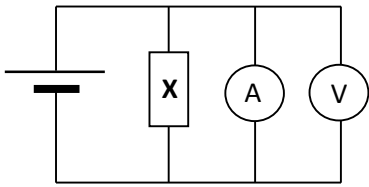


MULTIPLE CHOICE QUESTIONS

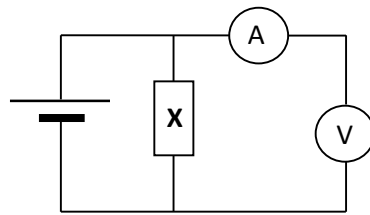
- Which ONE of the circuits below can be used to measure the current in a conductor **X** and the potential difference across its ends?



C

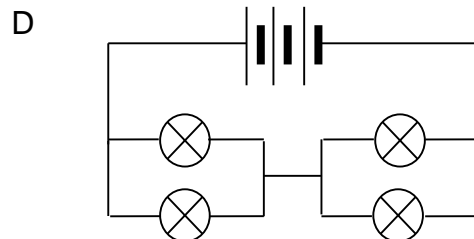
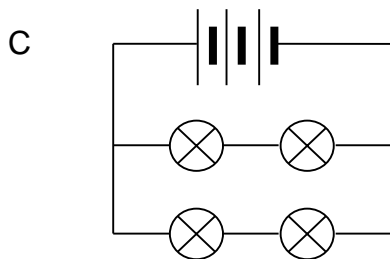
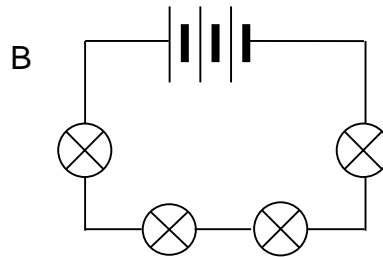
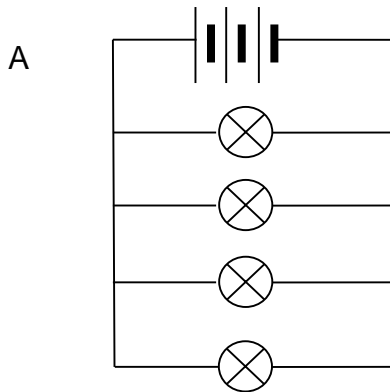


D



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

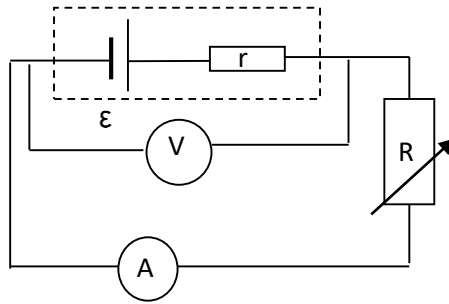
In which ONE of these circuits will the light bulbs glow the brightest?



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

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

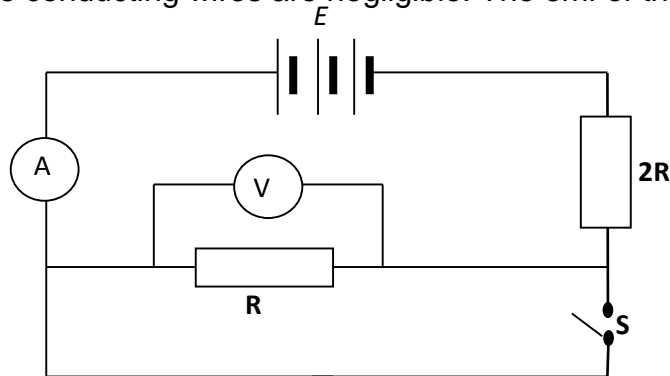
4. In the circuit represented below, the resistance of the variable resistor is decreased.



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

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

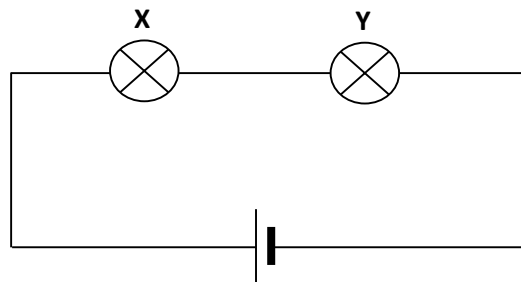
5. In the circuit diagram below, the internal resistance of the battery and the resistance of the conducting wires are negligible. The emf of the battery is E .



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

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

6. Which ONE of the following is the unit of measurement for the rate of flow of charge?
- A watt
 B coulomb
 C volt
 D ampere
7. The diagram below shows two light bulbs, X and Y, connected in series to a battery with negligible internal resistance.



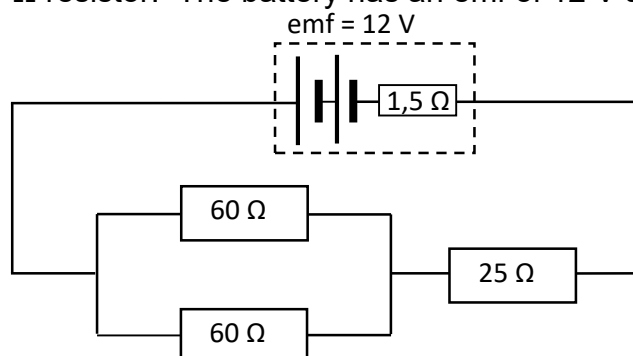
If bulb X glows brighter than bulb Y, then the ...

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

STRUCTURED QUESTIONS

QUESTION 1

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

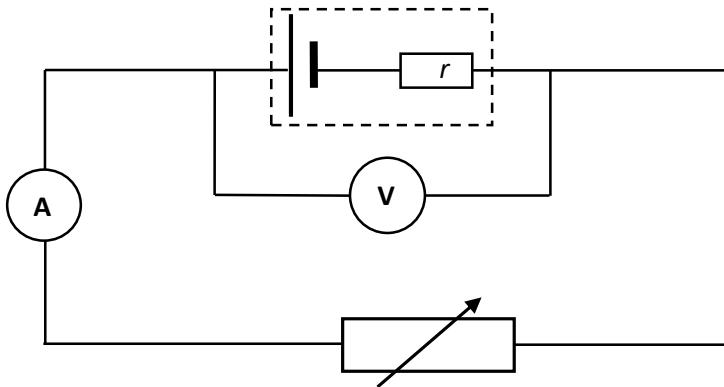


Calculate the:

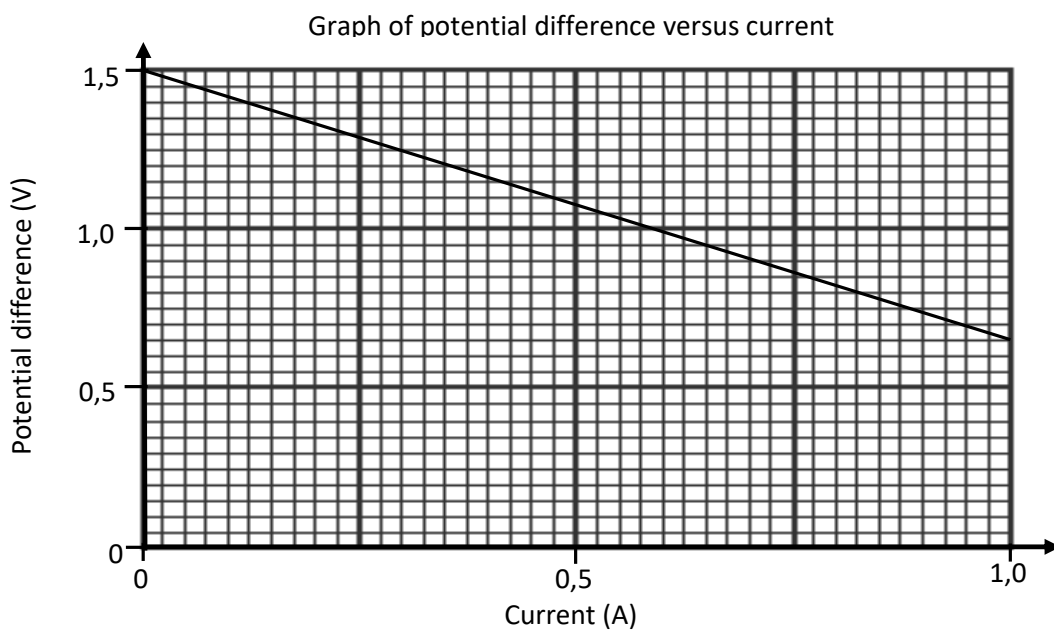
- 1.1 Equivalent resistance of the parallel combination
 1.2 Total current in the circuit
 1.3 Potential difference across the parallel resistors

QUESTION 2

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



The results obtained are shown in the graph below.

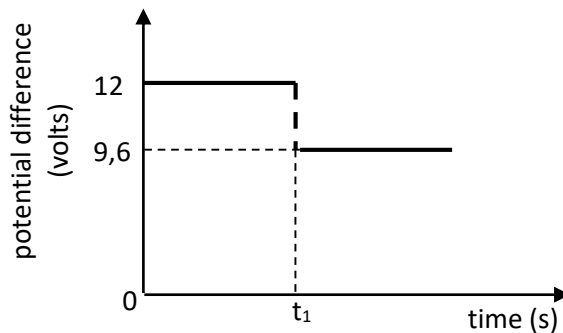
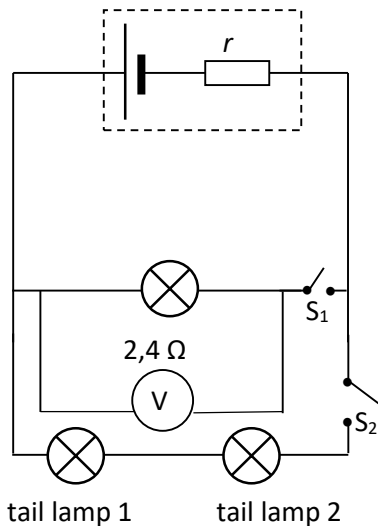


- 2.1 Use the graph to determine the emf of the battery.
- 2.2 Calculate the gradient of the graph.
- 2.3 Which physical quantity is represented by the magnitude of the gradient of the graph?
- 2.4 How does the voltmeter reading change as the ammeter reading increases? Write down INCREASES, DECREASES or REMAINS THE SAME. Use the formula $\text{emf} = IR + Ir$ to explain the answer.

QUESTION 3

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

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



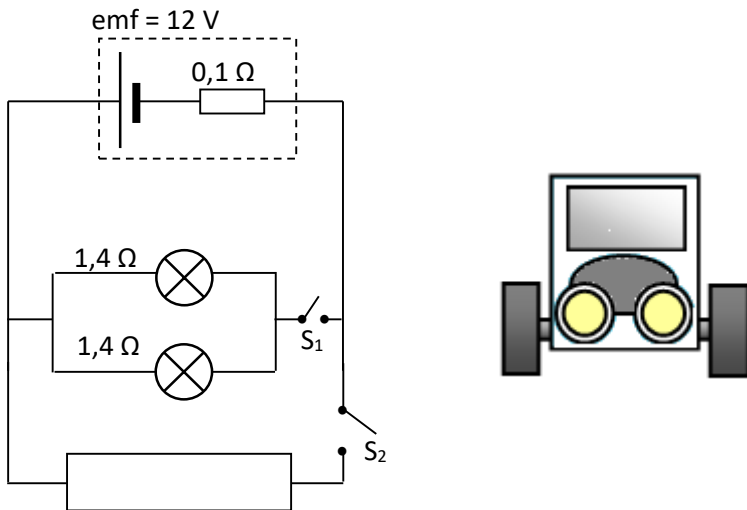
- 3.1 Use the graph to determine the emf of the battery.
- 3.2 WITH ONLY SWITCH S_1 CLOSED, calculate the following:
 - 3.2.1 Current through the headlamp
 - 3.2.2 Internal resistance, r , of the battery

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

- 3.3 Calculate the resistance of each tail lamp.
- 3.4 How will the reading on the voltmeter be affected if the headlamp burns out? (Both switches S_1 and S_2 are still closed.)
Write down only INCREASES, DECREASES or REMAINS THE SAME. Give an explanation.

QUESTION 4

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



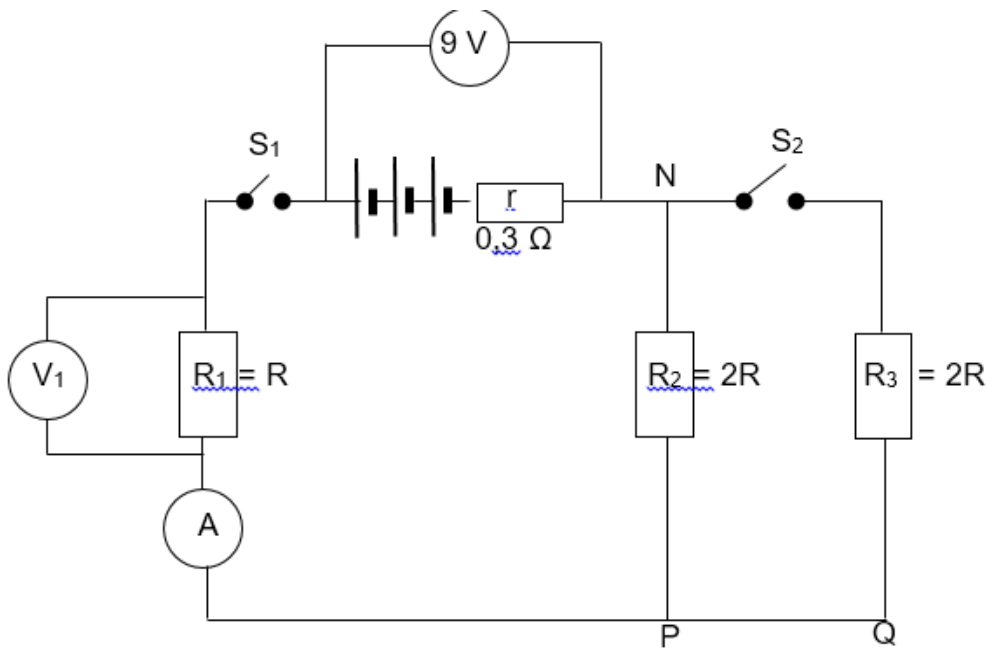
- 4.1 State Ohm's law in words.
- 4.2 With only switch **S₁** closed, calculate the following:
- 4.2.1 Effective resistance of the two headlights
- 4.2.2 Potential difference across the two headlights
- 4.2.3 Power dissipated by one of the headlights

Ignition switch **S₂** is now closed (whilst **S₁** is also closed) for a short time and the starter motor, with VERY LOW RESISTANCE, rotates.

- 4.3 How will the brightness of the headlights be affected while switch **S₂** is closed? Write down INCREASES, DECREASES or REMAINS THE SAME. Fully explain how you arrived at the answer.

QUESTION 5

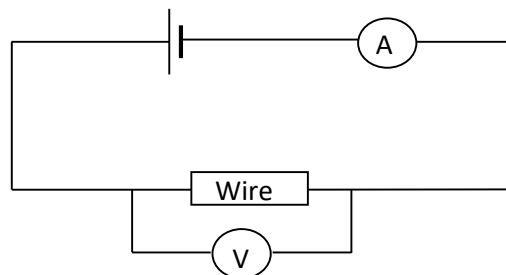
Three resistors, R_1 , R_2 and R_3 , are connected to a battery, as shown in the circuit diagram below. The internal resistance of the battery is 0,3 Ω. The resistance of R_2 and R_3 is equal. The resistance of R_1 is half that of R_2 . When both switches are open, the voltmeter across the battery reads 9 V



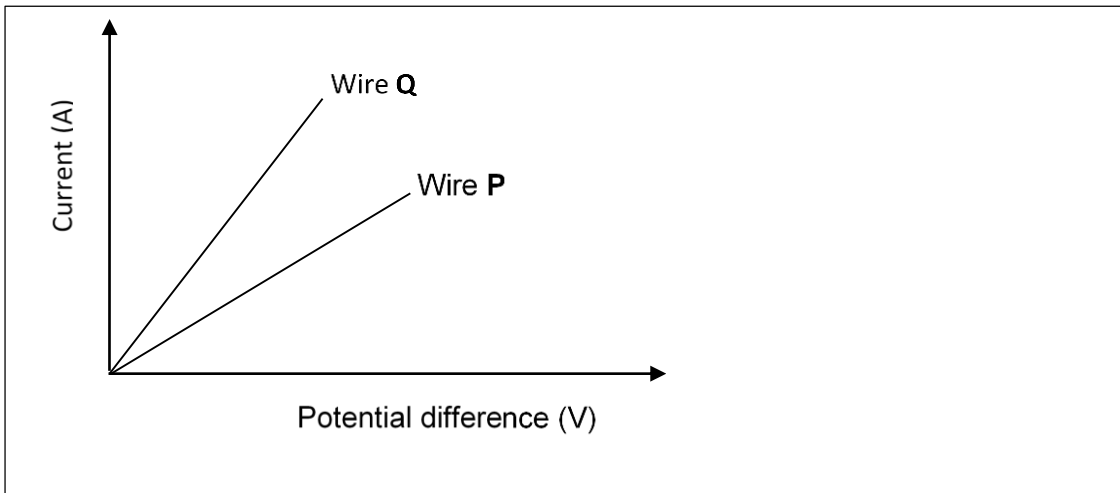
- 5.1 What is the value of the emf of the battery? Give a reason for your answer.
- 5.2 When **only switch S₁ is closed**, the reading on the ammeter is 3 A. Calculate the resistance of R₁.
- Both switches **S₁** and **S₂** are now closed.
- 5.3 How will the resistance of the circuit change? Write down only INCREASES, DECREASES or REMAINS THE SAME.
- 5.4 A conducting wire of negligible resistance is connected between points **Q** and **N**. What effect will this have on the 'lost volts'? Explain the answer.

QUESTION 6

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



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

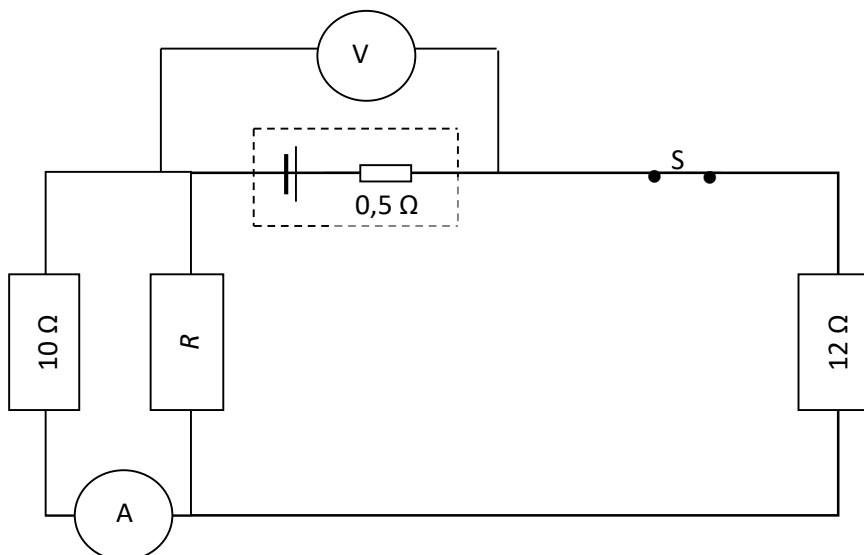


6.1 Name TWO variables that the learners would have controlled in each of the experiments.

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

QUESTION 7

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



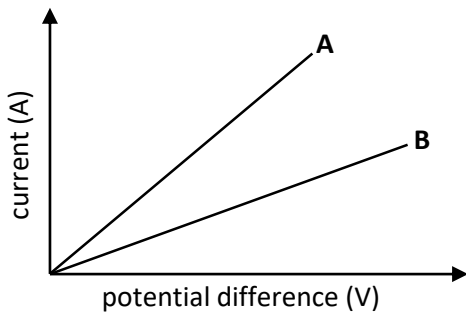
7.1 Calculate the reading on ammeter A . Show ALL your calculations.

7.2 Determine the resistance of resistor R .

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

QUESTION 8

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



The learners are supplied with the following apparatus:

6 V battery

Voltmeter

Ammeter

Rheostat

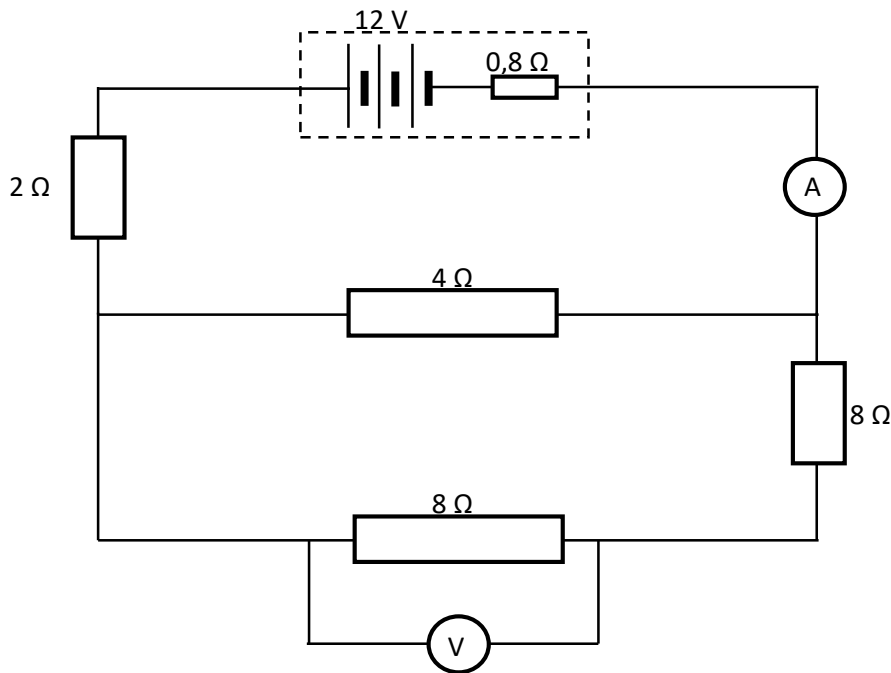
Resistors **A** and **B**

Conducting wires

- 8.1 Draw a circuit diagram to show how the learners must use the above apparatus to obtain each of the graphs shown above.
- 8.2 Write down ONE variable that must be kept constant during this investigation.
- 8.3 Which ONE of **A** or **B** has the higher resistance? Give an explanation for the answer.

QUESTION 9

In the circuit diagram below, the battery has an emf of 12 V and an internal resistance of $0,8 \Omega$. The resistance of the ammeter and connecting wires may be ignored.

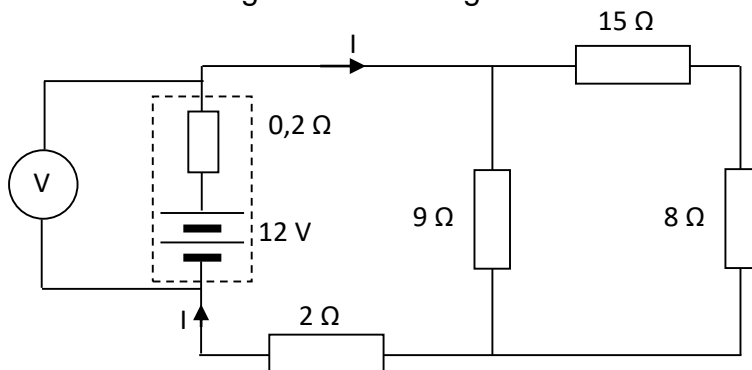


Calculate the:

- 9.1 Effective resistance of the circuit
- 9.2 Reading on the ammeter
- 9.3 Reading on the voltmeter

QUESTION 10

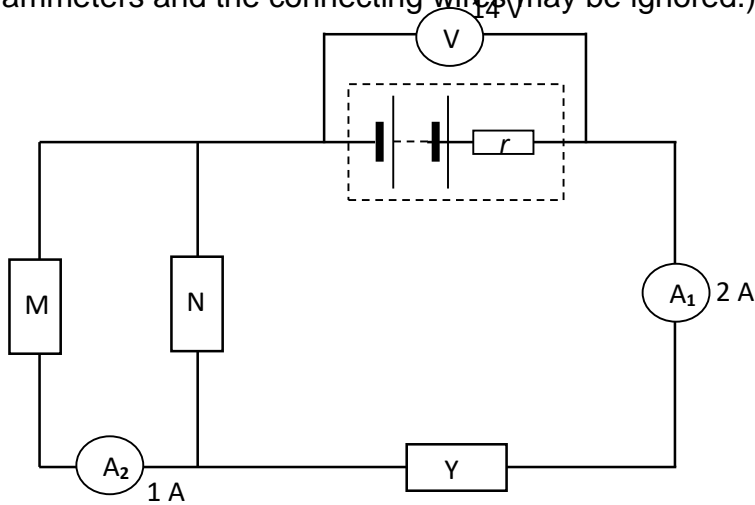
The battery in the circuit below has an emf of 12 V and an internal resistance of $0,2 \Omega$. The resistance of the connecting wires can be ignored.



- 10.1 Calculate the current, I , that flows through the battery.
- 10.2 How will the reading on the voltmeter be affected if the 9Ω resistor is removed and replaced with a conducting wire of negligible resistance? Explain your answer.

QUESTION 11

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



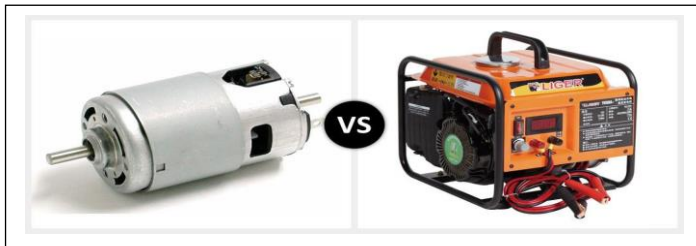
- 11.1 State Ohm's law in words.
- 11.2 How does the resistance of **M** compare with that of **N**? Explain how you arrived at the answer.
- 11.3 If the emf of the battery is $17\ \text{V}$, calculate the internal resistance of the battery.
- 11.4 Calculate the potential difference across resistor **N**.
- 11.5 Calculate the resistance of **Y**.

ELECTRODYNAMICS

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

Electrical machines

1. Generator
2. Motor



MOTOR

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

Two types of motor:

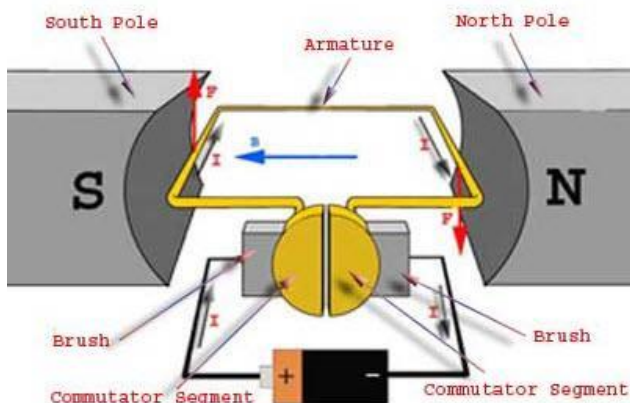
1. DC motor
2. AC motor

DC (Direct Current) current flowing in one direction

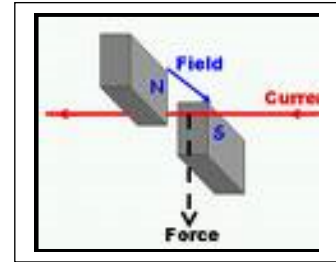
AC (Alternating Current) current that changes direction

DC MOTOR

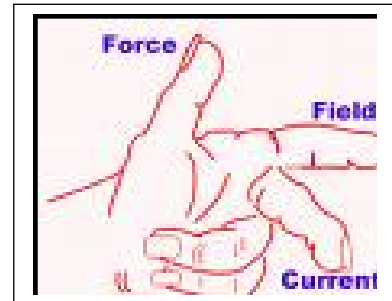
- Has split ring commutator
- DC- direct current
-



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



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



Function of the split ring

1. Changes the direction of the current every half cycle
2. Maintains constant direction of rotation of the coil

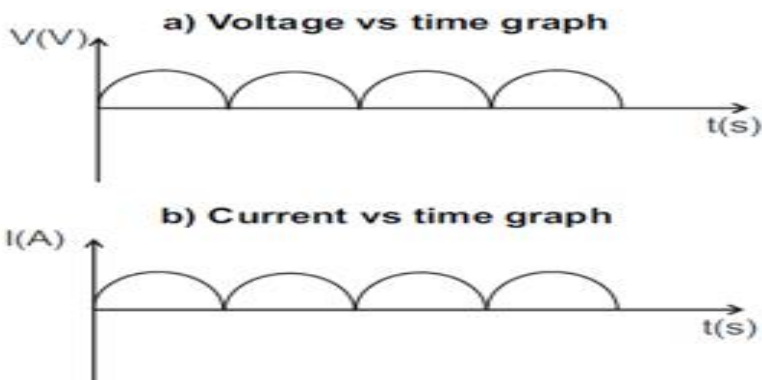
Function of carbon brush

- Makes electrical contact with the commutator

Two types of graphs:

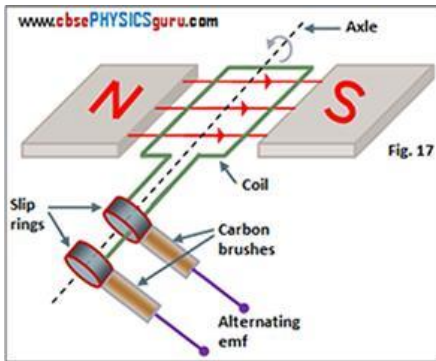
1. Potential difference vs time
2. Current vs time

D.C GRAPHS



AC MOTOR

- Has slip rings

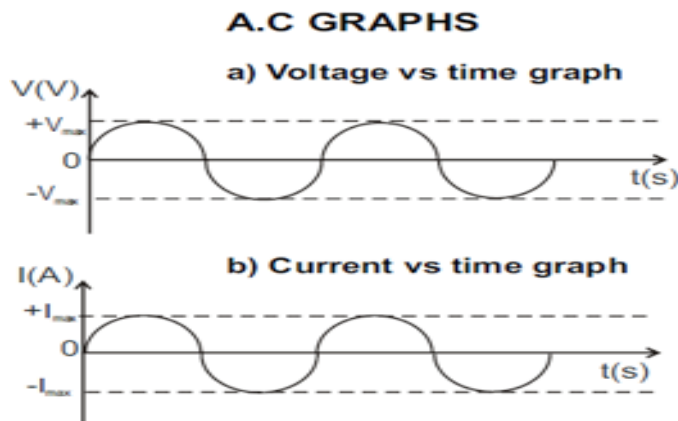


Function of a slip ring

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

Two types of graphs:

- Potential difference vs time
- Current vs time



Ways to improve efficiency of a motor

- Increase current in the coil
- Use a stronger magnet
- Increase number of turns in the coil

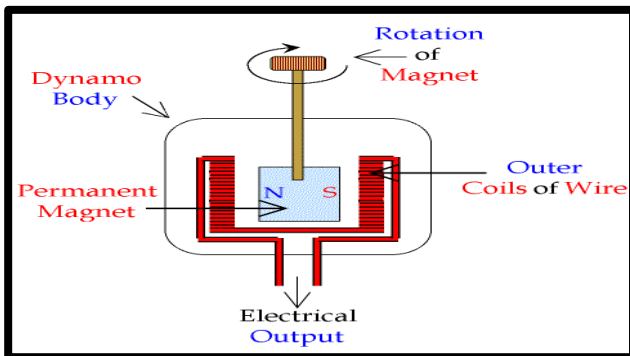
GENERATOR

Converts mechanical energy to electrical energy

Principle on which generators operate is called **electromagnetic induction** or **Faradays law**

Electromagnetic induction: is a process where the relative motion between the magnetic field and the conductor induces current in the conductor

How does it work??



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

Faradays law

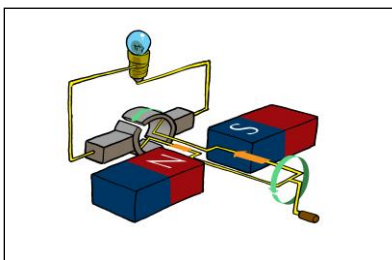
1. States that the induced emf is equal to the rate of change of magnetic flux
2. Or the induced emf is directly proportional to the rate of change of magnetic flux.
3.
$$\text{emf} = \frac{-N\Delta\Phi}{\Delta t}$$
4. Magnetic flux(Φ) is a measure of the number of field lines passing an area
5. $\Phi = BA$

Types of generators

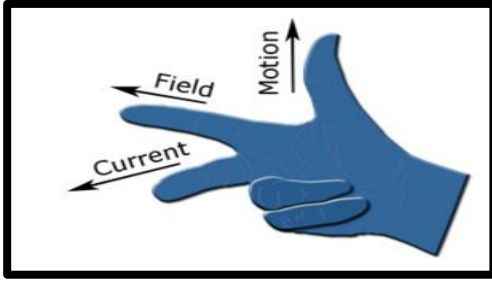
- DC generator
- AC generator

DC generator

- has split rings
- also called dynamo



Determining the direction of the induced current.

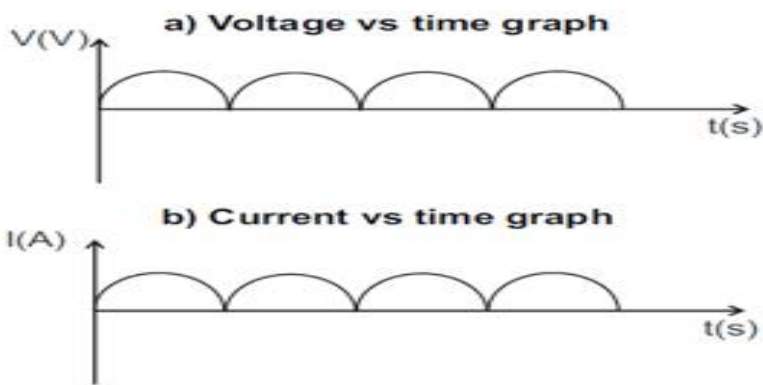


Flemings Right Hand Dynamo Rule

Two types of graphs:

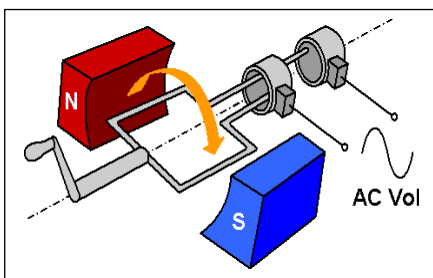
- Potential difference vs time
- Current vs time

D.C. GRAPHS



AC GENERATOR

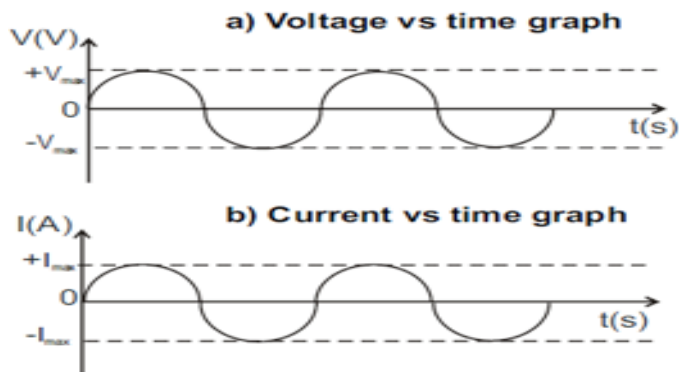
- Has slip rings
- Also called alternator



Two types of graphs:

- Potential difference vs time
- Current vs time

A.C GRAPHS



Ways to improve efficiency of a generator

- Increase the speed of rotation
- Use a stronger magnet
- Increase number of turns in the coil

Advantages of AC over DC

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

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

Uses of AC Generators

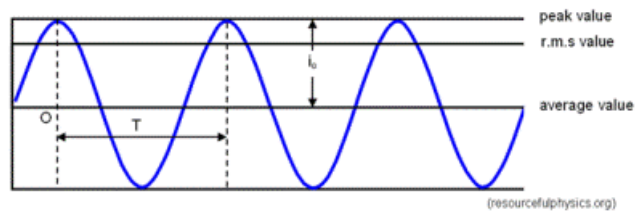
The main generators in nearly all electric power plants are AC generators. This is because a simple electromagnetic device called a transformer makes it easy to increase or decrease the voltage of alternating current. Almost all household appliances utilize AC.

Uses of DC Generators

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

Alternating current

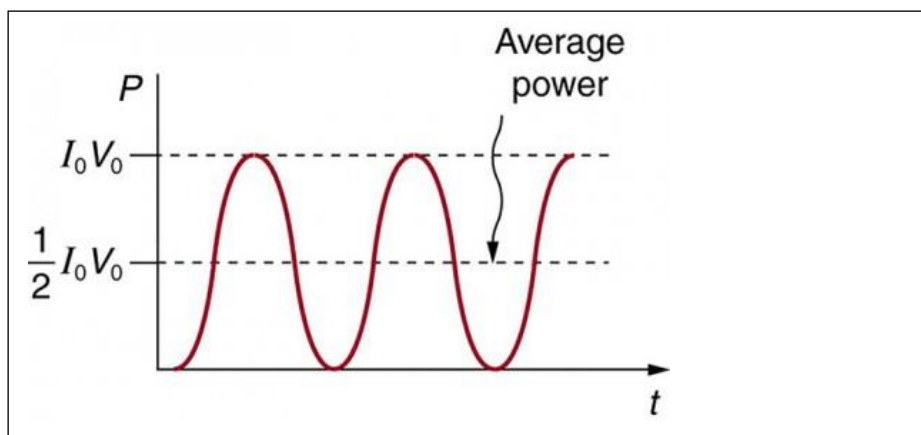
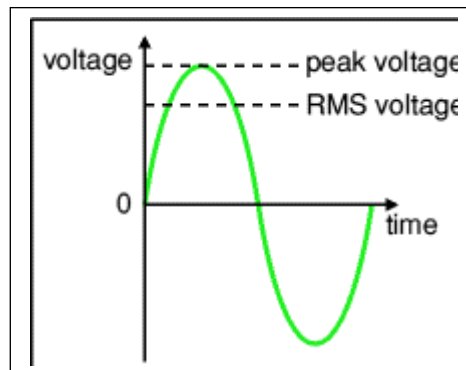
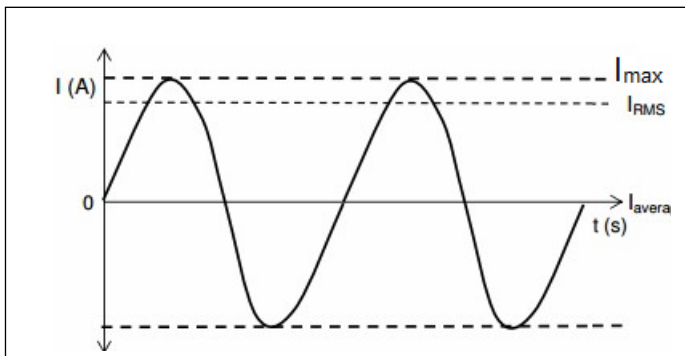
- Define the term *rms* for an alternating voltage or an alternating current. The rms value of AC is the DC potential difference/current which dissipates the same amount of energy as AC.



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

Solve problems using $P_{\text{ave}} = I_{\text{rms}} V_{\text{rms}} = \frac{1}{2} I_{\text{max}} V_{\text{max}}$ (for a purely resistive circuit),

$$P_{\text{ave}} = I_{\text{rms}}^2 R \text{ and } P_{\text{ave}} = \frac{V_{\text{rms}}^2}{R}$$

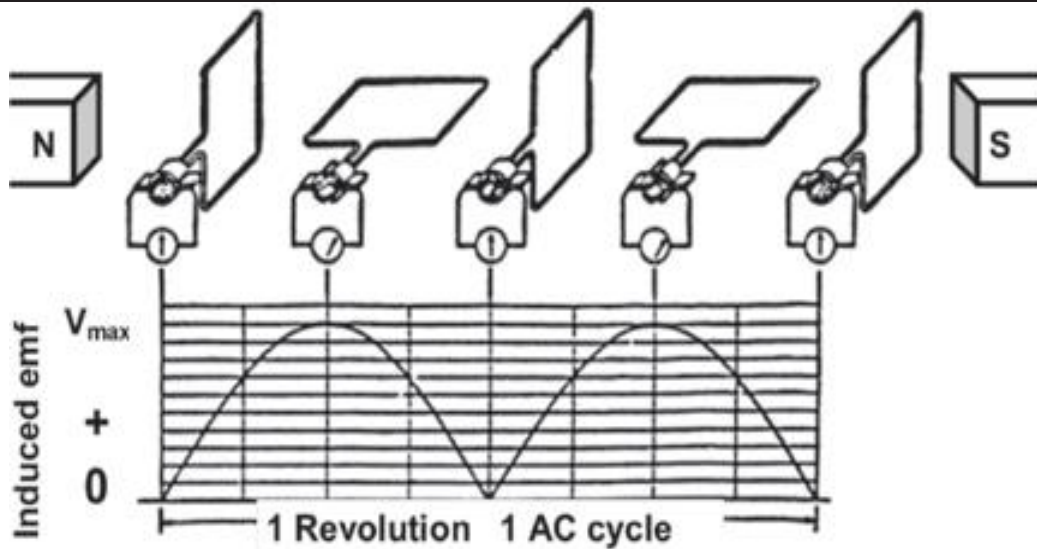


Note that V_{av} and I_{ave} are both zero so they convey little information about the actual behavior of V and I . a more useful and appropriate type of average is called rms (root mean squared) is used.

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

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

The direct current (DC) cycle



When the coil is vertical

- ab and cd are parallel to the normal to the magnetic field, and do not cut through the magnetic field
- there is no changing magnetic flux
- no emf or current is induced in the coil
- $V = 0 \text{ V}$ and $I = 0 \text{ A}$

When the coil is horizontal

- ab and cd are perpendicular to the normal to the field, and therefore cut through the magnetic field
- there is a changing magnetic flux
- emf and current are induced in the coil
- $V = V_{\text{max}}$ and $I = I_{\text{max}}$
- The emf and current are always positive.

Differences between a motor and a generator

An electric motor and an electric generator are basically the same device. The primary difference is in the case of a motor, electricity is used to turn it, whereas in the case of a generator, turning it mechanically generates electricity.

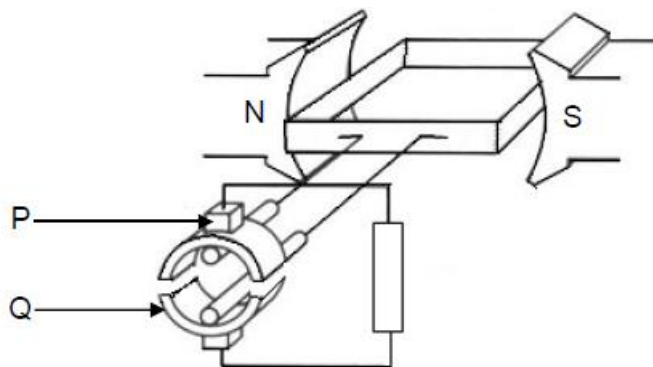
Direct Current (DC) Motors	Direct Current (DC) Generators
Coil, Split ring, Carbon brush, Battery	
<ul style="list-style-type: none"> • Connected to a battery. The battery is a source of electric energy. 	<ul style="list-style-type: none"> • NOT connected to a battery.

<ul style="list-style-type: none"> • Converts electrical energy to mechanical energy. 	<ul style="list-style-type: none"> • Converts mechanical energy to electrical energy.
<ul style="list-style-type: none"> • The magnetic fields of the magnets and those around the current-carrying conductor, interact. • The resultant magnetic field exerts a magnetic force on the coil. • The coil turns due to the resultant magnetic force acting on it. 	<ul style="list-style-type: none"> • The coil is turned mechanically (e.g. by steam, flowing water or wind). • When the coil cuts through the magnetic field of the magnets, there is a change in the magnetic flux. • According to Faraday's Law of Electromagnetic Induction, a change in magnetic flux induces an emf across the ends of the coil and current is induced in the coil.

STRUCTURED QUESTIONS

QUESTION 1 March 2013(DBE)

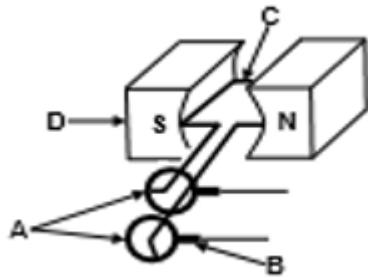
AC generators and DC generators differ in their construction and the type of current they deliver. The simplified sketch below represents a DC generator.



- 1.1 Which component (P or Q) enables this generator to produce DC (1)
- 1.2 What structural change must be made to this generator to change it to an AC Generator? (1)
- 1.3 Briefly explain why Eskom prefers using AC instead of DC for the long distance transmission of electricity? (2)
- 1.4 An AC generator delivers $240V_{rms}$ to a 60W light bulb. The peak current in the light Bulb is 0,35A. Calculate the:
- 1.4.1 rms current in the light bulb (3)
- 1.4.2 Resistance of the light bulb (3)

QUESTION 2 Nov 2013 (DBE)

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



2.1 Write down the name of component:

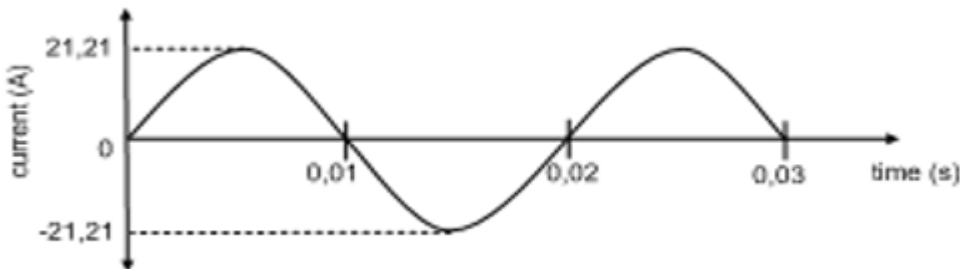
2.1.1 A (1)

2.1.2 B (1)

2.2 Write down the function of component B (1)

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

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



2.4 How many rotations are made by the coil in 0,03 seconds? (1)

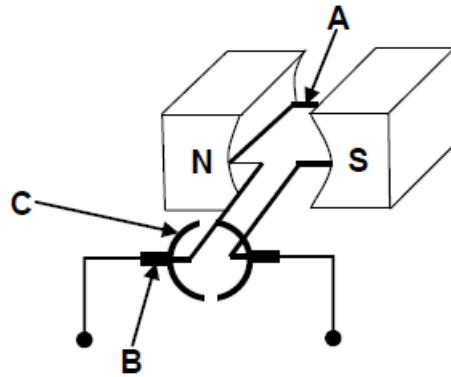
2.5 Calculate the frequency of the alternating current. (3)

2.6 Will the plane of the coil be PERPENDICULAR or PARALLEL to the magnetic field at $t = 0,015s$? (1)

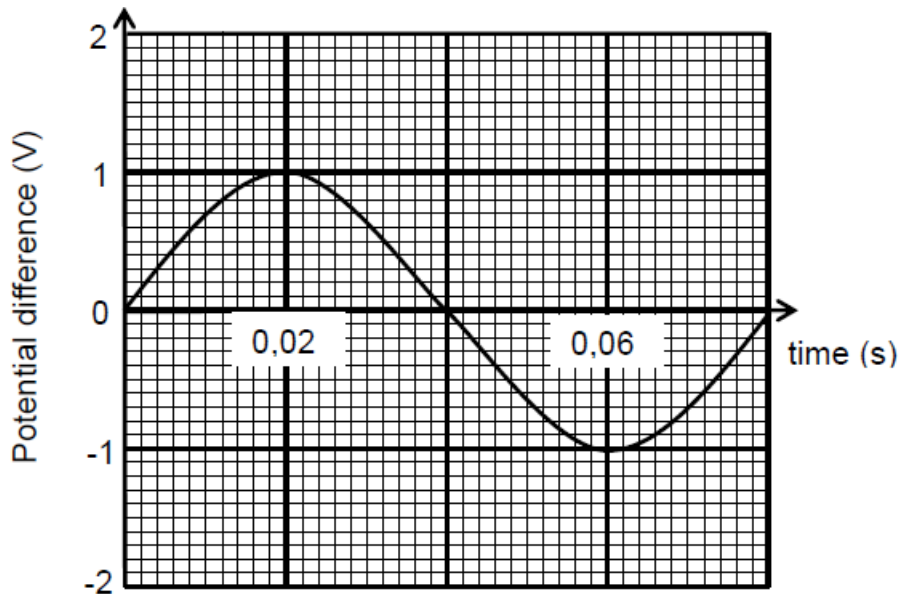
2.7 If the generator produces a maximum potential difference of 311V, calculate its average power output. (5)

QUESTION 3 March 2014(DBE)

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



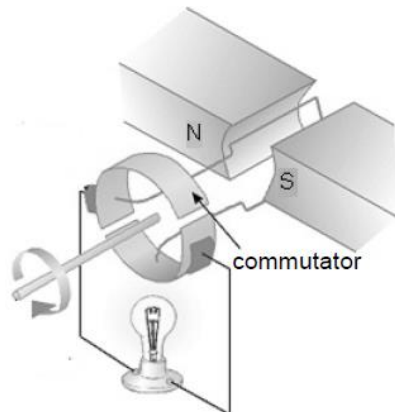
- 3.1.1 Name the components labelled A, B and C
 Write down only the name of the component next to the letter (A-C) (3)
- 3.1.2 Write down the function of the component labelled B (1)
- 3.1.3 Is this motor an AC motor or a DC motor? (1)
- 3.1.4 Give a reason why component A experiences a magnetic force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



- 3.2.1 Calculate the induced rms potential difference (3)
- 3.2.2 The coil is now rotated at twice the original speed. Write down the period of the new wave (2)
- 3.2.3 Calculate the average power generated if the generator produces a maximum current of 2A (4)

QUESTION 4 Nov 2014(DBE)

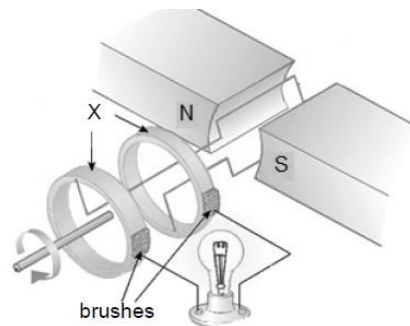
The diagram below represents a simplified version of an electrical machine used to light up a bulb.



4.1 Name the principle on which the machine operates? (1)

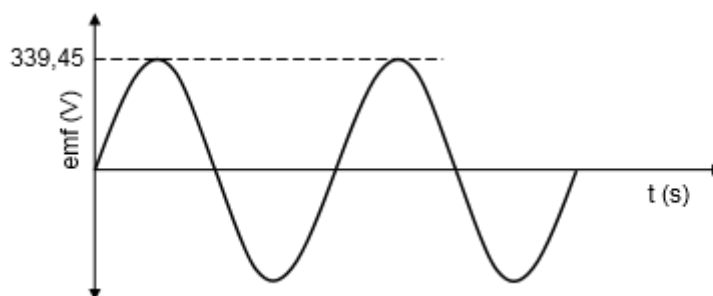
4.2 State one way in which to make this bulb burn brighter (1)

Some changes have been made to the machine and a new device is obtained as shown below



4.3 Name part X in the new device (1)

4.4 The graph of output emf versus time obtained using the device in Question 4.3 is shown below

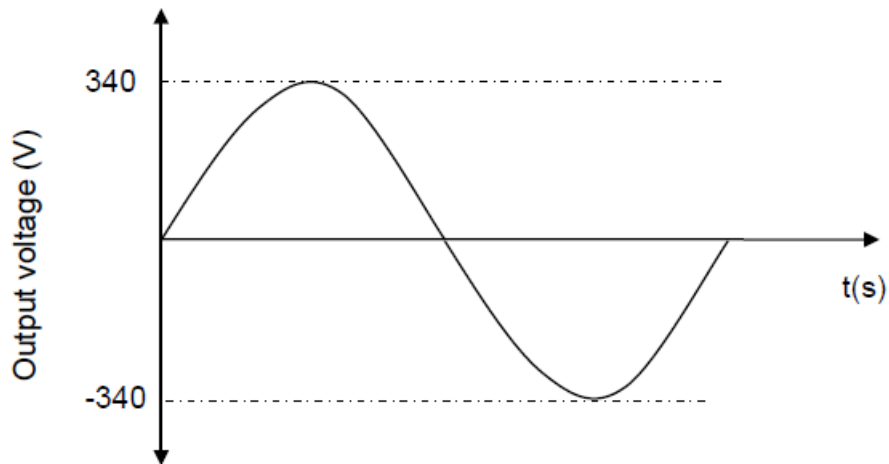


4.4.1 Define the term *root mean square value* of an AC voltage (2)

4.4.2 Calculate the rms voltage (3)

QUESTION 5 March 2015(DBE)

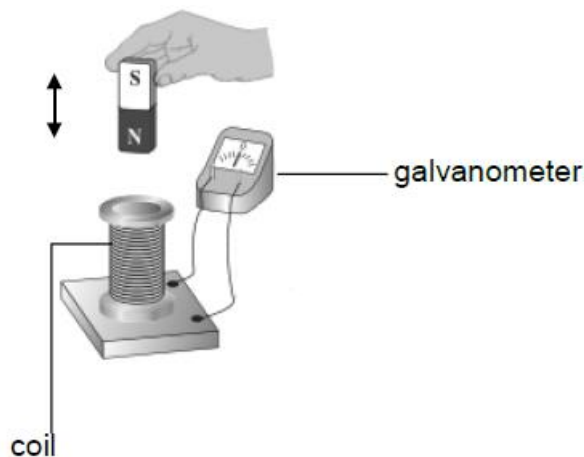
The graph below shows the output voltage from a household AC generator for one cycle of rotation of the coils.



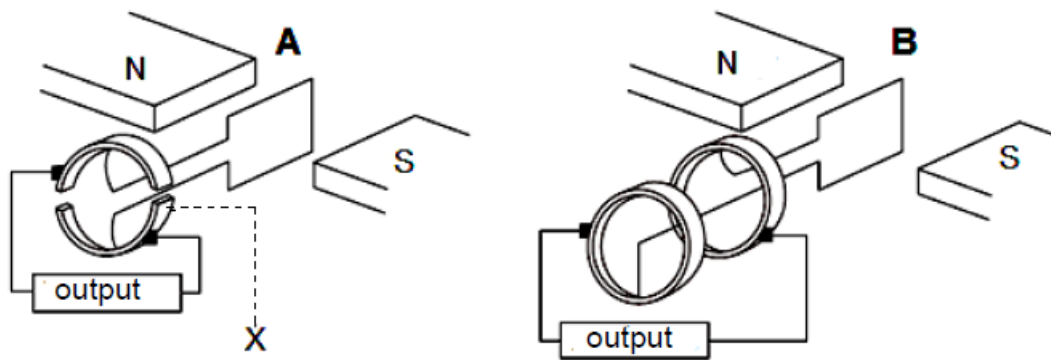
- 5.1 A 100 W light bulb is connected to this generator and it glows at its maximum brightness. Use the information from the graph to calculate the:
- 5.1.1 Resistance of the bulb (5)
- 5.1.2 rms current through the bulb (3)
- 5.2 Give ONE reason why the AC voltage is preferred to DC voltage for everyday use (1)

QUESTION 6 Nov 2015 (DBE)

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



- 6.1.1 Briefly describe how the magnet must be moved in order to obtain a LARGE deflection on the galvanometer (2)
- The two devices A and B, below operate on the principle described in QUESTION 6.1.1 above



6.1.2 Write down the name of the principle (1)

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

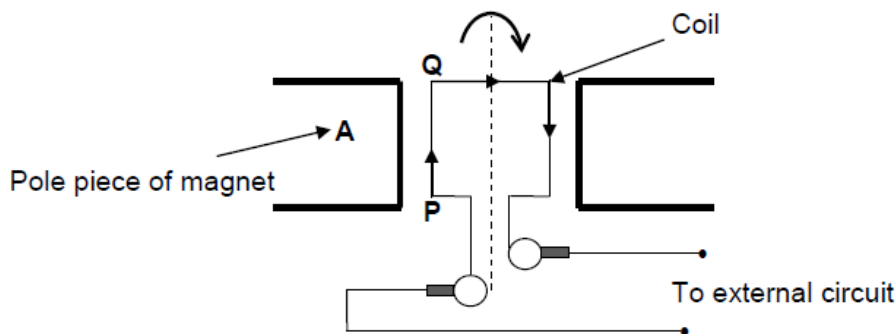
6.2 A 220V, AC voltage is supplied from a wall socket to an electric kettle of resistance $40,33\Omega$. Wall sockets provide rms voltages and currents
Calculate the:

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

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

QUESTION 7 March 2016(DBE)

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



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

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

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

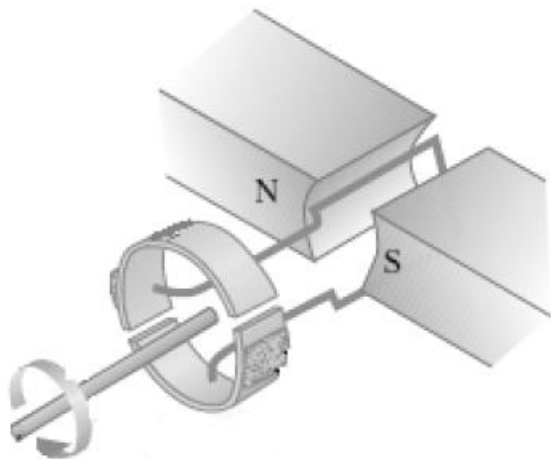
7.2 An electrical device is connected to a generator which produces an rms potential difference of 220V. The maximum current passing through the device is 8 A.
Calculate the:

7.2.1 Resistance of the device (5)

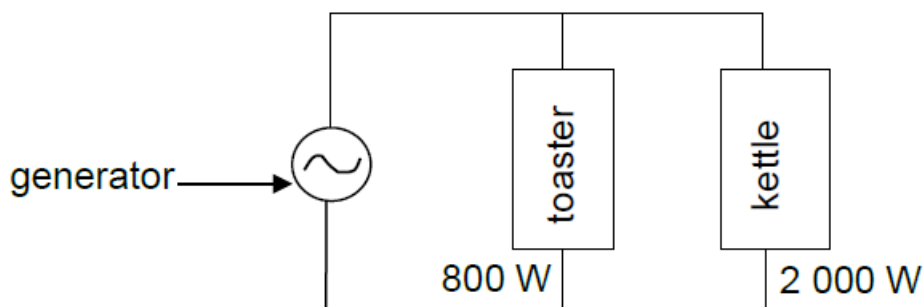
7.2.2 Energy the device consumes in two hours (5)

QUESTION 8 Nov 2016 (DBE)

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



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



The toaster is rated at 800 W , while the kettle is rated at 2000 W . Both are working under normal conditions.

Calculate the:

- 8.2.1 rms current through the toaster (3)
- 8.2.2 Total rms current delivered by the generator (4)

MATTER AND MATERIALS: PHOTOELECTRIC EFFECT & SPECTRA

TERMS, DEFINITIONS AND FORMULAE	
Photoelectric effect	Emission of electrons from the surface of a metal by radiation or when light shines onto the metal.

Frequency	The number of vibrations / waves per second Symbol: f Unit: hertz (Hz) or per second (s ⁻¹)
Wavelength	The distance between two consecutive points in phase. Symbol: λ Unit: metre (m)
Wave equation for light waves	The speed of light equals its frequency multiplied by its wavelength. c = fλ
Period	The time taken for one vibration / wave. $T = \frac{1}{f}$ Symbol: T Unit: seconds (s)
Threshold frequency	The minimum FREQUENCY of light needed to emit electrons from a specific metal surface. Symbol: f ₀ Unit: hertz (Hz)
Work function	The minimum ENERGY needed to remove an electron from the surface of a specific metal. Symbol: W ₀ Unit: joule (J) The work function of a metal is directly proportional to the threshold frequency of light: W ₀ = hf ₀
Photons	The 'packets' of energy or quanta (singular: quantum) of which light consists.
Photoelectrons	Electron emitted by light from the surface of a metal.
Energy of a photon	The energy of a photon is directly proportional to the frequency of the incident light: E ∝ f E = hf E: energy in joule (J) h: Planck's constant (6,63 x 10 ⁻³⁴ Js) f: frequency in hertz (Hz)
Kinetic energy of photoelectrons	Kinetic energy = energy of incident photon – work function E _k = hf – W ₀ OR E = W ₀ + E _k OR hf = hf ₀ + ½mv ²
Continuous spectrum	The type of spectrum formed when white light passes through a triangular prism.
Line emission spectrum	The type of spectrum formed when electrons in an atom in the excited state falls back to the ground state (or to a lower energy level) emitting light of certain frequencies. OR The type of spectrum formed when light emitted by a HOT GAS (when electric current passes through a gas or when a gas is heated) passes through a triangular prism or is viewed through a diffraction grating.

Line absorption spectrum	The type of spectrum formed when white light passes through a COLD GAS and atoms in the gas absorb characteristic frequencies. (A continuous spectrum in which some of the frequencies are missing and thus appear as black lines in the spectrum.)
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EXPLAINING THE PHOTOELECTRIC EFFECT:

- When a photon with energy $E = hf$ strikes a metal surface, all the energy of the photon is transferred to an electron.
- A certain minimum amount of energy (work function) is necessary to overcome the attraction force exercised by the metal on the electron so that the electron can be released from the surface of the metal.
- If $hf < W_0$, the photon does not have enough energy to release an electron.
- If $hf = W_0$, the photon has exactly enough energy to release an electron from the metal surface. The frequency of the photon is thus equal to the threshold frequency (f_0).
- If $hf > W_0$, more than the minimum energy necessary is transferred to the electron. The extra energy ($hf - W_0$) is the kinetic energy (E_k) with which the electron moves.

IMPORTANT FACTS

- Effect of FREQUENCY on the photoelectric effect:
 - Frequency of light determines whether the photoelectric effect will take place.
 - The frequency of light incident on a metal surface must be equal to or higher than the threshold frequency for the photoelectric effect to take place.
 - The kinetic energy (E_k) of the photoelectrons depends on the frequency of the incident light. Any increase of the frequency above the threshold frequency of the metal will lead to an increase in E_k of the photoelectrons.
- Effect of INTENSITY on the photoelectric effect:
 - Once the frequency is high enough for the photoelectric effect to take place, a HIGHER INTENSITY CAN INCREASE THE NUMBER OF PHOTOELECTRONS.
 - Light with a higher intensity (degree of brightness), or shining light for a longer period onto the metal surface, will NOT result in the photoelectric effect IF THE FREQUENCY OF THE INCIDENT LIGHT IS LOWER THAN THE THRESHOLD FREQUENCY.

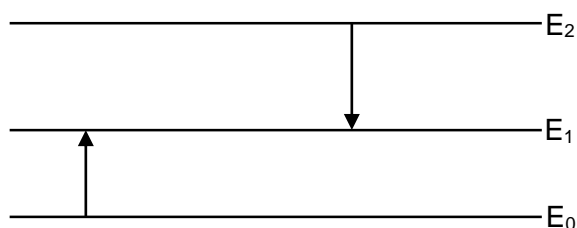
TYPICAL QUESTIONS

ONE WORD ITEMS

1. The minimum energy needed to remove electrons from the surface of a metal
2. The phenomenon that gives experimental proof of the particle nature of light
3. A particle of light whose energy is given by the equation $E = hf$
4. The 'packets of energy' (quanta) of which light consists
5. The type of line spectrum observed when electrons in an atom move from the excited state to the ground state
6. The 'packets of energy' making up electromagnetic radiation
7. The minimum energy needed to eject an electron from a metal surface
8. The tiny 'packets' (quanta) of energy that light consists of
9. The number of complete waves that pass a point in one second
10. The minimum frequency of light needed to eject electrons from the surface of a metal

MULTIPLE-CHOICE QUESTIONS

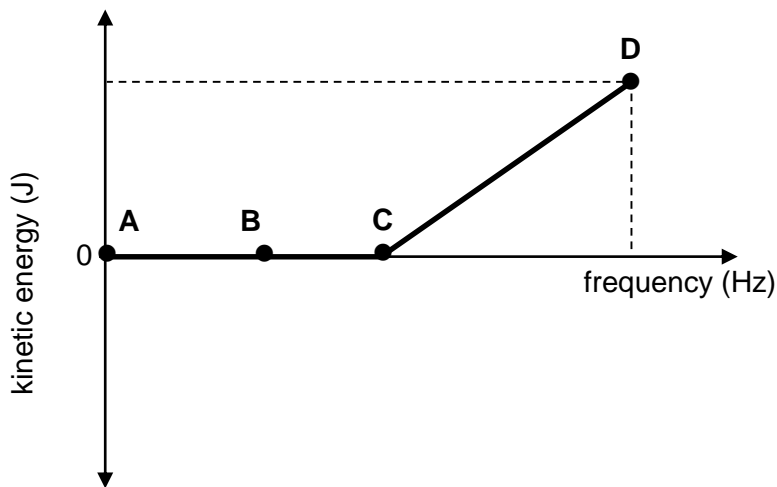
1. The energy level diagram for an element is shown below. E_0 represents the ground state. The energy change from E_0 to E_1 is smaller than that for E_2 to E_1 .



The electron transition from E_2 to E_1 corresponds to a green line in the element's spectrum. The transition E_0 to E_1 corresponds to ...

- A absorption of green light.
- B emission of green light.
- C emission of red light.
- D absorption of red light.

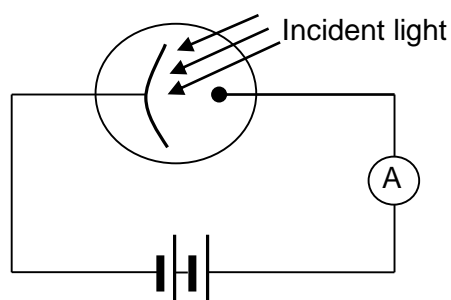
2. When light shines on a metal plate in a photocell, electrons are emitted. The graph below shows the relationship between the kinetic energy of the emitted photoelectrons and the frequency of the incoming light.



Which ONE of the points (A, B, C or D) on the graph represents the threshold frequency?

- A A
B B
C C
D D
3. A line emission spectrum is formed when electrons in an atom, that moves from
A higher to lower energy levels, emit energy as light.
B higher to lower energy levels, absorb light energy.
C lower to higher energy levels, emit energy as light.
D lower to higher energy levels, absorb light energy.
4. A neon tube lights up when a large external voltage is applied across it. Which ONE of the following best describes the type of spectrum observed when the gas inside the tube is viewed through a diffraction grating?
A Continuous
B Absorption
C Line emission
D Line absorption
5. When a clean metal plate is irradiated with light of sufficient energy, photoelectrons are emitted. The INTENSITY of the light is now increased. This change will ...
A increase the number of photoelectrons emitted per second.
B decrease the number of photoelectrons emitted per second.
C increase the kinetic energy of the emitted photoelectrons.

- D decrease the kinetic energy of the emitted photoelectrons.
6. Which ONE of the following descriptions best explains the formation of a line emission spectrum? A line emission spectrum is formed when ...
- A white light passes through a cold gas.
 - B white light passes through a triangular prism.
 - C electrons in the ground state move to a higher energy level.
 - D electrons in the excited state move to a lower energy level.
7. The diagram below shows light incident on the cathode of a photocell. The ammeter registers a reading.



Which ONE of the following correctly describes the relationship between the intensity of the incident light and the ammeter reading?

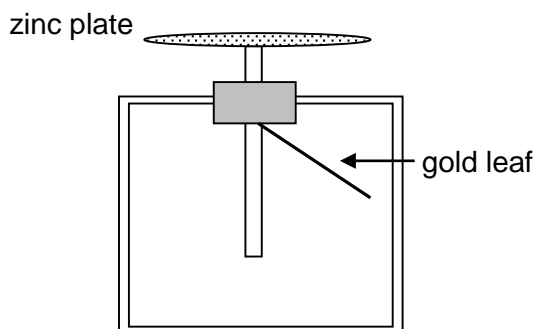
	INTENSITY	AMMETER READING
A	Increases	Increases
B	Increases	Remains the same
C	Increases	Decreases
D	Decreases	Increases

8. Which ONE of the following provides evidence that light behaves as particles?
- A Light can be diffracted.
 - B Light is refracted by a triangular prism.
 - C Light ejects electrons from a metal surface.
 - D The speed of light decreases when it travels from air to glass.

STRUCTURED QUESTIONS

QUESTION 1

The following apparatus is set up to illustrate the photoelectric effect of light. A clean piece of zinc plate is connected to the top of an electroscope. The zinc plate and the electroscope are then negatively charged. The gold leaf of the electroscope is repelled and rises.



The following observations are made:

- When bright white light from a **100 W** light bulb is shone onto the zinc plate the gold leaf does not drop down.
- When ultraviolet (UV) light from a **4 W** UV light is shone onto the zinc plate the gold leaf drops down.

- 1.1 Explain briefly why the 4 W UV light causes the leaf to drop but the more intense 100 W white light has no effect on the leaf.
- 1.2 What would be observed if a 6 W UV light is shone onto the zinc plate?
- 1.3 Explain the observation in QUESTION 1.2.
- 1.4 If the work function of zinc is $6,9 \times 10^{-19}$ J, calculate the amount of kinetic energy a photoelectron emitted from the zinc plate will have if UV light with a wavelength of 100 nm shines on the metal.

QUESTION 2

A learner wants to demonstrate the photoelectric effect. He uses a disk of zinc placed on an electroscope. The work function of zinc is $6,9 \times 10^{-19}$ J.

- 2.1 Define the concept *work function*.
- 2.2 Calculate the maximum wavelength of light that will eject electrons from the zinc.
- 2.3 The electroscope is negatively charged and then exposed to ultraviolet light from a mercury discharge lamp. One of the wavelengths of the light is 260 nm. Calculate the kinetic energy of an electron emitted from the zinc disk by a photon of this light.
- 2.4 When the student attempts the experiment with a positively charged electroscope, he finds that the ultraviolet light has no apparent effect. Explain this observation.

QUESTION 3

The work function of three metals is shown in the table below.

METAL	WORK FUNCTION (W_0) in J
Aluminium	$6,54 \times 10^{-19}$
Zinc	$6,89 \times 10^{-19}$
Silver	$7,58 \times 10^{-19}$

- 3.1 Give a reason why different metals have different work functions.
- 3.2 Light of wavelength $2,3 \times 10^{-7}$ m is shone onto a metal **X**. The average speed of the emitted electrons is $4,78 \times 10^5$ m·s⁻¹. Identify metal **X** by performing a relevant calculation.
- 3.3 What conclusion about the nature of light is drawn from the photo-electric effect?

QUESTION 4

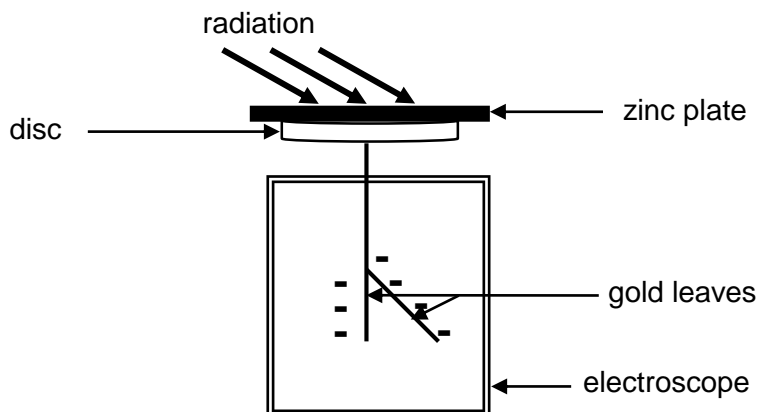
During an experiment to determine the work function of a certain metal light of different frequencies was shone on the metal surface and the corresponding kinetic energies of the photoelectrons were recorded as shown in the table below.

Frequency of incident light ($\times 10^{14}$ Hz)	Kinetic energy of photoelectrons ($\times 10^{-19}$ J)
6,6	0,7
8,2	1,6
9,2	2,2
10,6	3,0
12,0	3,8

- 4.1 Define the term *work function*.
- 4.2 Use the data in the table above to draw a graph of kinetic energy versus frequency on graph paper.
- 4.3 Extrapolate your graph to cut the X-axis.
 - 4.3.1 What is the frequency at the point of intercept?
 - 4.3.2 What term is used to describe this frequency?
- 4.4 Use your graph to determine the work function of the metal.

QUESTION 5

A group of learners performs an investigation to compare the effect of two types of radiation on the emission of photoelectrons from zinc. They place a zinc plate on top of the disc of a negatively charged electroscope. Ultraviolet and red light are shone alternately onto the zinc plate as shown below, with the electroscope fully charged in each case



They record the following observations:

RADIATION	OBSERVATION
Ultraviolet light	Gold leaves collapse.
Red light	No effect on the deflection of gold leaves.

- 5.1 Write down an INVESTIGATIVE QUESTION for this investigation.
- 5.2 Explain the observation made for ultraviolet light.
- 5.3 What conclusion can be drawn from this investigation?

The following safety precaution is printed on the ultraviolet light source:
OVEREXPOSURE TO ULTRAVIOLET LIGHT IS A HEALTH RISK

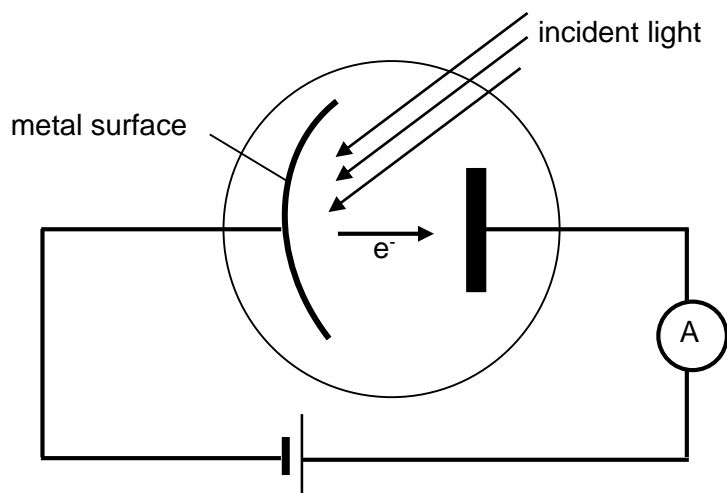
- 5.4 Name ONE health risk associated with overexposure to ultraviolet light.
- 5.5 The learners have access to the following information:

Work function of zinc	$6,88 \times 10^{-19} \text{ J}$
Frequency of ultraviolet light	$7,89 \times 10^{14} \text{ Hz}$
Frequency of red light	$4,29 \times 10^{14} \text{ Hz}$

- 5.5.1 Define the term *work function* of a metal.
- 5.5.2 Name ONE type of electromagnetic radiation with a higher frequency than that of ultraviolet light.
- 5.5.3 Use a calculation to explain why red light fails to emit photoelectrons from the surface of the zinc plate.

QUESTION 6

In the diagram shown below, electrons are released from a metal plate when light of a certain frequency is shone on its surface.



6.1 Name the phenomenon described above.

The frequency of the incident light on the metal plate is $6,16 \times 10^{14}$ Hz and electrons are released with a kinetic energy of $5,6 \times 10^{-20}$ J.

6.2 Calculate the:

6.2.1 Energy of the incident photons

6.2.2 Threshold frequency of the metal plate

6.3 The brightness of the incident light is now increased. What effect will this change have on the following: (Write down only INCREASES, DECREASES or REMAINS THE SAME)

6.3.1 The reading on the ammeter
Explain the answer.

6.3.2 The kinetic energy of the released photoelectrons
Explain the answer.

QUESTION 7

A fully automatic camera has a built-in light meter. When light enters the light meter, it strikes a metal object that releases electrons and creates a current.

7.1 What phenomenon is described by the underlined sentence?

A metal plate is irradiated with electromagnetic radiation of wavelength 200 nm. The metal has a work function of $7,57 \times 10^{-19}$ J.

7.2 Show by calculation that the metal plate will emit photo-electrons when irradiated with radiation of this wavelength.

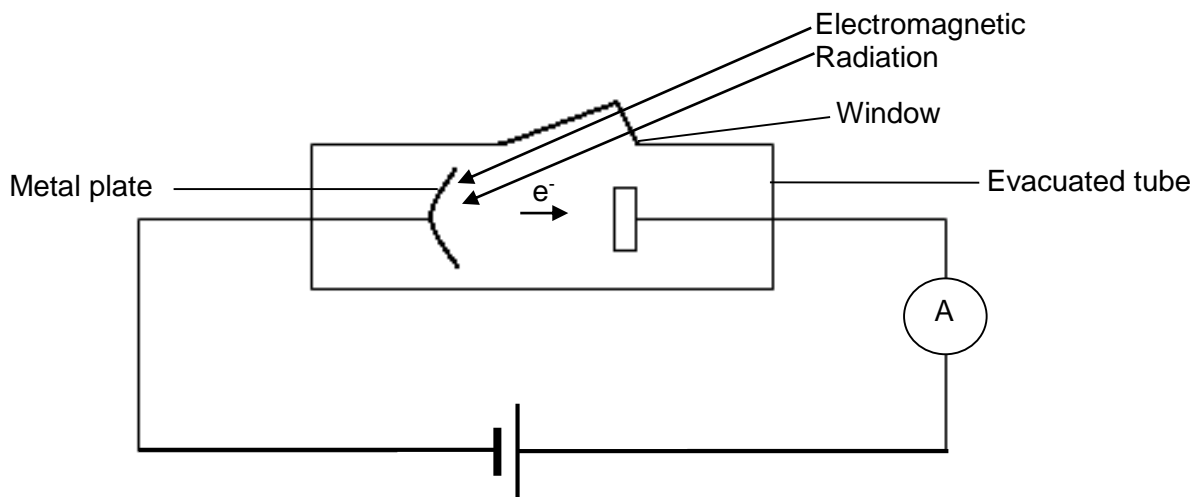
7.3 The intensity of the incident radiation on the metal plate is increased whilst maintaining a constant wavelength of 200 nm. State and explain what effect this change has on the following:

7.3.1 Energy of the emitted photo-electrons

7.3.2 Number of emitted photo-electrons

QUESTION 8

The diagram below shows a metal plate that emits electrons when a certain frequency of electromagnetic radiation is incident on it. The plate is connected to a source of potential difference and an ammeter as shown in the circuit below.



8.1 Name the phenomenon described above.

When radiation of wavelength 555 nm is incident on the metal plate, electrons are released with zero kinetic energy.

8.2 Define the term *work function* of a metal.

8.3 Calculate the work function of this metal.

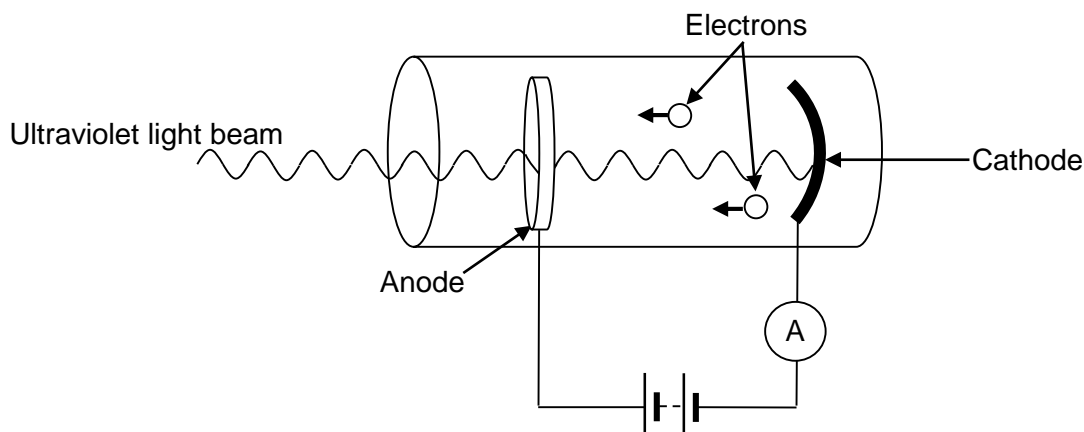
8.4 How will the reading on the ammeter change if the intensity of the electromagnetic radiation is increased? Write down only INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for your answer.

8.5 Incident radiation with a longer wavelength is now used. How will the reading on the ammeter change? Write down only INCREASES, DECREASES or REMAINS THE SAME.

QUESTION 9

The photo-electric effect has many practical applications. A photocell, such as the one below used in burglar alarm systems, is one such application.



Ultraviolet light of wavelength 100 nm is used to illuminate the photocell. When a person interrupts the ultraviolet beam, the sudden drop in current activates a switch, which sets off the alarm.

- 9.1 Define the term *threshold frequency*.
- 9.2 How will an increase in intensity of the ultraviolet light influence the ammeter reading? Write only INCREASES, DECREASES or REMAINS THE SAME. Explain your answer.
- 9.3 The work function of the metal used as a cathode in the photocell is $8,7 \times 10^{-19}$ J. Calculate the velocity at which the electrons are emitted.

QUESTION 10

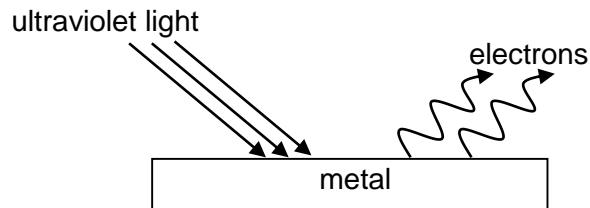
Sunlight is a major source of ultraviolet light. Overexposure to ultraviolet light could have harmful effects on humans.

- 10.1 State ONE of these harmful effects on humans.
- 10.2 Medical practitioners expose surgery equipment to ultraviolet light. Give a reason for doing this.
- 10.3 A certain metal has a work function of $3,84 \times 10^{-19}$ J. The surface of the metal is irradiated with ultraviolet light of wavelength 200 nm causing photoelectrons to be emitted.
 - 10.3.1 Calculate the energy of a photon of ultraviolet light.
 - 10.3.2 Calculate the maximum velocity of the emitted photoelectrons.
 - 10.3.3 Will photoelectrons be emitted from the surface of this metal if it is irradiated with X-rays? Give a reason for the answer.

QUESTION 11

A metal surface is illuminated with ultraviolet light of wavelength 330 nm. Electrons are emitted from the metal surface.

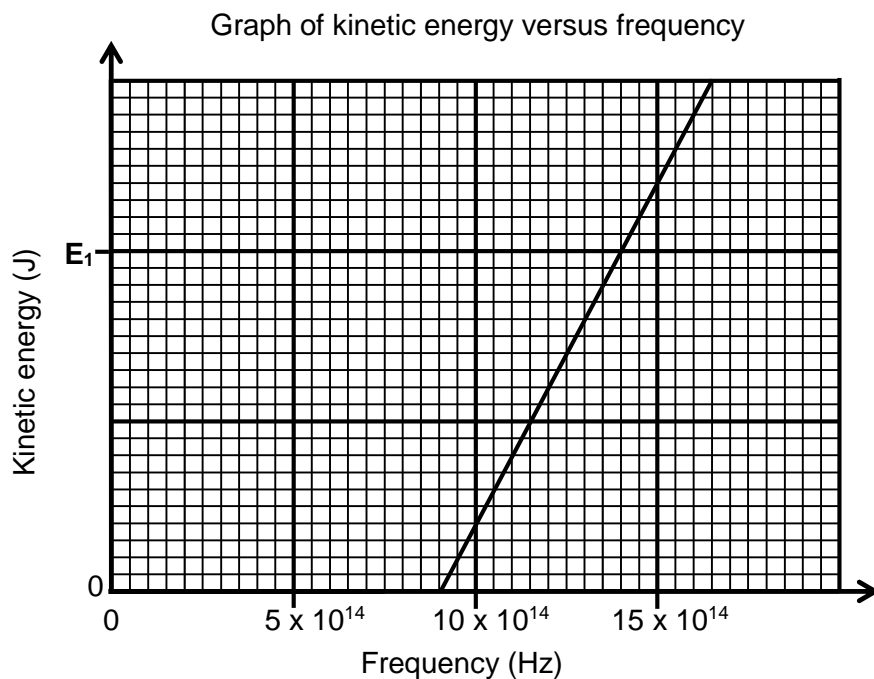
The minimum amount of energy required to emit an electron from the surface of this metal is $3,5 \times 10^{-19}$ J.



- 11.1 Name the phenomenon illustrated above.
- 11.2 Give ONE word or term for the underlined sentence in the above paragraph.
- 11.3 Calculate the frequency of the ultraviolet light.
- 11.4 Calculate the kinetic energy of a photoelectron emitted from the surface of the metal when the ultraviolet light shines on it.
- 11.5 The intensity of the ultraviolet light illuminating the metal is now increased. What effect will this change have on the following?
 - 11.5.1 Kinetic energy of the emitted photoelectrons (Write down only INCREASES, DECREASES or REMAINS THE SAME.)
 - 11.5.2 Number of photoelectrons emitted per second (Write down only INCREASES, DECREASES or REMAINS THE SAME.)
- 11.6 Overexposure to sunlight causes damage to skin cells.
 - 11.6.1 Which type of radiation in sunlight is said to be primarily responsible for this damage?
 - 11.6.2 Name the property of this radiation responsible for the damage.

QUESTION 12

During an investigation, light of different frequencies is shone onto the metal cathode of a photocell. The kinetic energy of the emitted photoelectrons is measured. The graph below shows the results obtained.



12.1 For this investigation, write down the following:

12.1.1 Dependent variable

12.1.2 Independent variable

12.1.3 Controlled variable

12.2 Define the term *threshold frequency*.

12.3 Use the graph to obtain the threshold frequency of the metal used as cathode in the photocell.

12.4 Calculate the kinetic energy at E_1 shown on the graph.

12.5 How would the kinetic energy calculated in QUESTION 12.4 be affected if light of higher intensity is used? Write down only INCREASES, DECREASES or REMAINS THE SAME

QUESTION 13

Light shines onto the cathode of a photocell as shown below. The ammeter registers a reading.

13.1 Define the term photon.

13.2 Each photon of light has an energy of $6,9 \times 10^{-19}$ J. The cathode has a work function of $6,4 \times 10^{-19}$ J. Calculate the:

13.2.1 Wavelength of the light

13.2.2 Maximum kinetic energy of the photoelectrons

13.3 How will the reading on the ammeter change if?

13.3.1 Light of the same frequency, but of higher intensity, is used. Write down INCREASES, DECREASES or REMAINS THE SAME. Fully explain the answer.

13.3.2 Light of the same intensity, but of higher frequency, is used. Write down INCREASES, DECREASES **PHOTOELECTRIC EFFECT**

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

ORGANIC CHEMISTRY

Representing Chemical Change

Balanced chemical equations

- Write and balance chemical equations.
- Interpret balanced reaction equations in terms of:
 - Conservation of atoms
 - Conservation of mass (use relative atomic masses)

Quantitative Aspects of Chemical Change

Molar volume of gases

- 1 mole of any gas occupies 22,4 dm³ at 0 °C (273 K) and 1 atmosphere (101,3 kPa).

Volume relationships in gaseous reactions

- Interpret balanced equations in terms of volume relationships for gases, i.e. under the same conditions of temperature and pressure, equal number of moles of all gases occupy the same volume.

Concentration of solutions

- Calculate the molar concentration of a solution.

More complex stoichiometric calculations

- Determine the empirical formula and molecular formula of compounds.
- Determine the percentage yield of a chemical reaction.
- Determine percentage purity or percentage composition, e.g. the percentage CaCO₃ in an impure sample of seashells.
- Perform stoichiometric calculations based on balanced equations.
- Perform stoichiometric calculations based on balanced equations that may include limiting reagents.

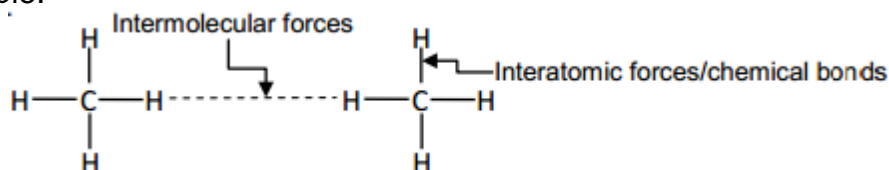
Intermolecular Forces

Intermolecular forces and interatomic forces (chemical bonds)

- Name and explain the different intermolecular forces (Van der Waal's forces):
 - i. Dipole-dipole forces:
Forces between two polar molecules
 - ii. Induced dipole forces or London forces:
Forces between non-polar molecules
 - iii. Hydrogen bonding:
Forces between molecules in which hydrogen is covalently bonded to nitrogen, oxygen or fluorine – a special case of dipole-dipole forces

- Describe the difference between intermolecular forces and interatomic forces (intramolecular forces) using a diagram of a group of small molecules; and in words.

Example:



- State the relationship between intermolecular forces and molecular size. For non-polar molecules, the strength of induced dipole forces increases with molecular size.
- Explain the effect of intermolecular forces on boiling point, melting point and vapour pressure.

Boiling point:

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

Melting point:

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

Vapour pressure:

The pressure exerted by a vapour at equilibrium with its liquid in a closed system. The stronger the intermolecular forces, the lower the vapour pressure.

Organic Molecules

- Define organic molecules as molecules containing carbon atoms.

Organic molecular structures – functional groups, saturated and unsaturated structures, isomers

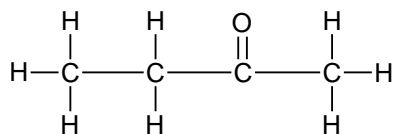
- Write down condensed structural formulae, structural formulae and molecular formulae (up to 8 carbon atoms, one functional group per molecule) for:
 - Alkanes (no ring structures)
 - Alkenes (no ring structures)
 - Alkynes
 - Halo-alkanes (primary, secondary and tertiary haloalkanes; no ring structures)
 - Alcohols (primary, secondary and tertiary alcohols)
 - Carboxylic acids
 - Esters
 - Aldehydes
 - Ketone
- Know the following definitions/terms:

Molecular formula: A chemical formula that indicates the type of atoms and the correct number of each in a molecule.

Example: C₄H₈O

Structural formula: A structural formula of a compound shows which atoms are attached to which, within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together.

Example:



Hydrocarbon: Organic compounds that consist of hydrogen and carbon only.

Homologous series: A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH₂ group.

Saturated compounds: Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains.

Unsaturated compounds: Compounds with one or more multiple bonds between C atoms in their hydrocarbon chains.

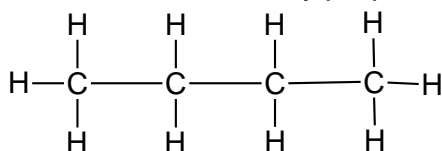
Functional group: A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

Homologous Series	Structure of functional group	
	Structure	Name/Description
Alkanes	$ \begin{array}{c} \quad \\ -\text{C}-\text{C}- \\ \quad \end{array} $	Only C–H and C–C single bonds
Alkenes	$ \begin{array}{c} \diagup \quad \diagdown \\ \text{C}=\text{C} \\ \diagdown \quad \diagup \end{array} $	Carbon-carbon double bond
Alkynes	$ -\text{C}\equiv\text{C}- $	Carbon-carbon triple bond
Haloalkanes	$ \begin{array}{c} \\ -\text{C}-\text{X} \\ \\ (\text{X} = \text{F}, \text{Cl}, \text{Br}, \text{I}) \end{array} $	Halogen atom bonded to a saturated C atom.
Alcohols	$ \begin{array}{c} \\ -\text{C}-\text{O}-\text{H} \\ \end{array} $	Hydroxyl group bonded to a saturated C atom
Aldehydes	$ \begin{array}{c} \text{O} \\ \\ -\text{C}-\text{H} \end{array} $	Formyl group
Ketones	$ \begin{array}{c} \quad \text{O} \quad \\ -\text{C}-\text{C}-\text{C}- \\ \quad \quad \end{array} $	Carbonyl group bonded to two C atoms
Carboxylic acids	$ \begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}-\text{H} \end{array} $	Carboxyl group
Esters	$ \begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}-\text{C}- \\ \end{array} $	-

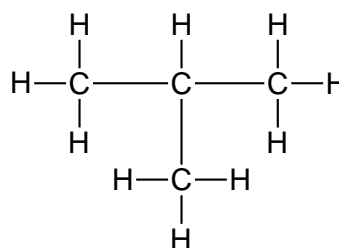
Structural isomer: Organic molecules with the same molecular formula, but different structural formulae

- Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.
- Restrict structural isomers to chain isomers, positional isomers and functional isomers.

- **Chain isomers:** Same molecular formula, but different types of chains, e.g. butane and 2-methylpropane.

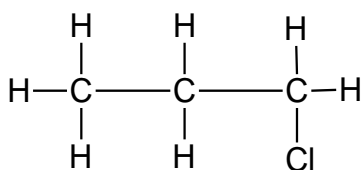


butane

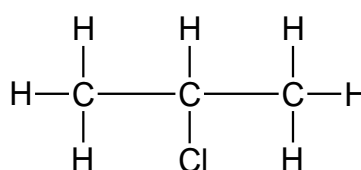


2-methylpropane

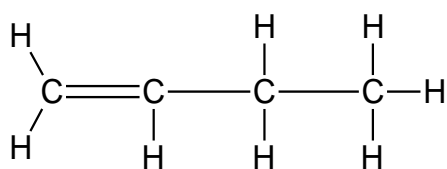
- **Positional isomers:** Same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain, e.g. 1-chloropropane and 2-chloropropane or but-2-ene and but-1-ene



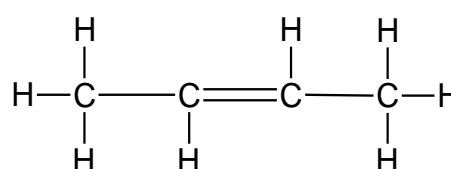
1-chloropropane



2-chloro propane

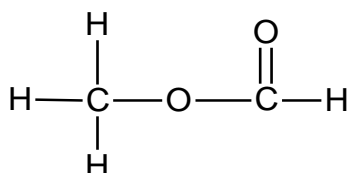


but-1-ene

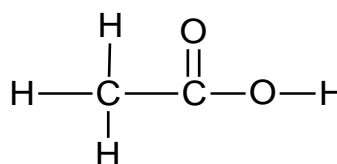


but-2-ene

- **Functional isomers:** Same molecular formula, but different functional groups, e.g. methyl methanoate and ethanoic acid



methyl methanoate



ethanoic acid

IUPAC naming and formulae

- Write down the IUPAC name when given the structural formula or condensed structural formula for compounds from the homologous series above, restricted to one functional group per compound, except for haloalkanes. For haloalkanes, maximum two functional groups per molecule.
- Write down the structural formula when given the IUPAC name for the above homologous series.
- Identify alkyl substituents (methyl- and ethyl-) in a chain to a maximum of THREE alkyl substituents on the parent chain.
- When naming haloalkanes, the halogen atoms do not get preference over alkyl groups – numbering should start from the end nearest to the first substituent, either the alkyl group or the halogen. In haloalkanes, where e.g. a Br and a Cl have the same number when numbered from different ends of chain,

- Br gets alphabetical preference.
- When writing IUPAC names, substituents appear as prefixes written alphabetically (bromo, chloro, ethyl, methyl), ignoring the prefixes di- and tri.

Structure and physical properties (boiling point, melting point, vapour pressure, viscosity) relationships

- For a given example (from the above functional groups), explain the relationship between physical properties and:
 - Strength of intermolecular forces (Van der Waal's forces), i.e. hydrogen bonds, dipole-dipole forces, induced dipole forces
 - Type of functional groups
 - Chain length
 - Branched chains

Factors that influence the strength of IMF

1. Surface area

Length of the carbon chain and branched molecules.

For compounds that belong to the same homologous series, the larger the surface area the higher the Melting point, the Boiling point, the Viscosity and the lower the Vapour pressure.

- The more branched the organic molecules are, the more compact it becomes.
- The surface area is smaller and less Van der Waals forces are available.
- The IMF are weaker resulting in lower boiling points and melting points.
- The vapour pressure will increase.

2. The type of functional group

For compounds with comparable molecular mass (C-chain length) the functional group will be the determining factor regarding the strength of the IMF. The more polar the functional group the stronger the IMF.

Carboxylic acid > Alcohol > Ketone, Aldehyde & Ester > Haloalkane > Alkyne, Alkene & Alkane

C A K A E H A A A

The **stronger** the intermolecular force the **higher** the **boiling point** and **melting point**, **lower vapour pressure**

London forces	Dipole-dipole forces	Hydrogen Bond
Alkanes	Aldehydes	Alcohols (1 site)
Alkenes	Ketones	Carboxylic acids (2 sites)
Alkynes	Halo- alkanes	
	Esters	

ORGANIC REACTIONS

Substitution and addition reactions

- Identify reactions as elimination, substitution or addition.
- Write down, using structural formulae, equations and reaction conditions for the following addition reactions of alkenes:

- **Hydrohalogenation:**

The addition of a hydrogen halide to an alkene

- **Halogenation:**

The reaction of a halogen (Br_2 , Cl_2) with a compound

- **Hydration:**

The addition of water to a compound

- **Hydrogenation:**

The addition of hydrogen to an alkene

- Write down, using structural formulae, equations and reaction conditions for the following elimination reactions:

- **Dehydrohalogenation of haloalkanes:**

The elimination of hydrogen and a halogen from a haloalkane

- Write down, using structural formulae, equations and reaction conditions for the following substitution reactions:

- **Hydrolysis of haloalkanes**

Hydrolysis: The reaction of a compound with water

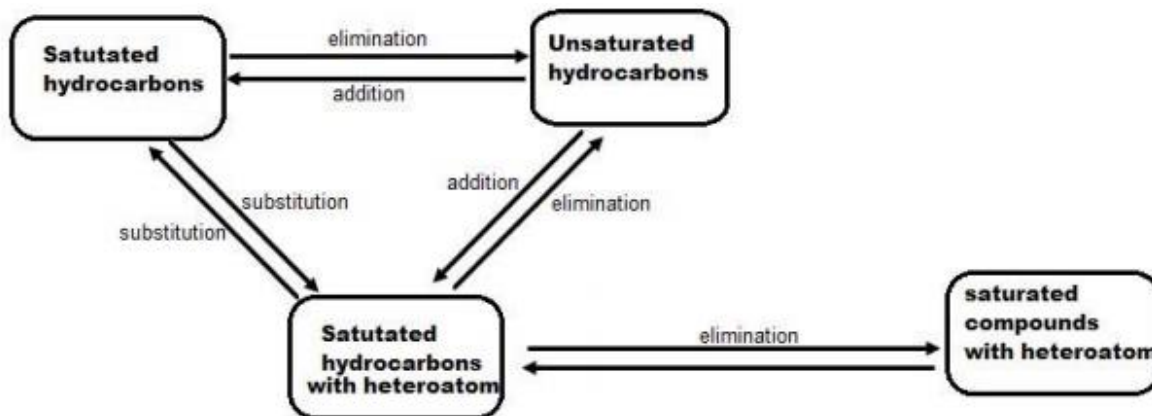
- Reactions of HX ($\text{X} = \text{Cl}, \text{Br}$) with alcohols to produce haloalkanes

- **Halogenation of alkanes**

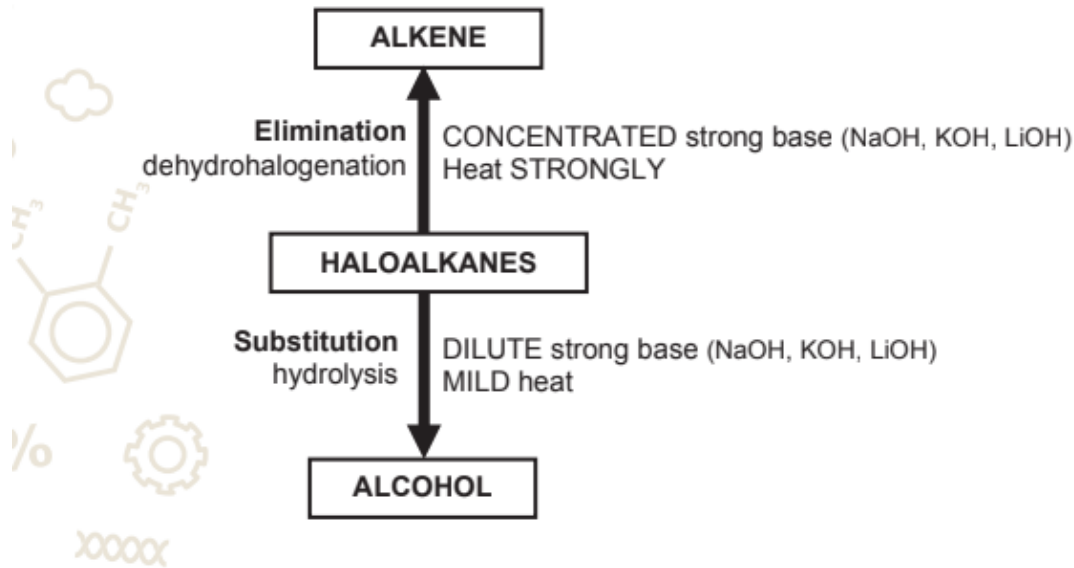
The reaction of a halogen (Br_2 , Cl_2) with a compound

- Distinguish between saturated and unsaturated hydrocarbons using bromine water.

U S A UNSATURATED – SATURATED – ADDITION
S S S SATURATED – SATURATED – SUBSTITUTION
S U E SATURATED – UNSATURATED – ELIMINATION



COMMON ERRORS

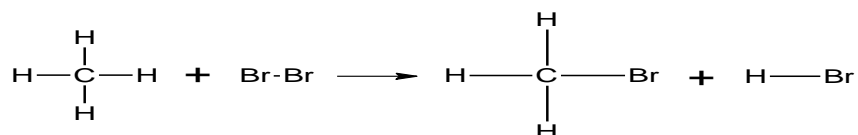


REACTIONS OF ALKANES

1. SUBSTITUTION

Alkane → haloalkane

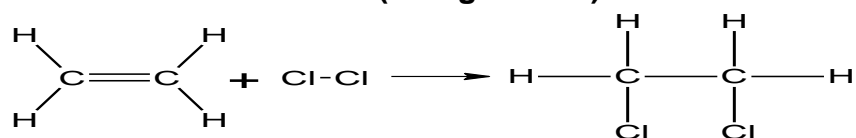
Conditions: Heat OR sunlight (uv)
Reactants: alkane + X₂ (F, Cl, Br, I)
Type of substitution: halogenation(bromination)



Substitution reaction will only occur when the compound is saturated.

REACTIONS OF ALKENES

ADDITION REACTION 1 (Halogenation)

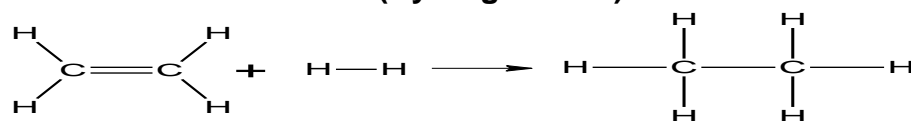


Conditions: Unreactive solvent
Type of addition: halogenation
Reactants: alkene + X₂ (X = Cl, Br)
Product: haloalkane

Bromine test: to distinguish between **alkane** and **alkene**

- Add bromine water (orange-brown) to unknown substances.
- If bromine water discolours the substance is an alkene.
- $\text{CH}_2\text{CH}_2 + \text{Br}_2 \rightarrow \text{CH}_2\text{BrCH}_2\text{Br}$

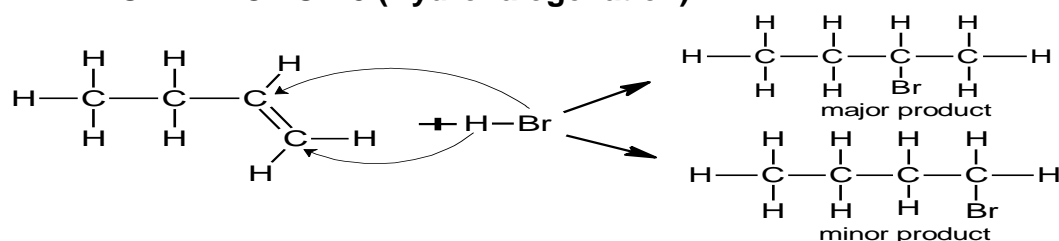
ADDITION REACTION 2 (Hydrogenation)



Conditions: Pt, Pd or Ni as catalyst
Type of addition: hydrogenation
Reactants: alkene + H₂
Product: Alkane

Application: Hydrogenation of unsaturated vegetable oils is used to manufacture margarine.

ADDITION REACTION 3 (Hydrohalogenation)



Conditions: No water; Unreactive solvent

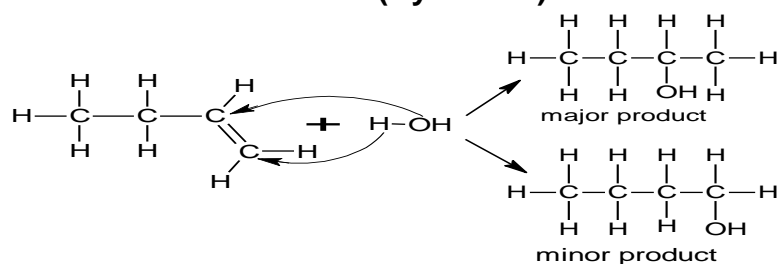
Type of addition: hydrohalogenation

Reactants: alkene + HX (X = I, Br, Cl)

Product(s): haloalkane(s)

Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)

ADDITION REACTION 4 (Hydration)



Conditions: Excess H₂O; Acid (H₂SO₄/ H₃PO₄) as catalyst.

Type of addition: hydration

Reactants: alkene + H₂O **Product:** Alcohol(s)

Major product: The H-atom attaches to the C-atom already having the greater number of H-atoms. (Markovnikov's rule)

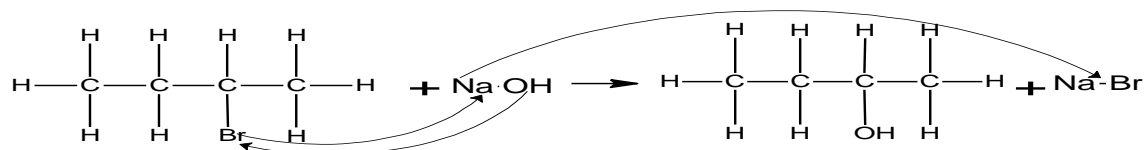
Addition reaction will only occur when the compound is unsaturated.

REACTIONS OF HALOALKANES

1. SUBSTITUTION :

Haloalkane → alcohol

2.1



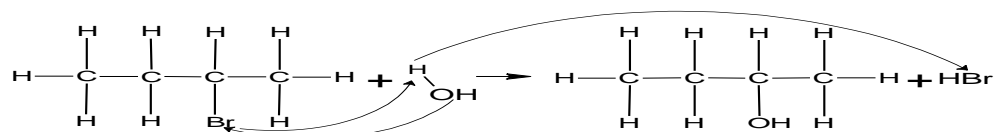
Conditions: Diluted strong base (NaOH/KOH/LiOH) + mild heat

Type of substitution: hydrolysis/ hydration

Reactants: Haloalkane in ethanol + diluted strong base

Products: Alcohol + NaBr/KBr/LiBr

2.2



Conditions: Excess H₂O + mild heat

Type of substitution: hydrolysis

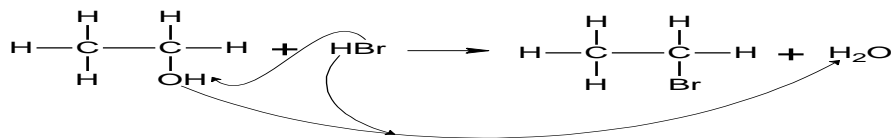
Reactants: Haloalkane + H₂O

Products: Alcohol + HBr

REACTIONS OF ALCOHOL

1. SUBSTITUTION

Alcohol → haloalkane



Conditions: Heat

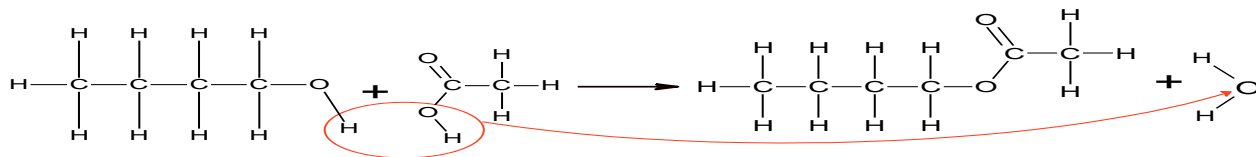
Reactants needed: Alcohol + HX

For primary & secondary alcohols: NaBr + conc H₂SO₄ is used to prepare HBr in reaction flask.

For tertiary alcohols: HBr (or HCl) are directly applied.

Products: Haloalkane + H₂O

ESTERIFICATION



Conditions: Concentrated H₂SO₄ as catalyst + heat

Reactants: Alcohol + carboxylic acid + H₂SO₄

Products: Ester + water

- The process whereby esters is formed is called **esterification**.
- Esters form when an **alcohol** reacts with a **carboxylic acid** when **heated** (condensation reaction).
- The catalyst is **concentrated sulphuric acid (H₂SO₄)**, a **dehydrating agent** that **extracts the water**.
- The **homologous series** is an **esters** and the name, therefore, ends in “-oate”.

The name of the example above is therefore, **butyl ethanoate**.

Plastics and polymers (ONLY BASIC POLYMERISATION as application of organic chemistry)

- Describe the following terms:
 - Macromolecule: a molecule that consists of a large number of atoms
 - Polymer: a large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern
 - Monomer: small organic molecules that can be covalently bonded to each other in a repeating pattern
 - Polymerisation: a chemical reaction in which monomer molecules join to form a polymer
 - Plastics: synthetic materials derived from organic compounds
- Identify monomers from given addition polymers.
- Discuss the industrial uses of polythene.

QUESTION 1

MULTIPLE-CHOICE QUESTIONS

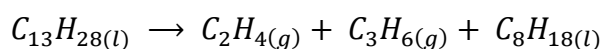
Four options are given as possible answers to the following questions. Each question has only ONE correct answer.

1.1 Which ONE of the compounds below is an aldehyde?

- A CH_3CHO
- B CH_3COCH_3
- C CH_3COOH
- D CH_3OH

(2)

1.2 The reaction represented by the equation below takes place in the presence of a catalyst.

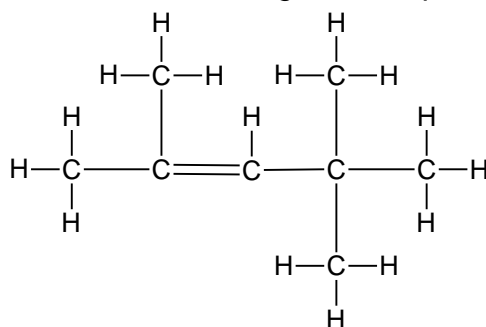


This reaction is an example of ...

- A addition.
- B cracking.
- C substitution.
- D polymerisation.

(2)

1.3 Consider the structural formula of an organic compound below.



In which homologous series does this organic compound belong?

- A Alkyne
- B Alkene
- C Alkane
- D Aldehyde

(2)

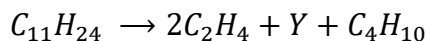
1.4 Which ONE of the following statements is CORRECT?

Alkenes ...

- A have the general formula $\text{C}_n\text{H}_{2n+2}$.
- B are unsaturated hydrocarbons.
- C readily undergo substitution reactions.
- D have one triple bond between two carbon atoms.

(2)

1.5 The following equation represents the cracking of a hydrocarbon at high temperature and pressure:



Which ONE of the following is the IUPAC name of product Y?

- A Prop-1-ene.
- B Propane.
- C Ethene.
- D Ethane.

(2)

1.6 When 2-chlorobutane is strongly heated in the presence of concentrated sodium hydroxide, the major product formed is ...

- A but-1-ene.
- B but-2-ene.
- C butan-1-ol.
- D butan-2-ol.

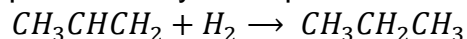
(2)

1.7 Which ONE of the following compounds is an aldehyde?

- A Pentanal
- B Pentan-2-ol
- C Pentan-2-one
- D Ethyl propanoate

(2)

1.8 Consider the reaction represented by the equation below:

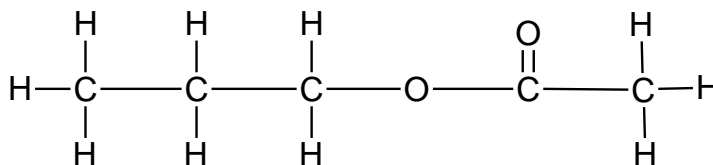


This reaction is an example of ...

- A hydration.
- B dehydration.
- C substitution.
- D hydrogenation.

(2)

1.9 Consider the structural formula of a compound below.



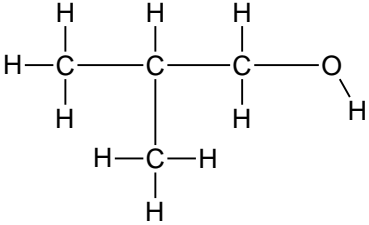
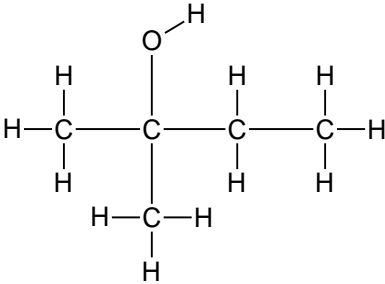
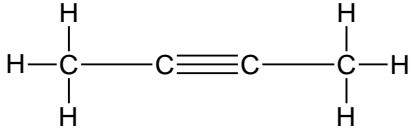
- A. Methyl propanoate
- B. Propyl ethanoate
- C. Butyl methanoate
- D. Pentanoic acid

- 1.10 Which ONE of the following pairs of reactants can be used to prepare propyl methanoate?
- A Propanoic acid and ethanol
 B Propanoic acid and methanol
 C Ethanoic acid and propan-1-ol
 D Methanoic acid and propan-1-ol
- (2)
- 1.11 Which ONE of the following compounds has dipole-dipole forces between its molecules?
- A Ethanal
 B Ethane
 C Ethene
 D Ethyne
- (2)
- 1.12 Which ONE of the following is a product formed during the hydrolysis of bromoethane?
- A Water
 B Ethene
 C Ethanol
 D Bromine
- (2)
- 1.13 Which ONE of the following is the EMPIRICAL FORMULA of 1, 2-dichloroethane?
- A $CHCl$
 B CH_2Cl
 C $CHCl_2$
 D $C_2H_4Cl_2$
- (2)
- 1.14 Which ONE of the following pairs of compounds are FUNCTIONAL isomers?
- A Methanol and methanal
 B Butane and 2-methylpropane
 C Propan-1-ol and propan-2-ol
 D Propanoic acid and methyl ethanoate
- (2)

QUESTION 2

The letters **A** to **G** in the table below represent seven organic compounds.

A		B	
---	--	---	--

C		D	
E	Butane	F	
G	Ethyl propanoate		

- 2.1. Write down the:
- 2.1.1. Name of the homologous series to which compound **F** belongs. (1)
 - 2.1.2. Name of the functional group of compound **D**. (1)
 - 2.1.3. Letter that represents a primary alcohol. (1)
 - 2.1.4. IUPAC name of compound **A**. (2)
 - 2.1.5. Structural formula of the monomer of compound **B**. (2)
 - 2.1.6. Balanced equation, using molecular formulae, for the combustion of compound **E** in excess oxygen. (3)
 - 2.2.1. Define the term POSITIONAL ISOMERS. (2)
 - 2.2.2. Identify the positional isomers from the table (1)
 - 2.3. Draw the structural formula of compound **G** (2)
 - 2.4. Name the carboxylic acid used in preparing Compound **G** (2)

QUESTION 3

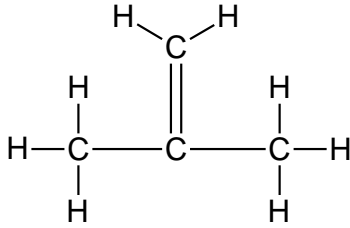
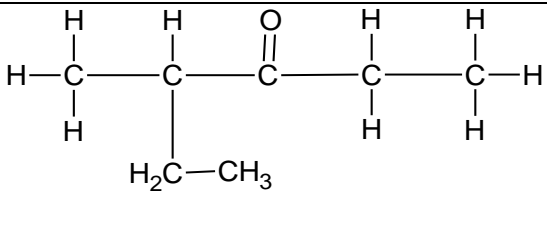
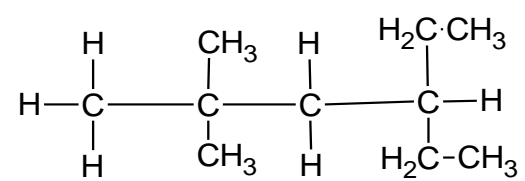
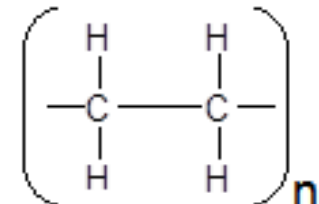
Consider the organic compounds represented by the letters A to F in the table below.

A	2,2,4-trimethylhexane	B	CH ₃ CH ₂ CH ₂ CH ₂ CHO
C		D	
E		F	Pentan-2-one

- 3.1. Write down the LETTER that represents the following:
- 3.1.1. An aldehyde. (1)
- 3.1.2. A condensation polymer (1)
- 3.1.3. A compound which has a carbonyl group bonded to two carbon atoms as its functional group. (1)
- 3.2. Write down the IUPAC name of:
- 3.2.1. Compound **C** (3)
- 3.2.2. The monomer of compound **D** (1)
- 3.3. Write down the structural formula of:
- 3.3.1. Compound **A** (2)
- 3.3.2. Compound **F** (2)
- 3.4. The table contains compounds which are functional isomers.
- 3.4.1. Define the term *functional isomer*. (2)
- 3.4.2. Write down the LETTERS that represent two compounds that are functional isomers. (1)

QUESTION 4

The letters **A** to **F** in the table below represent six organic compounds.

A		B	2-methylbutanoic acid
C		D	
E	But-2-ene	F	

4.1. Write down the:

4.1.1. NAME of the functional group of compound **B**

(1)

4.1.2. Homologous series to which compound **C** belongs.

(1)

4.1.3. Type of polymerisation reaction that produces compound **F**

(1)

4.2. Write down the IUPAC name of the monomer used to prepare compound **F**

(2)

4.3. Write down the NAME or FORMULA of each product formed during the complete combustion of compound **D**.

(2)

4.4. Write down the structural formula of:

4.4.1. Compound **B**

(2)

4.4.2. A CHAIN ISOMER of compound **A**

(2)

QUESTION 5

The letters **A** to **D** in the table below represents four organic compounds.

- 6.2.3 The boiling point of each alcohol is much higher than that of the alkane of comparable relative molecular mass. Explain this observation by referring to the TYPE and STRENGTH of the intermolecular forces in alkanes and alcohols (3)

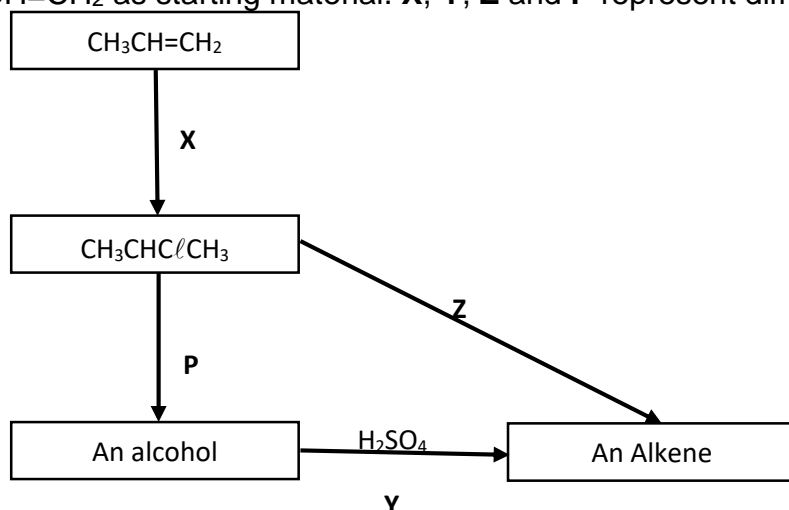
QUESTION 7

- 7.1 Give a reason why alkanes are *saturated* hydrocarbons. (1)
- 7.2 Write down the structural formula of:
- 7.2.1 The functional group of alcohols. (1)
- 7.2.1 A tertiary alcohol that is a structural isomer of butan-1-ol. (2)
- 7.3 Learners investigate factors that influence the boiling points of alkanes and alcohols. In one of the investigations they determine boiling points of the first three alkanes.
- 7.3.1 Write down an investigative question for this investigation. (2)
- 7.3.2 Fully explain why the boiling point increases from methane to propane. (3)
- 7.4 The learners find that the boiling point of propan-1-ol is higher than that of propane. Explain this observation by referring to the TYPE of INTERMOLECULAR FORCES present in each of these compounds. (3)

Questions 8 to 16 involve Types of Organic Reactions.

QUESTION 8

The flow diagram below shows the preparation of the organic compounds using $\text{CH}_3\text{CH}=\text{CH}_2$ as starting material. **X**, **Y**, **Z** and **P** represent different organic reactions.



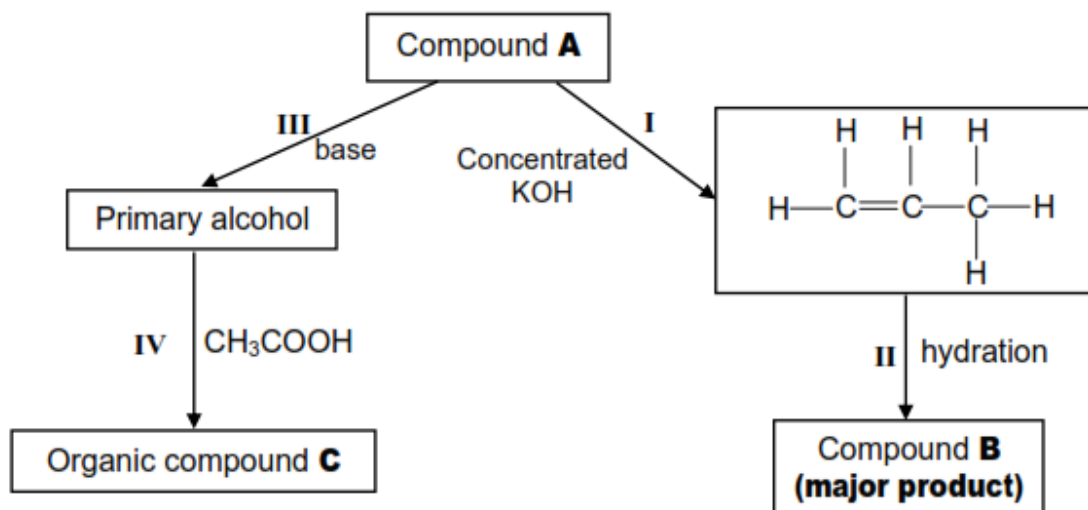
- 8.1 To which homologous series does $\text{CH}_3\text{CH}=\text{CH}_2$ belong? (1)
- 8.2 Write down the TYPE of reaction represented by:
- 8.2.1 X (1)
- 8.2.2 P (1)
- 8.2.3 Y (1)
- 8.2.4 Z (1)
- 8.3. Write down the IUPAC name of the alcohol produced during reaction **P**. (2)

8.4 State the function of the acid in reaction **Y**. (1)

8.5 For reaction **Z**, write down TWO reaction conditions needed. (2)

QUESTION 9

The flow diagram below shows how compound **A** can be used to prepare other organic compounds. The numbers **I**, **II**, **III** and **IV** represent different organic reactions.



Use the information in the flow diagram to answer the following questions.

9.1 Name the homologous series to which compound **A** belongs. (1)

9.2 Write down the TYPE of reaction represented by:

9.2.1 **I** (1)

9.2.2 **III** (1)

9.2.3 **IV** (1)

9.3 Consider **reaction III**. Write down the:

9.3.1 TWO reaction conditions for this reaction (2)

9.3.2 IUPAC name of the primary alcohol that is formed (2)

9.4 Draw the STRUCTURAL FORMULA for compound **B**. (2)

9.5 Consider **reaction IV**. Write down the:

9.5.1 Structural formula of organic compound **C** (2)

9.5.2 NAME or FORMULA of the catalyst that is used (1)

CHEMICAL CHANGE

- Is the change that involves the formation of a new substance e.g combustion of petrol, rusting of iron.

Energy changes in reactions related to bond energy changes

- Define *heat of reaction* (ΔH) as the energy absorbed or released in a chemical reaction.
- Define *exothermic reactions* as reactions that release energy.
- Define *endothermic reactions* as reactions that absorb energy.
- Classify (with reason) reactions as exothermic or endothermic.

Exothermic and endothermic reactions

- State that $\Delta H > 0$ for endothermic reactions, i.e. reactions in which energy is released.
- State that $\Delta H < 0$ for exothermic reactions, i.e. reactions in which energy is absorbed.

Activation energy

- Define *activation energy* as the minimum energy needed for a reaction to take place.
- Define an *activated complex* as the unstable transition state from reactants to products.
- Draw or interpret fully labelled sketch graphs (potential energy versus course of reaction graphs) of catalysed and uncatalysed endothermic and exothermic reactions.

○ HEAT OF REACTION/ENTHALPY CHANGE

-is the energy absorbed or released in a chemical reaction

-Symbol is ΔH

- Unit is kJ or kJ/mol

○ BOND ENERGY

- Is the amount of energy required to break a bond in a molecule?

ENERGY CHANGES THAT TAKE PLACE DURING CHEMICAL REACTIONS

TYPES OF CHEMICAL REACTIONS:

1. Exothermic reaction
2. Endothermic reaction

Exothermic reaction

-is the reaction that releases energy

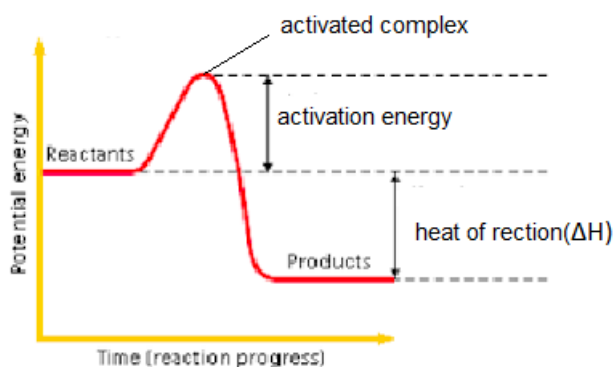
Endothermic reaction

-is the reaction that absorb energy

Exothermic reactions

-reactions in which energy is released

$\Delta H < 0$, ΔH is negative

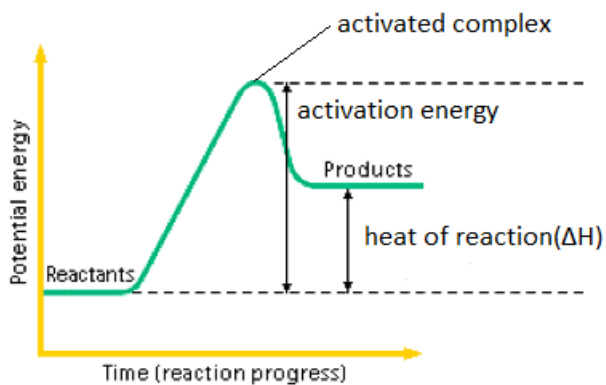


- **Are spontaneous reactions**- do not need a continuous supply of energy

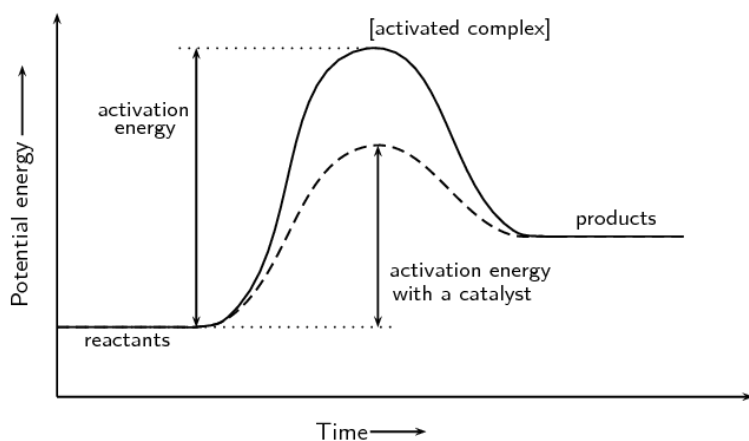
- Activation energy is the minimum energy needed for a reaction to take place
- Activated complex is the unstable transition state from reactants to products or is the temporary unstable state that is formed during the course of a chemical reaction.
- Enthalpy(H) is the amount of energy of reactants or products
- Enthalpy cannot be measured
- Enthalpy change (ΔH) can be calculated using: $\Delta H = H_{\text{products}} - H_{\text{reactants}}$

ENDOTHERMIC REACTIONS

- Reactions which energy is absorbed and are non-spontaneous
- $\Delta H > 0$, ΔH is positive



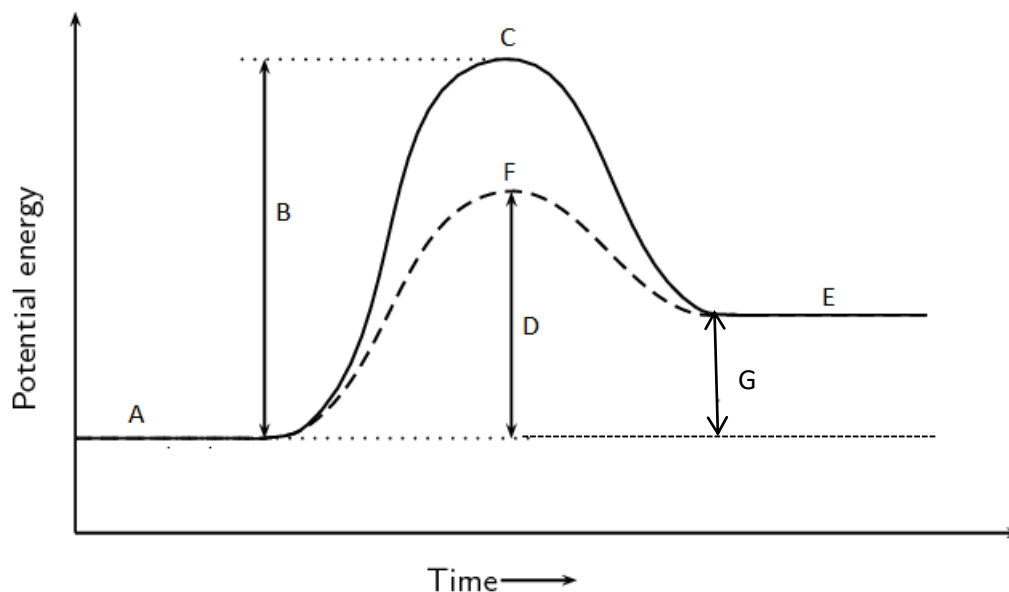
-addition of a catalyst will lower the activation energy



Comparing exothermic and endothermic reactions:

Exothermic reaction	Endothermic reaction
$\Delta H < 0$ negative	$\Delta H > 0$ positive
E_p of the reactants decreases as products form	E_p of the reactants increases as products form
Net energy is given out (liberated)	Net energy is taken in (gained)
The reaction flask becomes hot	The reaction flask becomes cold

Class activity



- 1.1 label parts A to F (6)
- 1.2 If $A = 40\text{kJ}\cdot\text{mol}^{-1}$ and $E = 60\text{kJ}\cdot\text{mol}^{-1}$, Calculate heat of the reaction for the forward reaction (3)
- 1.3 is the reverse reaction exothermic or an endothermic reaction? (1)
- 1.4 Is the forward reaction spontaneous or non-spontaneous reaction? (2)
- 1.5 A catalyst is added. How does this affect the activation energy for the forward reaction?

(Write down only **INCREASES**, **DECREASES** or **STAYS THE SAME**)

Rates of reaction and factors affecting rate

- Define *reaction rate* as the change in concentration of reactants or products per unit time.
- Calculate reaction rate from given data.

$$\text{Rate} = \frac{\Delta c}{\Delta t} \text{ (unit : mol}\cdot\text{dm}^{-3}\cdot\text{s}^{-1}\text{)}$$

Questions may also include calculations of rate in terms of change in mass/volume/ number of moles per time.

- List the factors that affect the rate of chemical reactions, i.e. nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.

- Explain in terms of the collision theory how the various factors affect the rate of chemical reactions. The collision theory is a model that explains reaction rate as the result of particles colliding with a certain minimum energy.

Measuring rates of reaction

- Answer questions and interpret data (tables or graphs) on different experimental techniques for measuring the rate of a given reaction.

Mechanism of reaction and of catalysis

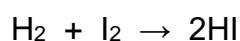
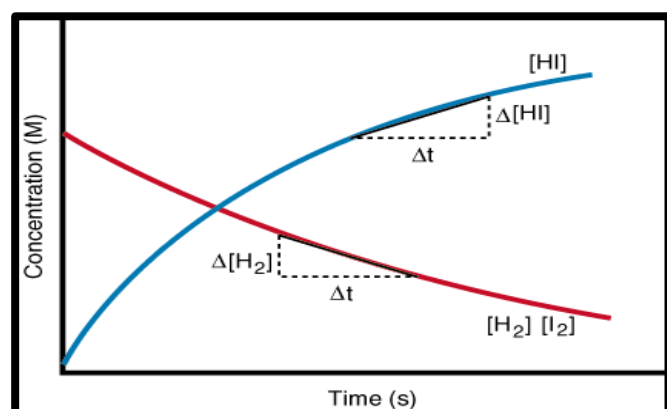
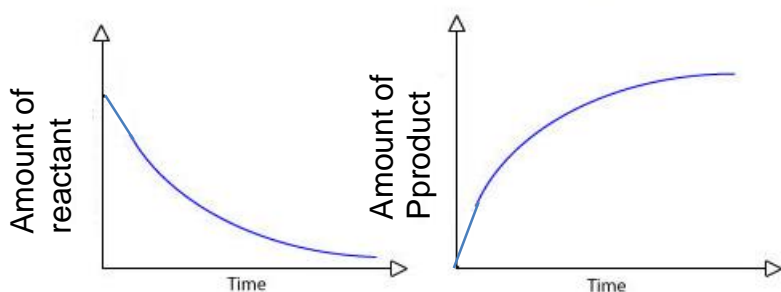
- Define the term *positive catalyst* as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.

Interpret graphs of distribution of molecular energies (number of particles against their kinetic energy or Maxwell-Boltzmann curves) to explain how a catalyst, temperature and concentration affect rate.

- Explain that a catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net/total activation energy.

○ RATE OF A CHEMICAL REACTION (REACTION RATE)

- Is the change in concentration of reactants or products per unit time
- Can be calculated using: $\text{Rate} = \frac{\Delta c}{\Delta t}$



The gradient of either curve will give the average rate of reaction for the time interval Δt .

Measuring the rate of a reaction:

For the products:

$$\text{Average rate} = \frac{\text{change in amount of product}}{\text{time taken}}$$

For the reactants:

$$\text{Average rate} = \frac{\text{change in amount of reactant}}{\text{time taken}}$$

Example

Use experimental data to determine the rate of a chemical reaction.

Calculate the rate of reaction if it takes 18 seconds to produce 42 moles of carbon dioxide from a wood fire.

$$\begin{aligned}\text{Average rate} &= \frac{\text{change in amount of product}}{\text{time taken}} \\ &= \frac{42 \text{ mol}}{18\text{s}} \\ &= 2,3 \text{ mol.s}^{-1}\end{aligned}$$

COLLISION THEORY

- For a chemical reaction to take place particles must collide.
- Not all collisions will result in a reaction
- A collision that results in a reaction that produce one or more products is called effective collision

Requirements for effective collisions:

1. Correct orientation of particles
2. Sufficient kinetic energy of the particles

THE RATE OF REACTION IS DETERMINED BY:

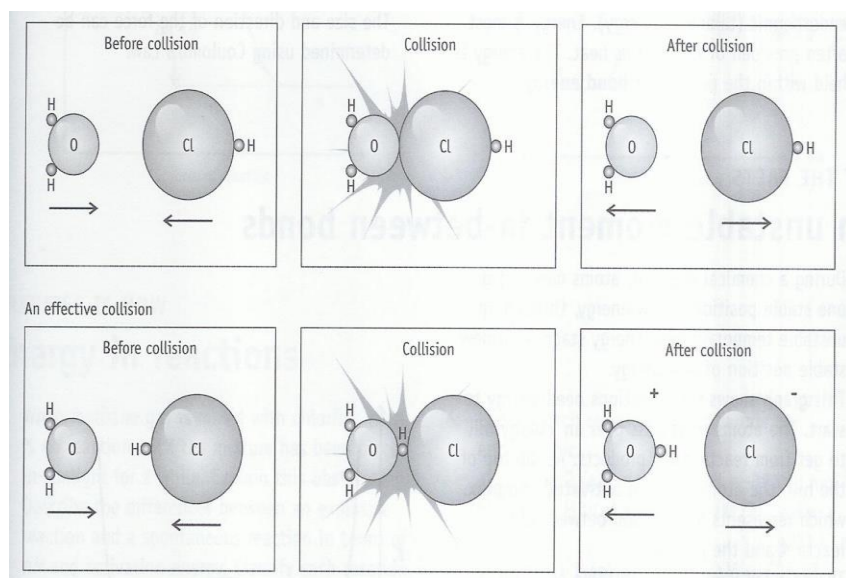
- the number of collisions per second or frequency of the collisions
- the energy of the colliding particles

-the orientation of the colliding particles

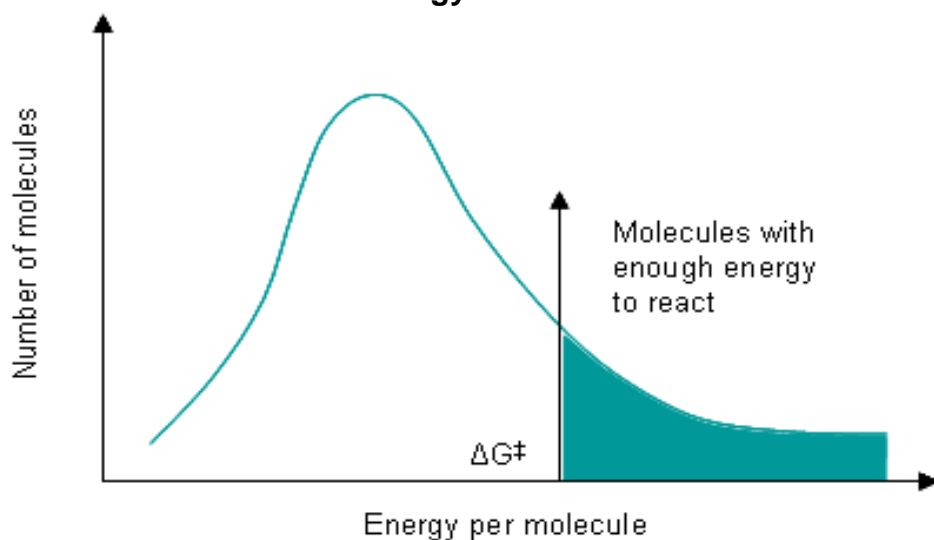
The Collision Theory

- reacting atoms, molecules or ions must collide with each other.
- the particles must have sufficient energy and must be oriented correctly.
- bonds in the original molecules must break and new bonds must form.
- electrons must re-arranged in order to form new bonds.

Amount of energy and orientation of colliding particles leads to some collisions being effective and others not.



Particles with sufficient energy



This Boltzmann curve shows that there is only a small fraction of molecules that have enough energy for the reaction.

FACTORS THAT AFFECT THE RATE OF A CHEMICAL REACTION

There are FIVE factors:

1. The nature of the reactants
2. Surface area
3. Temperature
4. Concentration
5. Catalyst

The nature of the reactants

- Some chemical compounds are more reactive than others.
- For example group 1 elements, their reactivity increases as you move down the group
- Sodium and potassium are reactive metals than heavy metals like copper and zinc
- Gold and silver are very unreactive metal
- The strength of the bond and activation energy required to break the bonds determines the reactivity of a substance.
- Simple substances with weak bonds and lower activation energy react faster than complex molecules.

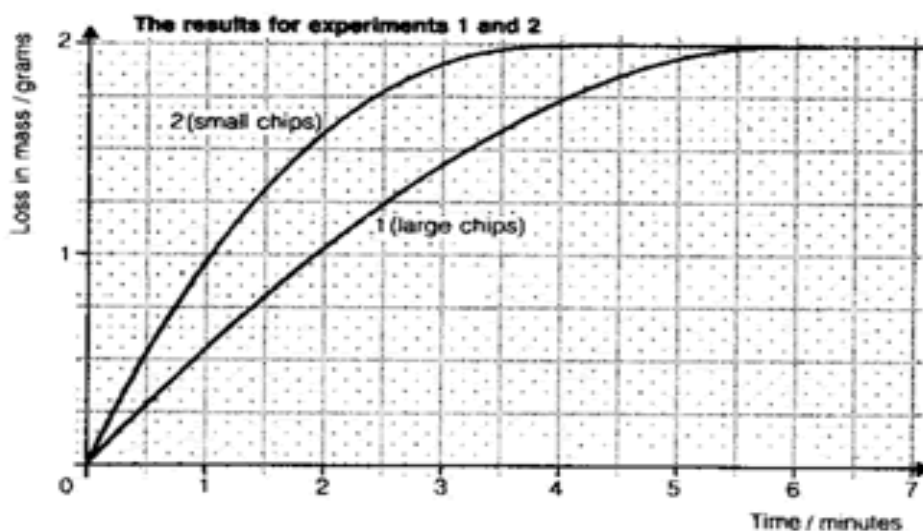
Surface area

- Applies on solids only
- When surface area increases the rate of the reaction also increases or vice versa.
- Surface area is greater when a solid is in powder form and is lesser when a solid is in lump form.

According to collision theory:

- When a solid is in powder form
- As the surface area increases, there are more particles available for reacting.
- Thus there will be more collisions per second, and thus a greater number of effective collisions per second and thus the reaction rate will increase.

The greater the exposed surface area of the particles of a solid (the finer the particles) the greater the chance of collisions with the particles on the surface and so the greater the rate of reaction



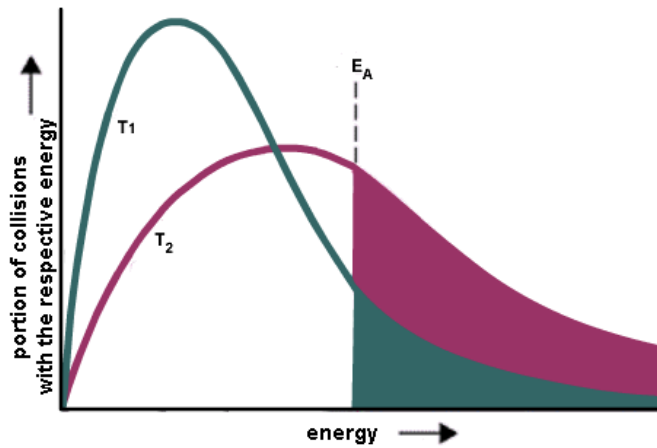
TEMPERATURE

- When the temperature increases the rate of the reaction increases or vice versa.
- According to collision theory:

If the temperature of the reaction mixture is increased

- The speed of the particles increases
- The average kinetic energy of the particles increases
- more particles have sufficient energy
- There are more collisions taking place resulting in more effective collisions per unit time
- Thus the rate of the reaction increases

The effect of increasing the temperature of the reaction mixture



More molecules with sufficient energy to react at the higher temperature

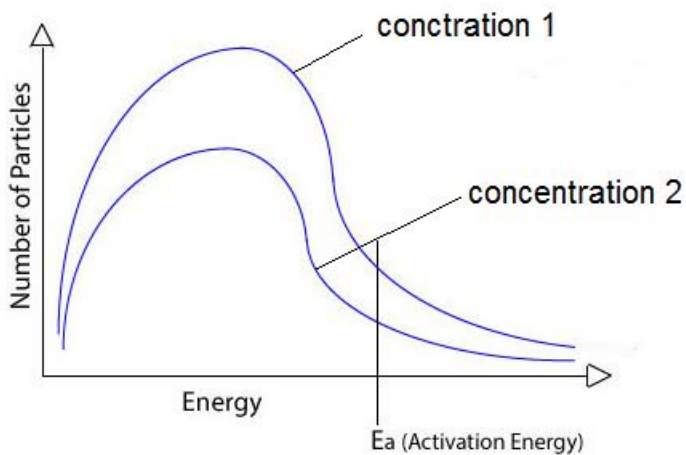
CONCENTRATION

- An increase in concentration of a solution (pressure in gases) increases the rate of a reaction or vice versa.
- According to collision theory:

When concentration is increased

- more collisions occur due to more particles per unit volume in the container
- more particles have sufficient energy
 - There are more effective collisions per unit time
 - Thus the rate of the reaction increases.

The effect of increasing concentration on the reaction mixture.



In solution:
Concentration 1 is greater than concentration 2

-more particles collide per unit volume.

CATALYST

○ is a substance that speeds up the rate of a chemical reaction without itself being used up.

○ Catalyst can be a solid or a gas or a liquid

-homogeneous catalysis: reactants and catalyst are in the same phase

-heterogeneous catalysis: reactants and catalyst are in the different phases

-less activation energy is required to form activated complex

-provides an alternative path with a lower activation energy

-products are formed quickly

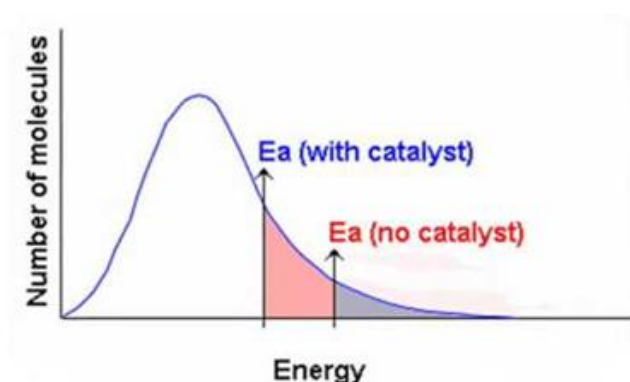
○ **Positive catalyst** as a substance that increases the rate of a chemical reaction without itself undergoing a permanent change.

○ **According to collision theory:**

When a suitable catalyst is used

-The catalyst provides an alternative pathway/route for the reaction

- with a lower activation energy
- More molecules/particles have enough energy
- and more effective collisions occur
- increasing the rate of reaction.
- Effect of a catalyst on reaction rate:



- A catalyst always lowers the activation energy
- And so more molecules have sufficient energy
- To make effective collisions.

QUESTION 1 (DBE NOV 2008)

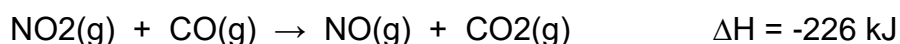
1.1 The collision theory can be used to explain how different factors affect the rate of a chemical reaction.

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

(2)

1.1.2 In terms of the collision theory, explain why the rate of a chemical reaction increases with increasing temperature.

1.2 The reaction between nitrogen dioxide and carbon monoxide is represented below.



The activation energy for the reaction, E_a , is 132 kJ.

1.2.1 Sketch a potential energy versus reaction coordinate graph for this reaction.

Label the axes and indicate the following on your graph:

$$\Delta H = -226 \text{ kJ}$$

$$E_a = 132 \text{ kJ}$$

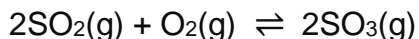
(4)

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

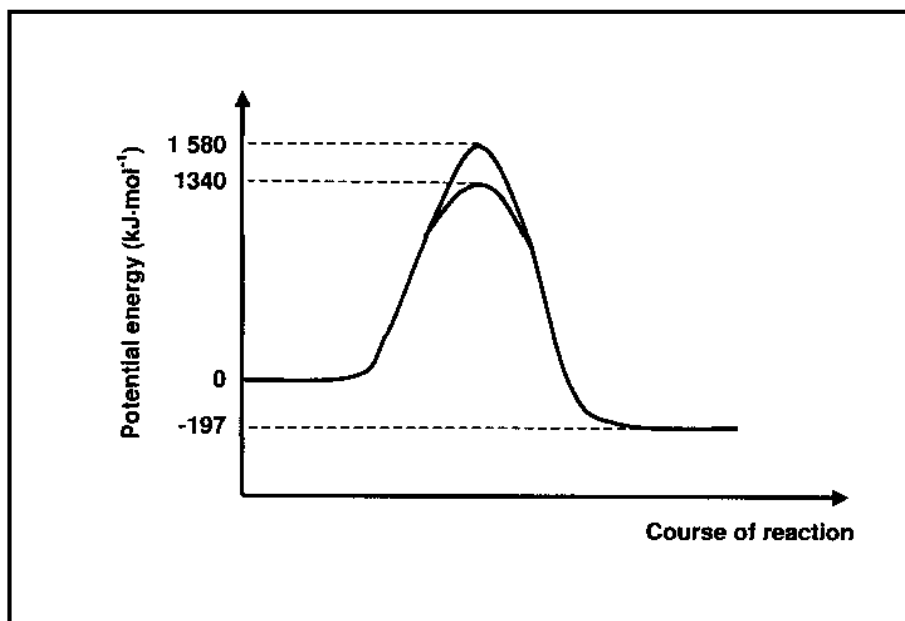
(1)

QUESTION 2(KZN JUNE 2012)

The contact process is used to prepare sulphuric acid in the high concentrations needed for industrial purposes. The heart of this process involves the oxidation of sulphur dioxide in the presence of a vanadium(V) oxide catalyst:



Consider the following graph (not drawn to scale) that represents the change in chemical potential energy for the above reaction:

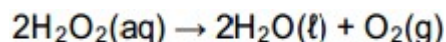


Use the reaction and the graph, where applicable, to answer the questions that follow.

- 2.1 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Prove your answer by writing down the value of ΔH for this reaction. (2)
- 2.2 Write down the activation energy for the forward reaction in the absence of the vanadium(V) oxide catalyst. (1)
- 2.3 If we assume that $1580 \text{ kJ}\cdot\text{mol}^{-1}$ is involved to break the bonds in the $\text{SO}_2(\text{g})$ and $\text{O}_2(\text{g})$ molecules, how much energy is released when the new bonds in the $\text{SO}_3(\text{g})$ molecules form? (2)
- 2.4 Determine the activation energy for the reverse reaction in the presence of the vanadium(V) oxide catalyst. (2)
- 2.5 In the contact process, the catalysed reaction reaches equilibrium in a closed container. Chemical engineers devise ways to shift the above equilibrium to the right, so that a higher yield of $\text{SO}_3(\text{g})$ can be obtained.
 - 2.5.1 Describe the role that vanadium(V) oxide plays in this chemical reaction. (2)
 - 2.5.2 What effect does the addition of vanadium(V) oxide have on the amount of $\text{SO}_3(\text{g})$ at equilibrium? Only answer INCREASES, DECREASES or NO EFFECT (1)

QUESTION 3 (DBE NOV 2013)

A hydrogen peroxide solution dissociates slowly at room temperature according to the following equation:



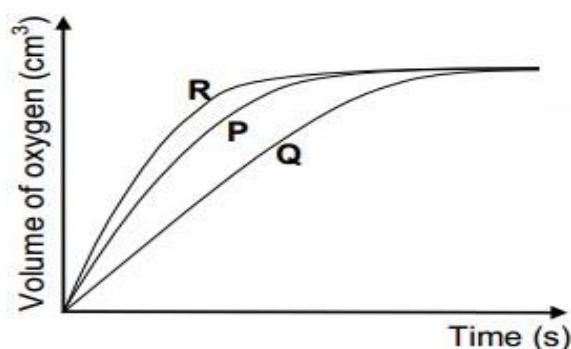
During an investigation, learners compare the effectiveness of three different catalysts on the rate of decomposition of hydrogen peroxide. They place EQUAL AMOUNTS of sufficient hydrogen peroxide into three separate containers. They then add EQUAL AMOUNTS of the three catalysts, **P**, **Q** and **R**, to the hydrogen peroxide in the three containers respectively and measure the rate at which oxygen gas is produced.

3.1 For this investigation, write down the:

3.1.1 Independent variable (1)

3.1.2 Dependent variable (1)

The results obtained are shown in the graph below.



3.2 Which catalyst is the most effective? Give a reason for the answer. (2)

3.3 Fully explain, by referring to the collision theory, how a catalyst increases the rate of a reaction. (3)

In another experiment, the learners obtain the following results for the decomposition of hydrogen peroxide:

TIME (s)	H ₂ O ₂ CONCENTRATION (mol·dm ⁻³)
0	0,0200
200	0,0160
400	0,0131
600	0,0106
800	0,0086

3.4 Calculate the AVERAGE rate of decomposition (in mol·dm⁻³·s⁻¹) of H₂O₂(aq) in the first 400s. (3)

3.5 Will the rate of decomposition at 600s be GREATER THAN, LESS THAN or EQUAL TO the rate calculated in QUESTION 3.4? Give a reason for the answer. (2)

3.6 Calculate the mass of oxygen produced in the first 600s if 50 cm³ of hydrogen peroxide decomposes in this time interval. (5)

QUESTION 4(DBE FEB/MARCH 2012)

A group of learners use the reaction between zinc and sulphuric acid to investigate one of the factors that affects reaction rate. The equation below represents the reaction that takes place.

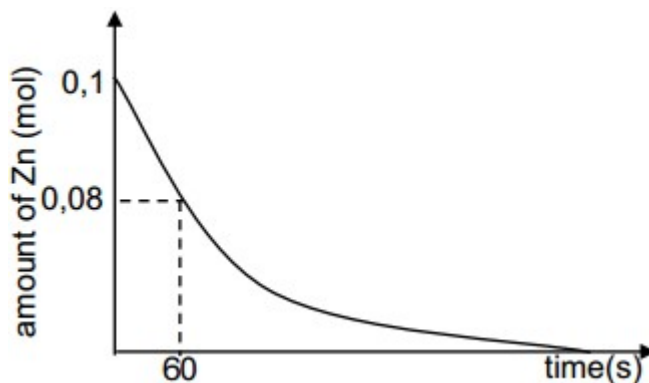


They add 6,5 g of zinc granules to excess DILUTE sulphuric acid and measure the mass of zinc used per unit time.

The learners then repeat the experiment using excess CONCENTRATED sulphuric acid.

- 4.1 Define the term reaction rate. (2)
- 4.2 Give a reason why the acid must be in excess. (1)
- 4.3 Write down a hypothesis for this investigation. (2)
- 4.4 Give a reason why the learners must use the same amount of ZINC GRANULES in both experiments. (1)

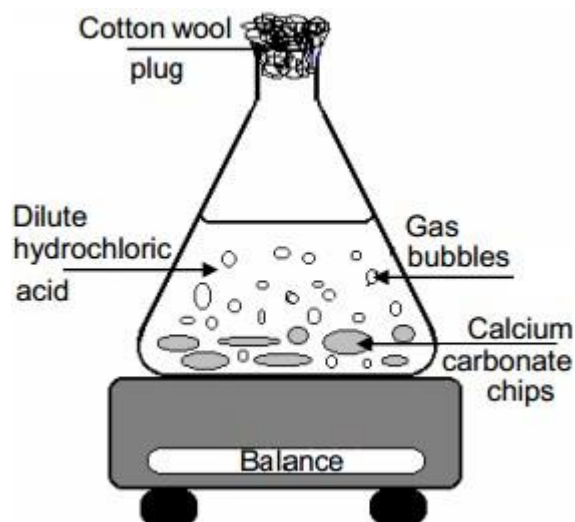
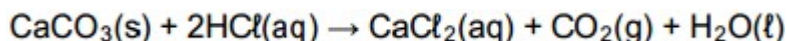
The results obtained for the reaction using DILUTE sulphuric acid are represented in the graph below.



- 4.5 Using the graph, calculate the mass of zinc used from t = 0s to t = 60s. (4)
- 4.6 Calculate the average rate of the reaction (in gram per second) during the first 60s. (2)
- 4.7 Copy the above graph into your ANSWER BOOK. ON THE SAME SET OF AXES, use a dotted line to show the curve that will be obtained when concentrated sulphuric acid is used. Label that curve P (no numerical values are required). (2)

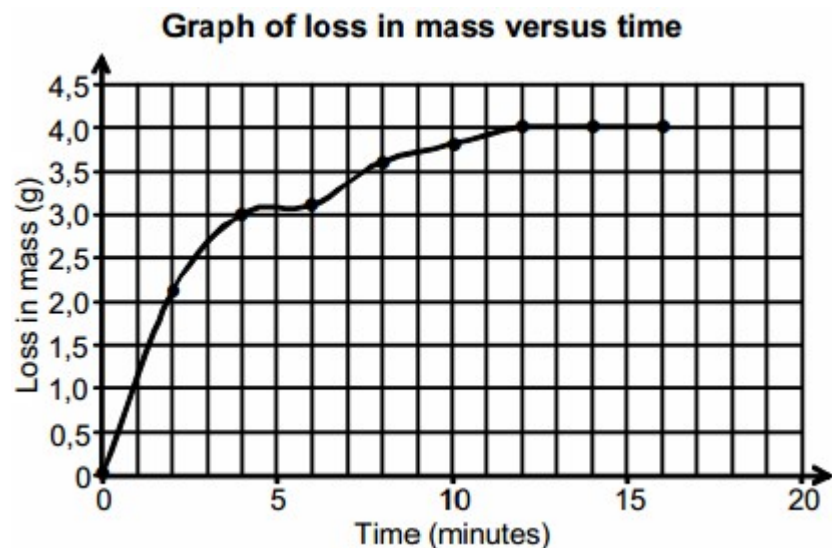
QUESTION 5 (DBE NOV 2012)

Calcium carbonate chips are added to an excess dilute hydrochloric acid solution in a flask placed on a balance as illustrated below. The cotton wool plug in the mouth of the flask prevents spillage of reactants and products, but simultaneously allows the formed gas to escape. The balance equation for the reaction that takes place is:



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

The loss in mass of the flask and its contents is recorded in intervals of 2 minutes. The results obtained are shown in the graph below.



5.2 From the graph, write down the following:

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

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

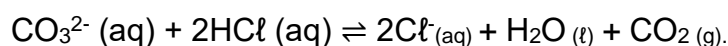
5.2.3 How long (in minutes) it takes 75% (three quarters) of the reaction to occur (1)

5.3 The experiment is now repeated using hydrochloric acid of a higher concentration. It is found that the rate of the reaction INCREASES. Use the collision theory to explain this observation. (2)

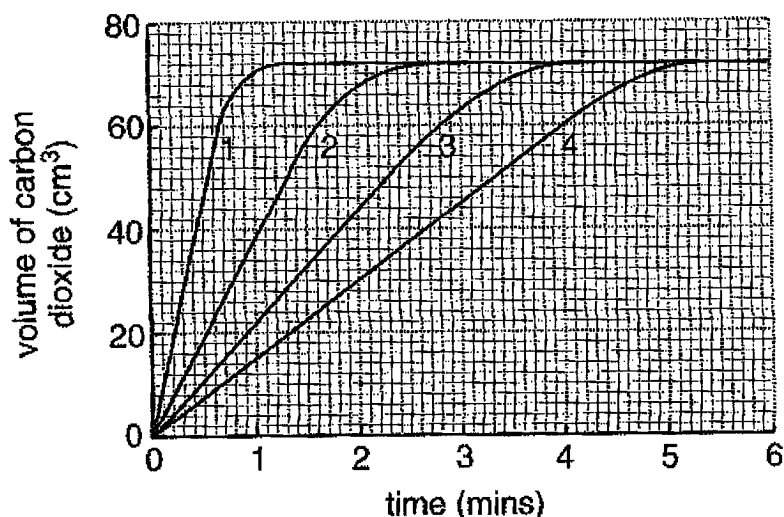
5.4 How would a higher concentration of hydrochloric acid affect the following: (Write down only INCREASES, DECREASES or REMAINS THE SAME.)

QUESTION 6 (KZN JUNE 2011)

There are many antacid tablets available on the market today to help relieve the pain of indigestion, which is caused by an increase in the acidity level in the stomach. Pain relief relies on the neutralisation reaction between the antacid and the hydrochloric acid in the stomach. The active ingredient in the antacid is carbonate ion which reacts with the hydrochloric acid in the stomach according to the reaction:



Shranda and Nichole investigated the reaction of a leading brand antacid. They used antacid in the form of small lumps of marbles. They conducted four experiments. In each experiment the temperature of the acid was changed each time. The rate at which this reaction takes place was studied by measuring the amount of carbon dioxide gas produced. The graphs below show the results of four experiments (1 to 4).



- 6.1 Give a possible hypothesis for this experiment. (2)
- 6.2 What is the independent variable in this situation? (1)
- 6.3 What is the dependent variable in this situation? (1)
- 6.4 Give THREE controlled variables. (3)

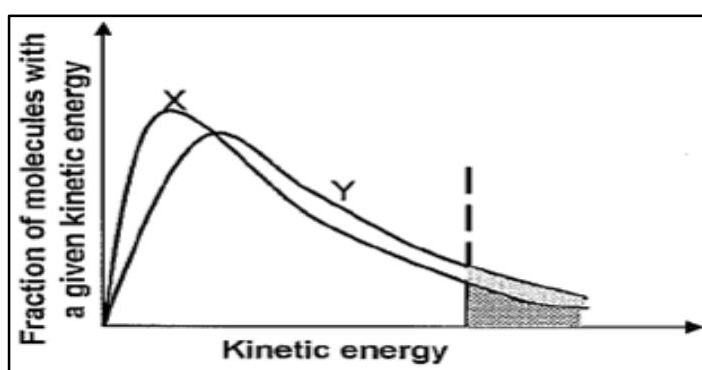
- 6.5 Apart from altering the temperature, suggest two ways in which the reaction of calcium carbonate and hydrochloric acid could be speeded up. (2)
- 6.6 Which of the graphs 1 to 4, shows the results of the experiment in which the acid had the highest temperature? Explain fully. (2)
- 6.7 Explain, using the collision theory, why the reaction rate changes during each experiment. (2)

QUESTION 7 (KZN JUNE 2013)

Kayla investigates a way to increase the rate at which hydrogen gas is produced in the reaction between zinc and hydrochloric acid.

7.1 By changing one reaction condition she obtains the graph below, in which:

- Curve X denotes the initial condition
- Curve Y denotes the changed condition that produced a higher reaction rate

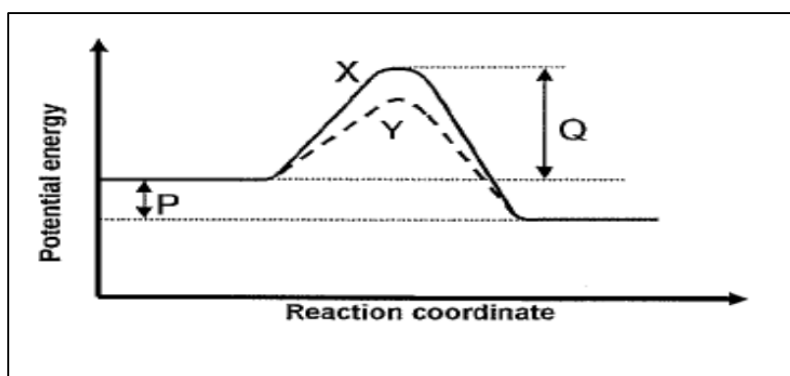


7.1.1 Which reaction condition did the learner change? (1)

7.1.2 Apply the collision theory and explain why the changed condition results in a higher reaction rate. (3)

7.2 Kayla then changes another condition in which the effect is represented by the graph below. Once again:

- Curve X denotes the initial condition
- Curve Y denotes the changed condition



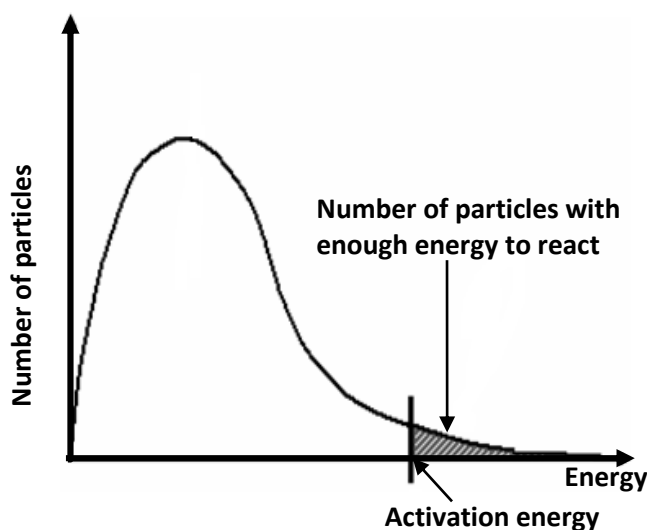
7.2.1 Which reaction condition did the Kayla change? (1)

7.2.2 What is the name of the energy value denoted by the following:

- (a) P (1)
- (b) Q (1)

A catalyst speeds up the rate of a reaction. This behaviour of a catalyst can be explained in terms of the activation energy and the collision theory.

7.3 The diagram below shows the Maxwell-Boltzmann distribution curve for a certain reaction.



7.3.1 Explain in terms of the collision theory and activation energy, how a catalyst influences the rate of a reaction. (4)

7.3.2 Redraw the above distribution curve into the answer book and show the new activation energy when a catalyst is added to the reaction mixture on the diagram. (2)

QUESTION 8 (DBE FEB/MARCH 2011)

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



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

8.1 INVESTIGATION A:

The learners conduct two experiments using the conditions as shown in the table below.

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

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

8.1.2 Write down an INVESTIGATIVE QUESTION for this investigation. (2)

8.1.3 The learners now repeat **Experiment 1**, but use 4 g of calcium carbonate in excess acid, instead of 2 g. They find that the rate of the reaction INCREASES.

Give a reason why the rate increases. (2)

8.2 INVESTIGATION B:

The learners conduct two experiments using the conditions as shown in the table below.

	Mass of CaCO ₃ (g)	State of CaCO ₃	Concentration of HCl (mol·dm ⁻³)	Temperature of HCl (°C)
Experiment 3	2	lumps	0,2	25
Experiment 4	2	lumps	1,0	25

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

8.2.2 Write down a hypothesis for this investigation.

8.2.3 Is it fair to compare results obtained in **Experiment 3** with that in **Experiment 4**? Give a reason for the answer. (2)

8.2.4 The reactions in **Experiments 3** and **4** both run to completion. How will the yield of CO₂ (g) in **Experiment 3** compare to that in **Experiment 4**? Write down only LARGER THAN, SMALLER THAN or EQUAL TO and give a reason for the answer. (2)

8.3 INVESTIGATION C:

The learners conduct two experiments using the conditions as shown in the table below.

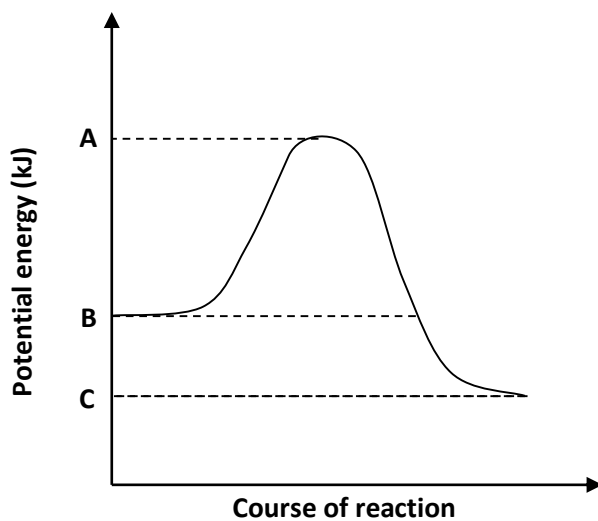
	Mass of CaCO ₃ (g)	State of CaCO ₃	Concentration of HCl (mol·dm ⁻³)	Temperature of HCl (°C)
Experiment 5	4	powder	0,2	25
Experiment 6	4	powder	0,2	35

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

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

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

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



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

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

(a) The energy of the activated complex (1)

(b) ΔH for the forward reaction (1)

[20]

CHEMICAL EQUILIBRIUM

Definitions

Open system – reactants or products can escape from reaction vessel

(An open system continuously interacts with its environment)

Closed system – reactants or products can escape from reaction vessel

(A closed system is isolated from its surroundings)

Macroscopic changes – measurable or visible changes, eg. changes in colour, temperature, pressure, volume, concentration

Yield – the amount of product formed during a chemical reaction

Endothermic reaction – a reaction which absorbs more energy than is released

Exothermic reaction – a reaction which releases more energy than is absorbed

Reversible reaction – reaction that does not go to completion and occurs in both the forward and reverse directions (products can be converted back to reactants)

Dynamic chemical equilibrium – the rate of the forward reaction equals the rate of reverse reaction and they occur simultaneously

Homogeneous equilibrium – all the substances in the system are in the same phase

Heterogeneous equilibrium – substances of different phases occur in the system

Equilibrium constant – ratio of the concentration of products to the concentration of Reactants

FACTORS AFFECTING EQUILIBRIUM

- concentration
- temperature
- pressure (in the case of gases)

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

NB: *Adding a catalyst has NO EFFECT on the equilibrium position, a catalyst only increases the rate of both the forward and the reverse reactions equally.

*If a catalyst is added initially, then the equilibrium position is reached much quicker.

*The addition of an inert gas does not alter the equilibrium position.

Examples:

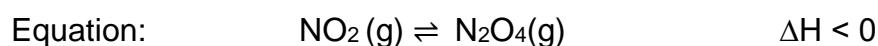
1. Equilibrium mixtures of solutions (**temperature and concentration** play a role)

Equation: $\text{CoCl}_4^{2-}(\text{aq}) + 6\text{H}_2\text{O} \rightleftharpoons \text{Co}(\text{H}_2\text{O})_6^{2+} + 4\text{Cl}^-$ $\Delta H < 0$

Disturbance	Effect on equilibrium	Colour change
1. Temperature		
○ increase	○ favours endothermic	○ turns blue

○ decrease	(reverse) reaction ○ favours exothermic (forward) reaction	○ turns pink
2. Concentration		
○ [H ₂ O] is increased by adding H ₂ O ○ [Cl ⁻] is increased by adding HCl/NaCl (with common Cl ⁻ ion) ○ [Cl ⁻] is decreased by adding Ag ⁺ (Ag ⁺ + Cl ⁻ → AgCl _(s)) ○ [H ₂ O] is decreased by adding a dehydrating agent, eg. H ₂ SO ₄	○ favours forward reaction (which uses up water) ○ favours reverse reaction (which will decrease Cl ⁻) ○ favours forward reaction (which produces more Cl ⁻) ○ favours reverse reaction (which will decrease Cl ⁻)	○ turns pink ○ turns blue ○ turns pink ○ turns blue

2. Gaseous equilibrium mixtures (**temperature and pressure** play a role)



	Disturbance	Effect on equilibrium	Colour change
1. Temperature	○ increase	○ favours endothermic (reverse) reaction	○ colourless to brown
	○ decrease	○ favours exothermic (forward) reaction	○ brown to colourless
2. Pressure	○ increase	○ favours forward reaction (less moles of gas molecules)	○ brown to colourless
	○ decrease	○ favours reverse reaction (more moles of gas molecules)	○ colourless to brown

THE EQUILIBRIUM CONSTANT

It indicates the relationship between the product and reactant concentrations at equilibrium, and is a constant at a specific temperature.

Important:

- The K_c value indicates to what extent reactants have changed into products by the time equilibrium is reached.
- This is of particular importance in the evaluation of the efficiency of industrial processes:
 - ✓ A high K_c value ($K_c > 1$) indicates that a lot product has been formed (the equilibrium lies to the right)
 - ✓ A low K_c value ($K_c < 1$) indicates that more reactants than products are present (the equilibrium lies to the left)
 - ✓ $K_c = 1$ indicates equal concentrations of reactants and products
- It is a number only, without units
- The K_c value changes ONLY if the TEMPERATURE changes
- The K_c value is only calculated using the concentrations of the gases and the aqueous substances in the equation, because these concentrations remain constant

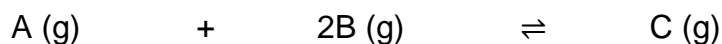
Calculating the equilibrium constant

- Set up a table
- Use the balanced equation to determine the mole ratio of the substances in the equation
- Fill in all the information given in the question in the block where the information belongs
- Calculate whatever you can in the table, keeping in mind that the mole ratio ONLY applies in the 'used/formed' row of the table
- Once the number of moles at equilibrium is known, the concentration at equilibrium can then be calculated
- Once the concentration of each substance at equilibrium has been filled in, the equilibrium constant can then be calculated

Examples

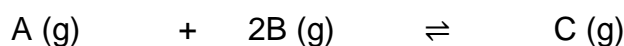
1. 1 mol of A and 2 mol of B react in a 2 dm³ container. If at equilibrium 0,75 mol of C has formed, calculate the value of K_c.

Solution



Mole ratio	1	2	1
Start	1 mol	2 mol	0 mol
Used/Formed	n = 0,75 mol	n = 2 x 0,75 = 1,5 mol	n = 0,75 mol
Equilibrium	n = 1 - 0,75 = 0,25 mol	n = 2 - 1,5 = 0,5 mol	n = 0,75 mol
Concentration	c = n/V = 0,25/2 = 0,125 mol.dm ⁻³	c = n/V = 0,5/2 = 0,25 mol.dm ⁻³	c = n/V = 0,75/2 = 0,375 mol.dm ⁻³

Table "cleaned up"

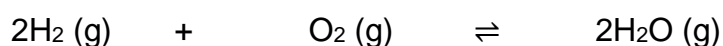


Mole ratio	1	2	1
Start	1	2	0
Used/Formed	- 0,75	- 1,5	+ 0,75
Equilibrium	0,25	1,5	0,75
Concentration	0,125	0,25	0,375

$$K_C = \frac{[C]}{[A][B]^2} = 0,375(0,125)^2 = 48$$

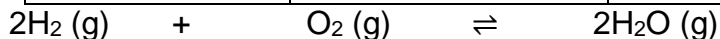
2. 0,5 mol H₂ and 0,5 mol O₂ are placed in a container and allowed to react according to the chemical reaction below. At equilibrium, 9,6 g O₂ remains. Calculate the value of K_c if the volume of the container is 200 cm³.

Solution



Mole ratio	2	1	2
Start	0,5 mol	0,5 mol	0 mol
Used/Formed	n = 0,2 x 2 = 0,4 mol	n = 0,5 - 0,3 = 0,2 mol	n = 0,4 mol
Equilibrium	n = 0,5 - 0,4 = 0,1 mol	n = m/M = 9,6/32 = 0,3 mol	0,4 mol
Concentration	c = n/V	c = n/V	c = n/V

	= 0,1/0,2 = 0,5 mol.dm ⁻³	= 0,3/0,2 = 1,5 mol.dm ⁻³	= 0,4/0,2 = 2 mol.dm ⁻³
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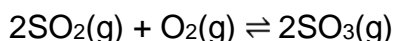
Mole ratio	2	1	2
Start	0,5	0,5	0
Used/Formatted	-0,4	-0,2	+0,4
Equilibrium	0,1	0,3	0,4
Concentration	0,5	1,5	2

$$K_C = \frac{[\text{H}_2\text{O}]}{[\text{H}_2][\text{O}_2]^2} = \frac{2^2}{0,5^2 (1,5)} = 10,67$$

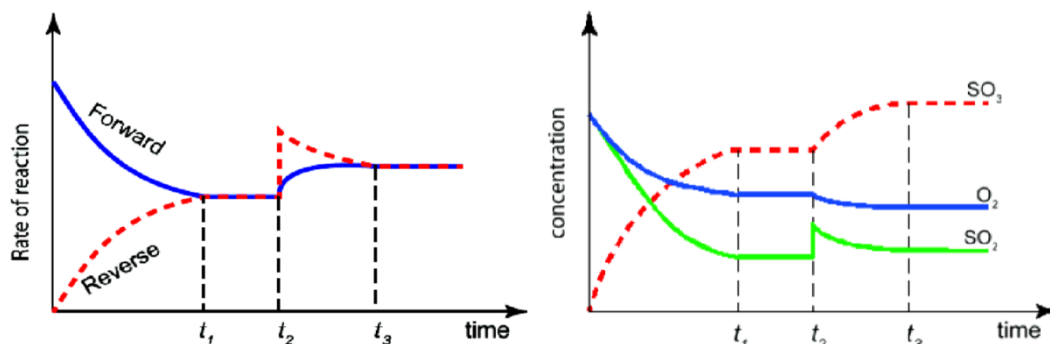
Graphs for Equilibrium

Changing the concentration of reactants or products

Increasing concentration of a reactant will speed up the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. Forward reaction will be favoured to re-establish the equilibrium.

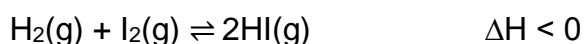


At time t_2 , the concentration of SO_2 is increased.

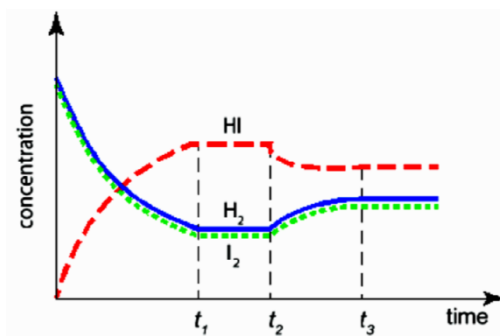
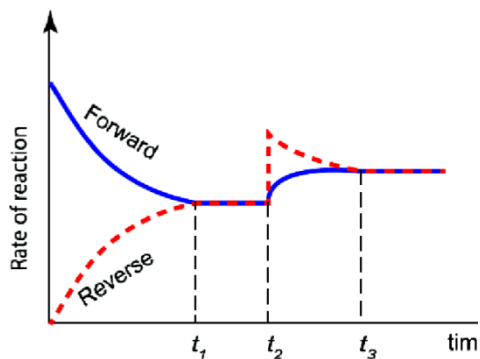


Changing the temperature

Increasing temperature increases the rates of both reactions but the rate of the endothermic reaction increases more than the rate of the exothermic reaction. An increase in a temperature will favour the endothermic reaction to re-establish of a reactant will speed up the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. The forward reaction will be favoured to re-establish the new equilibrium.



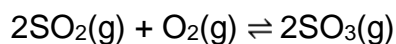
At time t_2 , the temperature of the container is increased.



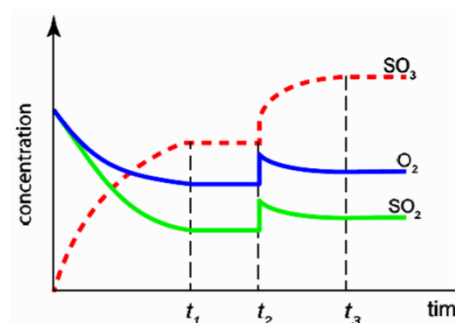
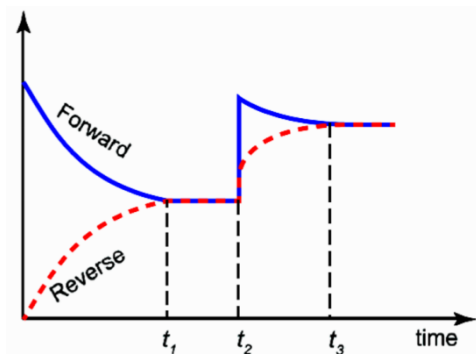
Changing the pressure

Changing the volume of the gases will change the pressure in system. **But this change will also change the concentration of both reactants and products.**

If the pressure is increased by decreasing the volume of the container, concentration of both reactants and products are increased. The reaction with the fewer mole sides will be favoured to re-establish the new equilibrium. Pressure is only for gases.

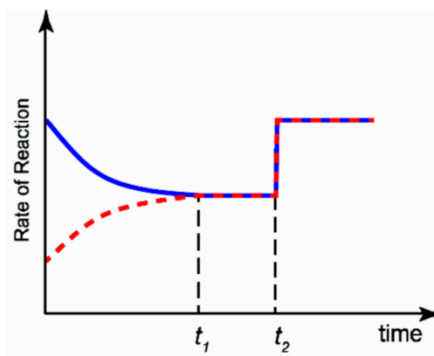


In this example when the pressure is increased, the rates of both reactions will increase but forward reaction will increase more than the reverse reaction.



Use of a catalyst

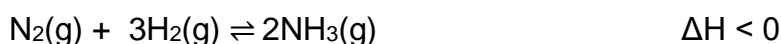
A catalyst increases the rate of both the **forward and the reverse reactions equally so that the equilibrium position won't be changed**. The reaction will take place at a higher rate. No change in the concentration.



Activities

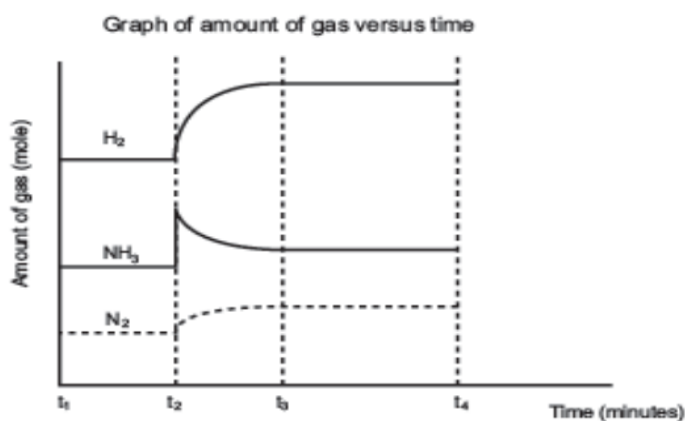
QUESTION 1

1.1 The following equation represents a reversible reaction that has reached equilibrium at 470°C in a closed container:



A change was then made to the system at t_2 . A graph showing the effect of this change is drawn below.

(The graph is not drawn to scale.)



- 1.1.1 What is implied by the horizontal lines between t_1 and t_2 ? (1)
- 1.1.2 State the change that was made to the system at time t_2 . (1)
- 1.1.3 Using Le Chatelier's principle explain why the concentrations of H₂ and N₂ gases changed as shown in the graph at t_2 . (3)

1,5 mol of N₂(g) and 2 mol H₂(g) were injected into a 0,5 dm³ closed reaction vessel and allowed to reach equilibrium at 470°C. When equilibrium was reached it was found that 1 mol of NH₃(g) was present.

1.1.4 Calculate the equilibrium constant (K_c) at 470°C .

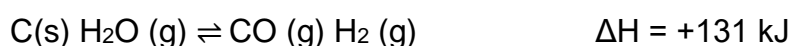
Show ALL your calculations. (8)

1.1.5 The temperature is now increased to 800°C .

a) How will the value of K_c be affected if the temperature is increased to 800°C ? Write down only INCREASES or DECREASES or REMAINS THE SAME. (1)

b) Explain, with reference to Le Chatelier's principle, your answer to question 1.1.5a). (5)

1.2 A rigid container holds a mixture of graphite pellets, water vapour, carbon monoxide and hydrogen gas at equilibrium.



State whether the number of moles of CO (g) in the container will **increase, decrease, or remain the same** after each of the following disturbances is applied to the original mixture.

For each case, assume that all other variables remain constant except for the given disturbance.

1.2.1 The volume of the container is decreased at constant temperature. (2)

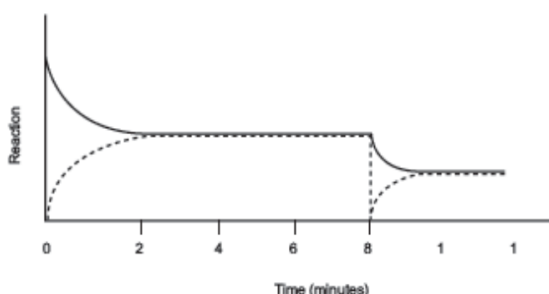
1.2.2 The graphite pellets are pulverized (crushed). (2)

QUESTION 2

The gas XA_3 is introduced into an empty flask which is then sealed. The XA_3 gas decomposes and sets up equilibrium at 300°C , as represented by the following balanced chemical equation.



The graph below shows the change in reaction rate over 12 minutes:



2.1 Write down the balanced equation which is represented by the broken line. (2)

2.2 After 8 minutes the pressure is decreased.

2.2.1 State *Le Chatelier's Principle*. (2)

2.2.2 Apply Le Chatelier's principle to the reaction in order to EXPLAIN the changes shown on the graph between 8 and 10 minutes. (3)

2.3 Write down an expression for the equilibrium constant (K_c) for this reaction. (2)

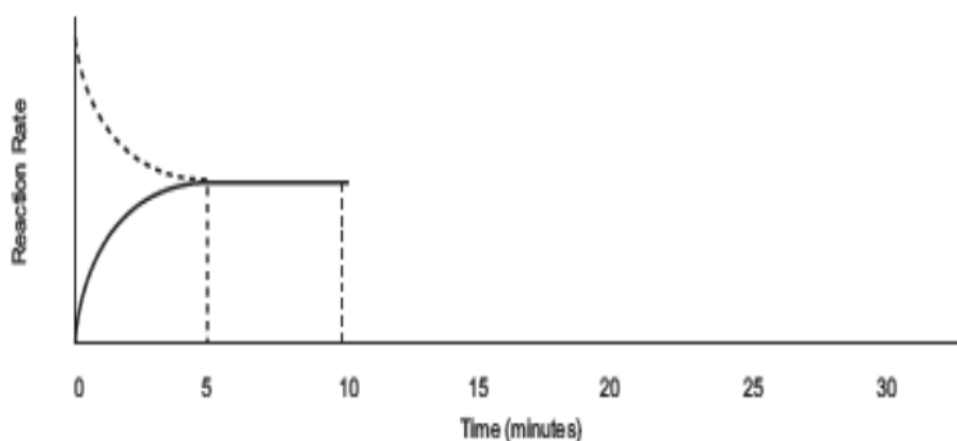
2.4 Initially 5 mol of XA_3 (g) was sealed in a 2 dm^3 flask. At equilibrium the reaction mixture contained exactly 1, 5 mol of A_2 (g) at 300°C . Calculate the value of the equilibrium constant (K_c) at this temperature. (6)

QUESTION 3

Nitrogen monoxide is an atmospheric pollutant, formed inside car engines by the reaction between nitrogen and oxygen:



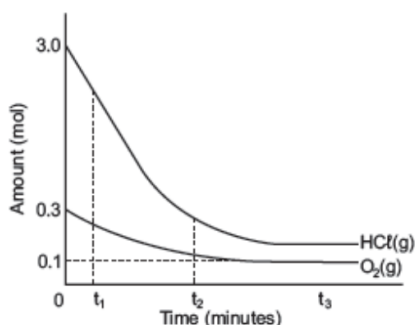
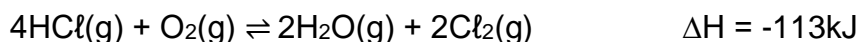
Consider the graph below of reaction rate versus time for the reaction shown above. 4 mol of NO were added to a $0,5 \text{ dm}^3$ container and sealed at 25°C . The equilibrium constant for this reaction at 25°C is $4,8 \times 10^{-4}$.



- 3.1 Which reaction (forward or reverse) is represented by the solid line? Give a reason for your answer. (2)
- 3.2 What does the magnitude of the equilibrium constant indicate for this reaction? (2)
- 3.3 At what time did the system reach equilibrium? (1)
- 3.4 How will the value of the equilibrium constant at 8 minutes compare with its value at 17 minutes? Write down only *greater than*, *less than* or *equal to*. (2)
- 3.5 Explain, with reference to the rates of the forward and reverse reactions, how the yield of NO would be affected by a decrease in temperature. (4)
- 3.6 Write the expression for the equilibrium constant for this reaction. (2)

QUESTION 4

The reaction between hydrogen chloride and oxygen reaches equilibrium in a closed container according to the following balanced equation:



4.1 The graph above, not drawn to scale, shows how the amounts of reactants present in the container change with time at a specific temperature. The volume of the container is 5 dm^3 .

4.1.1 How does the rate of the forward reaction at time t_1 compare to that at time t_2 ? Write down GREATER THAN, SMALLER THAN or EQUAL TO. Use the graphs to give a reason for the answer. (2)

4.1.2 How does the rate of the forward and the reverse reactions compare at time t_3 ? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

4.1.3 Calculate the number of moles of HCl at equilibrium. (4)

4.1.4 Calculate the number of moles of H_2O and Cl_2 at equilibrium. (3)

4.1.5 Write down an expression for the equilibrium constant (K_c) for this reaction. (4)

4.1.6 Calculate the equilibrium constant (K_c) for this reaction at this temperature. (5)

4.2 The temperature is NOW increased. How will this change affect the value of the equilibrium constant? Write down INCREASES, DECREASES or REMAINS THE SAME. Explain your answer. (4)

4.3 How will each of the following changes affect the equilibrium concentration of $\text{Cl}_2(\text{g})$? Write down INCREASES, DECREASES or REMAINS THE SAME.

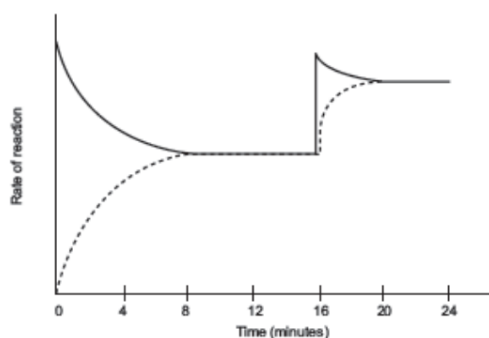
4.3.1 Water vapour is added into the container. (2)

4.3.2 A catalyst is added. (2)

4.3.3 The volume of the container is increased. (2)

QUESTION 5

Exactly 12,0 mol SO_3 (g) is sealed in an empty 2,0 dm^3 container. The following reaction reaches equilibrium at 700 K after 8 minutes.

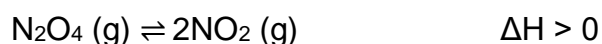


The temperature is increased to 800 K at the 16th minute. The graph below shows the changes in the rate of the reaction over 24 minutes from the time that the 12,0 mol of SO_3 was introduced into the container.

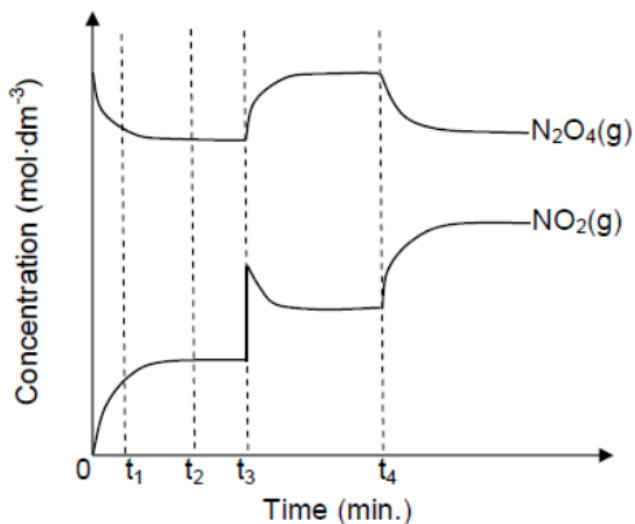
- 5.1 Write down the balanced equation for the reaction that is represented by the broken line. (2)
- 5.2 What is the reason for the decrease in the reaction rate represented by the solid line between $t = 0$ minutes and $t = 8$ minutes? (2)
- 5.3 Explain how we can determine that the value of K_c at the 24th minute is than larger the value of K_c at the 12th minute? (2)
- 5.4 What does the horizontal part of the graph between the 20th minute and the 24th minute indicate about the reaction? (1)
- 5.5 Extend the graph on the answer sheet if the volume of the container is increased slightly after 24 minutes. (2)

QUESTION 6

A sample of N_2O_4 gas is sealed in a container and heated. The N_2O_4 gas decomposes to NO_2 gas and the reaction reaches equilibrium according to the following balanced equation:



The graph below shows how the concentrations of the two gases change as a result of changes made to the reaction conditions.



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

6.2 How does the rate of the forward reaction compare to that of the reverse reaction at each of the following times? Only write down HIGHER THAN, LOWER THAN or EQUAL TO.

6.2.1 t_1 (1)

6.2.2 t_2 (1)

6.3 What change was made to the reaction conditions at each of the following times? In both instances, the equilibrium constant for the reaction did not change.

6.3.1 t_3 (1)

6.3.2 t_4 (1)

6.4 How will an increase in temperature influence the yield of $\text{NO}_2(\text{g})$?

Write down INCREASES, DECREASES or REMAINS THE SAME. Use Le Chatelier's principle to explain the answer. (3)

6.5 Initially 0,92 mol N_2O_4 gas is sealed in a 2 dm^3 container and heated to $100\text{ }^\circ\text{C}$. At equilibrium it is found that 20,7% of the N_2O_4 gas has decomposed to NO_2 gas. Calculate the equilibrium constant (K_c) for this reaction at $100\text{ }^\circ\text{C}$. (7)

ACIDS AND BASES

Acid	(Arrhenius theory): is a substance that produces hydrogen ions (H^+) / hydronium ions (H_3O^+) when it dissolves in water (Brønsted-Lowry theory): is a proton (H^+ ion) donor.
Strong acid	Ionises completely in water to form a high concentration of H_3O^+ ions. Examples of strong acids are hydrochloric acid (HCl), sulphuric acid (H_2SO_4) and nitric acid (HNO_3).
Weak acid	Ionises incompletely in water to form a low concentration of H_3O^+ ions. Examples of weak acids are ethanoic acid (CH_3COOH) and oxalic acid ($(COOH)_2$).
Concentrated acid	Concentrated acids contain a large amount (number of moles) of acid in proportion to the volume of water.
Diluted acid	Dilute acids contain a small amount (number of moles) of acid in proportion to the volume of water.
Base	(Arrhenius theory): is a substance that produces hydroxide ions (OH^-) when it dissolves in water. (Brønsted-Lowry theory): is a proton (H^+ ion) acceptor.
Strong base	Dissociates (breaks up) completely in water to form a high concentration of OH^- ions. Examples of strong bases are sodium hydroxide ($NaOH$) and potassium hydroxide (KOH).
Weak base	Dissociates/ionises incompletely in water to form a low concentration of OH^- ions. Examples of weak bases are ammonia (NH_3), calcium carbonate ($CaCO_3$), potassium carbonate (K_2CO_3), and sodium hydrogen carbonate ($NaHCO_3$).
Concentrated base	Concentrated bases contain a large amount (number of moles) of base in proportion to the volume of water.
Diluted base	Dilute bases contain a small amount (number of moles) of base in proportion to the volume of water.
Equivalence point	is the point at which the acid / base has completely reacted with the base/acid.
End point	is the point where the indicator changes colour.
Ionisation	a process that takes place when a covalent compound reacts with water to form new ions OR Breaking up of a molecule into charged components (ions). In acid-base reactions this usually means dissolving in water.

1. Properties of acids and bases

	ACIDS	BASES
PROPERTIES	<ul style="list-style-type: none"> • Have a sour taste; • Influence the colour of indicators; • Are electrolytes in solution; • Increase the H⁺-ion concentration in a solution; • Decrease the OH⁻-ion concentration in a solution; • Decrease the pH of a solution. 	<ul style="list-style-type: none"> • Have a bitter taste and feel soapy; • Influence the colour of indicators; • Are electrolytes in solution; • Decrease the H⁺-ion (or H₃O⁺-ion) concentration in a solution; • Increase the OH⁻-ion concentration in a solution; • Increase the pH of a solution.
ACID-BASE THEORIES	ARRHENIUS	
	<ul style="list-style-type: none"> • An acid releases H⁺/ H₃O⁺ -ions/ in aqueous solutions. • $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$ • $\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$ 	<ul style="list-style-type: none"> • A base releases OH⁻ -ions in aqueous solutions. • $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$
ACID-BASE THEORIES	BRØNSTED-LOWRY	
	<ul style="list-style-type: none"> • An acid is a proton donor. • $\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$ • $\text{NH}_4^+ + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{NH}_3$ 	<ul style="list-style-type: none"> • A base is a proton acceptor. • $\text{OH}^- + \text{H}^+ \rightarrow \text{H}_2\text{O}$ • $\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{OH}^- + \text{NH}_4^+$
REACTIONS WITH WATER	<ul style="list-style-type: none"> • Ionise in water to produce hydronium ions <p>E.g. $\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$</p>	<ul style="list-style-type: none"> • Ionic bases like NaOH dissociate in water to form hydroxyl ions. $\text{NaOH(s)} \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$ <ul style="list-style-type: none"> • Ammonia (NH₃) ionises in water to form hydroxyl ions $\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{OH}^- + \text{NH}_4^+$

Activity 1

1. An Arrhenius acid is a substance that

- Accept a proton
- Donates a proton
- Produces H⁺ in an aqueous solution
- Produces OH⁻ in an aqueous solution

(2)

2. Which of the following is an example of the strong base

- A. CaCO_3
- B. KOH
- C. K_2CO
- D. NaHCO_3

(2)

3. An aqueous solution that contains more hydronium ions than hydroxyl ions is a(an)

- A. Acidic solution
- B. Neutral solution
- C. Basic solution
- D. Standardised solution

(2)

4. A solution that has a large amount of dissolved substances in proportion to the volume of water

- A. Strong solution
- B. Weak solution
- C. Concentrated solution
- D. Diluted solution


(2)

5. Which of the following is the property of an acid

- A. Decreases H_3O^+ ion concentration in solution
- B. Decreases OH^- ion concentration in solution
- C. Increases OH^- ion concentration in solution
- D. Increases the pH of a solution



(2)

2. Common acids

	ACID	FORMULA	STRONG / WEAK		EXAMPLES & USES
<p style="text-align: center;">  STRONGEST INCREASING STRENGTH WEAKEST </p>	Hydrochloric acid	HCl	Strong	Ionises almost completely in water	<ul style="list-style-type: none"> Stomach acid (to digest food) Used <ul style="list-style-type: none"> in swimming pools to control the pH (acidity) of the water; to clean metals for soldering.
	Sulphuric acid	H ₂ SO ₄	Strong		Used <ul style="list-style-type: none"> to produce fertilisers; to produce phosphoric acid; as dehydrating agent; as car battery acid and in gold extraction.
	Nitric acid	HNO ₃	Strong		Used <ul style="list-style-type: none"> to produce fertilisers and to produce explosives.
	Oxalic acid	(COOH) ₂	Weak	Ionises partially in water	Used <ul style="list-style-type: none"> to remove rust and stains and as bleach.
	Phosphoric acid	H ₃ PO ₄	Weak		Used <ul style="list-style-type: none"> to add taste to gaseous cold drinks; in dental cement and to produce fertilisers like superphosphates.
	Ethanoic acid	CH ₃ COOH	Weak		Vinegar <ul style="list-style-type: none"> Used to flavour food; to produce plastics; to neutralise hair relaxers and to treat jellyfish stings.
Carbonic acid	H ₂ CO ₃	Weak	Used <ul style="list-style-type: none"> to make gaseous cold drinks. 		

- Strong acid : HCl; H₂SO₄; HNO₃
- Weak acid : CH₃COOH; (COOH)₂
- Strong base : NaOH; KOH; Mg(OH)₂
- Weak base : NH₃; NaHCO₃ ; CaCO₃

3. Common bases

	BASE	FORMULA	STRONG / WEAK		EXAMPLES & USES
STRONGEST  INCREASING STRENGTH	Sodium hydroxide (Caustic soda)	NaOH	Strong	Dissociates completely in water	Used <ul style="list-style-type: none"> in the production of soap and as drain cleaner and to relax the curl in human hair.
	Potassium hydroxide (Caustic potash)	KOH	Strong		Used <ul style="list-style-type: none"> in the production of soap; in the production of biodiesels and as electrolytes in cells.
	Magnesium hydroxide	Mg(OH) ₂	Strong		Used <ul style="list-style-type: none"> in antacids (Milk of Magnesia); in laxatives and to neutralise acidic waste water.
	Calcium hydroxide (Slaked lime)	Ca(OH) ₂	Strong		Used <ul style="list-style-type: none"> to clarify water by removing particles from the water; to neutralise acidic water so that water pipes are not damaged and to neutralise acidic soil.
WEAKEST 	Sodium carbonate (Washing soda)	Na ₂ CO ₃	Weak	Dissociates / Ionises partially in water	Used <ul style="list-style-type: none"> to manufacture glass and to soften water or laundry.
	Calcium carbonate (Limestone)	CaCO ₃	Weak		Found in marble and sea shells. Used <ul style="list-style-type: none"> in the production of cement; in chalk to write with; as an antacid.
	Ammonia	NH ₃	Weak		Used <ul style="list-style-type: none"> to produce nitric acid; to produce fertilizers and in cleaning materials.
	Sodium bicarbonate (Baking soda)	NaHCO ₃	Weak		Used <ul style="list-style-type: none"> in baking to let dough rise

4. Mono - and polyprotic acids

Acids can be classified according to the number of protons (H^+) that they can donate.

NB: **Monoprotic** acids have only one proton (H^+) to donate.

Polyprotic acids can donate two or three protons.

The protons are donated in steps as shown in the examples in the table below.

Monoprotic acids Can only donate only one proton (H^+)	Polyprotic acids Can donate more than one proton (H^+)	
HCl , HNO_3 , CH_3COOH	Diprotic acids Can donate 2 protons (H^+).	Triprotic acids Can donate 3 protons (H^+).
E.g. $HCl \rightarrow H^+ + Cl^-$	H_2SO_4 , H_2CO_3	H_3PO_4
	E.g. $H_2SO_4 \rightarrow H^+ + HSO_4^-$ $HSO_4^- \rightarrow H^+ + SO_4^{2-}$	E.g. $H_3PO_4 \rightarrow H^+ + H_2PO_4^-$ $H_2PO_4^- \rightarrow H^+ + HPO_4^{2-}$ $HPO_4^{2-} \rightarrow H^+ + PO_4^{3-}$

5. Conjugate acid-base pairs

5.1 Acid-base reactions

HINT!

- “Conjugate” is from Latin, it means literally “yoked together” or to be a couple.
- Acid-base reactions take place simultaneously. The acid donates a proton to the base, while the base accepts the proton from the acid.

5.2 Conjugate acids and bases

CONJUGATE ACIDS	
<ul style="list-style-type: none"> • When an acid donates a proton (H^+), a conjugate base is produced. • The acid and its conjugate base are called a conjugate acid-base pair. 	
acid	$\rightleftharpoons H^+ +$ conjugate base
Examples:	
HCl	$\rightleftharpoons H^+ + Cl^-$
acid	conjugate base
H_2SO_4	$\rightleftharpoons H^+ + HSO_4^-$
acid	conjugate base

CONJUGATE BASES	
<ul style="list-style-type: none"> • When a base receives a proton (H^+), a conjugate acid is produced. • The base and its conjugate acid are called a conjugate acid-base pair. 	
base	$+ H^+ \rightleftharpoons$ conjugate acid
Examples:	
OH^-	$+ H^+ \rightleftharpoons H_2O$
base	conjugate acid
HSO_4^-	$+ H^+ \rightleftharpoons H_2SO_4$
base	conjugate acid

Activity 2

1. In the reaction: $\text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\ell) \leftrightarrow \text{HSO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$, the Brønsted-Lowry bases are:

- A H_2O and H_3O^+
- B H_2SO_4 and H_3O^+
- C HSO_4^- and H_3O^+
- D H_2O and HSO_4^-

(2)

Steps to follow when identifying conjugates

1. Find the **acid** on the **left hand side** of the arrow. Label it acid₁.
2. Find the **conjugate base** of this acid on the **right hand side** of the arrow. Label it base₁.
3. Draw a **bracket** to show that these two form an **acid-base conjugate pair**.
4. Find the **base** on the **left hand side** of the arrow. Label it base₂.
5. Find the **conjugate acid** of this base on the **right hand side** of the arrow. Label it acid₂.
6. Draw a **bracket** to show that these two form an **acid-base conjugate pair**.

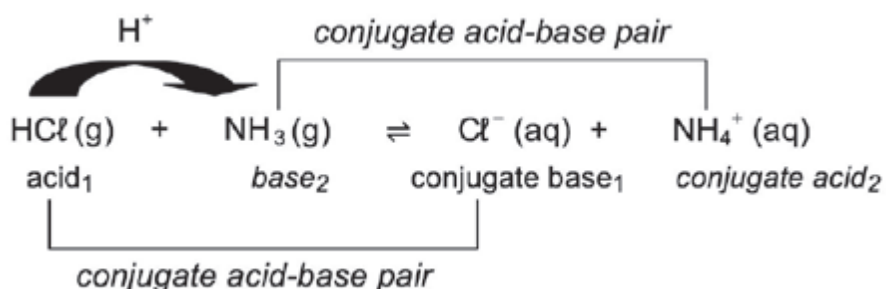
Worked example 1

For each of the following reactions, indicate the acid-base conjugate pairs.

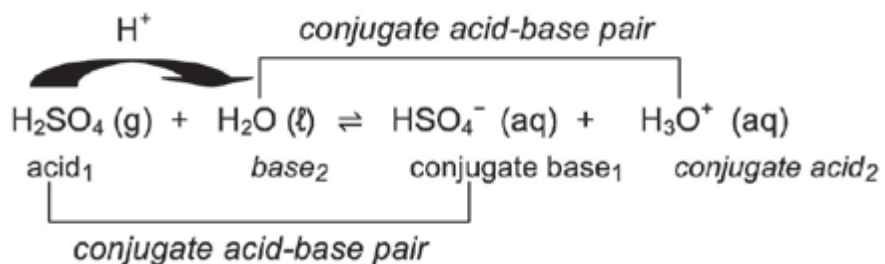
1. $\text{HCl}(\text{g}) + \text{NH}_3(\text{g}) \leftrightarrow \text{Cl}^-(\text{aq}) + \text{NH}_4^+(\text{aq})$
2. $\text{H}_2\text{SO}_4(\text{g}) + \text{H}_2\text{O}(\ell) \leftrightarrow \text{HSO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
3. $\text{H}_3\text{PO}_4(\text{g}) + \text{OH}^-(\text{aq}) \leftrightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O}(\ell)$

Solutions

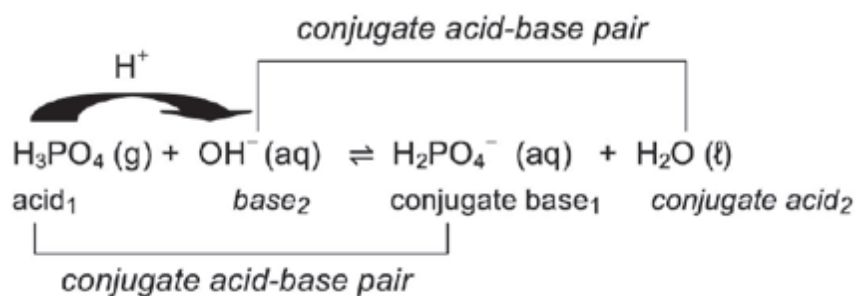
1.



2.



3.



Activity 3

Find the conjugate bases and conjugate acids.

HINT!

- To find the **conjugate base** of an acid, **remove one H⁺ (proton)** from the acid.
- To find the **conjugate acid** of a base, **add one H⁺ (proton)** to the base.



Acid	Conjugate base
HCl	
HNO ₃	
H ₂ SO ₄	
HSO ₄ ⁻	
H ₃ PO ₄	
H ₂ PO ₄ ⁻	
HPO ₄ ²⁻	
H ₂ CO ₃	
HCO ₃ ⁻	
CH ₃ COOH	
(COOH) ₂	
H ₂ O	
NH ₄ ⁺	
H ₃ O ⁺	

Base	Conjugate acid
Cl ⁻	
NO ₃ ⁻	
HSO ₄ ⁻	
SO ₄ ²⁻	
H ₂ PO ₄ ⁻	
HPO ₄ ²⁻	
PO ₄ ³⁻	
HCO ₃ ⁻	
CO ₃ ²⁻	
SO ₄ ²⁻	
HSO ₄ ⁻	
OH ⁻	
NH ₃	
H ₂ O	

6. Ampholyte (amphiprotic) substance

An ampholyte:

- acts as a **base** in the presence of an **acid** and
- acts as an **acid** in the presence of a **base**.

Example:

Water (H₂O) is an ampholyte:

Water as an acid			
H ₂ O(l)	+ NH ₃ (g)	⇌	OH ⁻ (aq) + NH ₄ ⁺ (aq)
acid ₁	base ₂		conjugate base ₁ conjugate acid ₂

Water as a base			
HCl(g)	+ H ₂ O(g)	⇌	Cl ⁻ (aq) + H ₃ O ⁺ (aq)
acid ₁	base ₂		conjugate base ₁ conjugate acid ₂

Show that hydrogen sulphate ion (HSO₄⁻) is an ampholyte. Activity 5

The hydrogen sulphate ion (HSO_4^-) donates a proton when it acts as an acid	
$\text{HSO}_4^-(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$	
acid	conjugate base

The hydrogen sulphate ion (HSO_4^-) accepts a proton when it acts as a base	
$\text{HSO}_4^-(\text{aq}) + \text{H}^+(\text{aq}) \rightleftharpoons \text{H}_2\text{SO}_4(\text{aq})$	
base	conjugate acid

In the acid-base equilibrium formed by adding HSO_4^- and OH^- the acids are:

- A HSO_4^- and H_2SO_4
- B HSO_4^- and H_2O
- C SO_4^{2-} and H_2SO^-
- D SO_4^{2-} and H_2O (2)

Which of the following is amphoteric in water?

- A SO_2
- B HSO_3^-
- C SO_3^{2-}
- D H_2SO_3 (2)

7. Salt hydrolysis

A salt is formed in the reaction between an acid and a base.

When an ionic salt dissolves in water, the ions in the salt dissociate. These ions react with the water and new ions form.

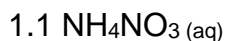
NB: **Hydrolysis** occurs when a salt (a compound made of a metal + nonmetal portion) reacts with water. Hydrolysis, more generally, is the splitting of any compound by reacting it with water.

In this chapter, we only deal with the hydrolysis of salts. (Salt is not just what you have on your table; that is just one type of salt, specifically NaCl . Any metal combined with any nonmetal is a salt).

Worked example 2

Determine whether the solutions of each of the following salts are:

1. acidic or basic, and the pH of each solution is above or below 7?



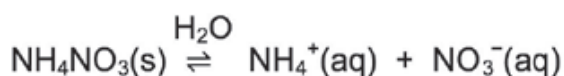
(2)



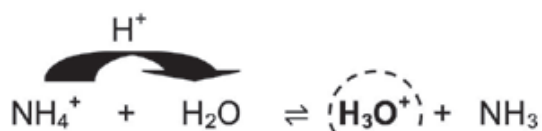
(2)

Solutions

Step 1.

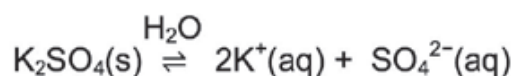


NO_3^- is a spectator ion
 \therefore consider only NH_4^+



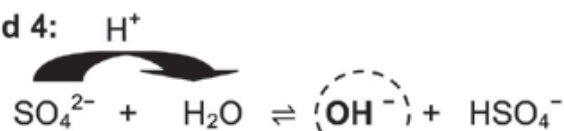
The solution is acidic (due to H_3O^+) ✓
pH < 7 ✓

Step 2.



K^+ is a spectator ion
 \therefore consider only SO_4^{2-}

Steps 3 and 4:

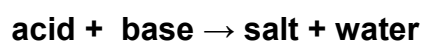


Step 5:

The solution is basic (due to OH^-) ✓
pH > 7 ✓

In summary:

Remember that acids and bases react with each other to form new compounds:



We can determine whether the salt solution is basic or acidic by comparing the strengths of the reacting acids and bases.

- A salt formed between a strong acid and a weak base is an **acidic salt**, for example NH_4Cl .
- When a salt reacts with water to form **hydronium ions** (H_3O^+), the solution is acidic (pH < 7).
- A salt formed between a weak acid and a strong base is a **basic salt**, for example NaCH_3COO .

- When a salt reacts with water to form **hydroxyl ions** (OH^-), the solution is basic ($\text{pH} > 7$).
- **Neutral salt** is formed when a strong acid and a strong base are neutralized in the reaction.

To determine the approximate pH of salts in salt hydrolysis:

H_2O forms H_3O^+	H_2O forms OH^-
<ul style="list-style-type: none"> • H_2O acts as a base; • it receives a proton (H^+) and • H_3O^+ ions form so • the solution is acidic and • $\text{pH} < 7$ 	<ul style="list-style-type: none"> • H_2O acts as an acid; • it donates a proton (H^+) and • OH^- ions form so • the solution is basic and • $\text{pH} > 7$
Hydrolysis reaction: $\text{ion} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{molecule / ion}$	Hydrolysis reaction: $\text{ion} + \text{H}_2\text{O} \rightleftharpoons \text{OH}^- + \text{molecule / ion}$

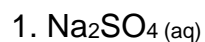
REMEMBER:

- When water reacts with a salt to form hydronium ions (H_3O^+), the solution is acidic ($\text{pH} < 7$).
- When a salt reacts with water to form hydroxyl ions (OH^-), the solution is basic ($\text{pH} > 7$).
- The ions that don't react are called **spectator ions**.
- ❖ Positive spectator ions: cations from Groups I and II e.g. K^+ and Mg^{2+}
- ❖ Negative spectator ions e.g. SO_4^{2-} ; Cl^- ; NO_3^- .

Salt of		Nature of solution	pH in an aqueous solution	Example
Acid	Base			
Strong	Strong	Neutral	pH = 7	NaCl(aq) (HCl + NaOH)
Weak	Weak	Neutral	pH = 7	CH ₃ COONH ₄ (aq) (CH ₃ COOH + NH ₃)
Strong	Weak	Acidic	pH < 7	NH ₄ Cl(aq) (HCl + NH ₃)
Weak	Strong	Basic	pH > 7	CH ₃ COONa(aq) (CH ₃ COOH + NaOH)

Worked example 3

Determine whether each of the following salt solutions are acidic, basic or neutral.



Solutions

1. Acid + Base

H₂SO₄ + NaOH
 Strong + Strong
 = neutral solution

2. Acid + Base

HNO₃ + NH₃
 Strong + Weak
 = acidic solution

8. Acid-base indicators

Indicators:

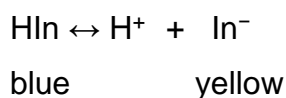
- can be used to determine whether a solution is acidic or basic;
- are weak acids that are in equilibrium with their conjugate bases (or vice versa) and
- have complex structures and formulae which will simply be represented as HIn

(H followed by In for "indicator").

Indicator in equilibrium	
$\text{HIn} \rightleftharpoons \text{H}^+ + \text{In}^-$	
<i>colour 1</i> <i>colour 2</i>	
Indicator in acid <ul style="list-style-type: none"> • The high $[\text{H}^+]$ of the acid will disturb the indicator equilibrium. • According to Le Châtelier's Principle, the reverse reaction, which lowers the $[\text{H}^+]$, will be favoured. • More HIn is produced and the indicator will exhibit colour 1. 	Indicator in base <ul style="list-style-type: none"> • The low $[\text{H}^+]$ of the base will disturb the indicator equilibrium. • According to Le Châtelier's principle the forward reaction, which increases the $[\text{H}^+]$, will be favoured. • More In^- is produced and the indicator will exhibit (show) colour 2.

Worked example 4

Bromothymol blue is an acid-base indicator. The colours it exhibits (shows) can be represented as follows:



A test tube contains a solution to which a drop of bromothymol blue has been added. The solution appears blue.

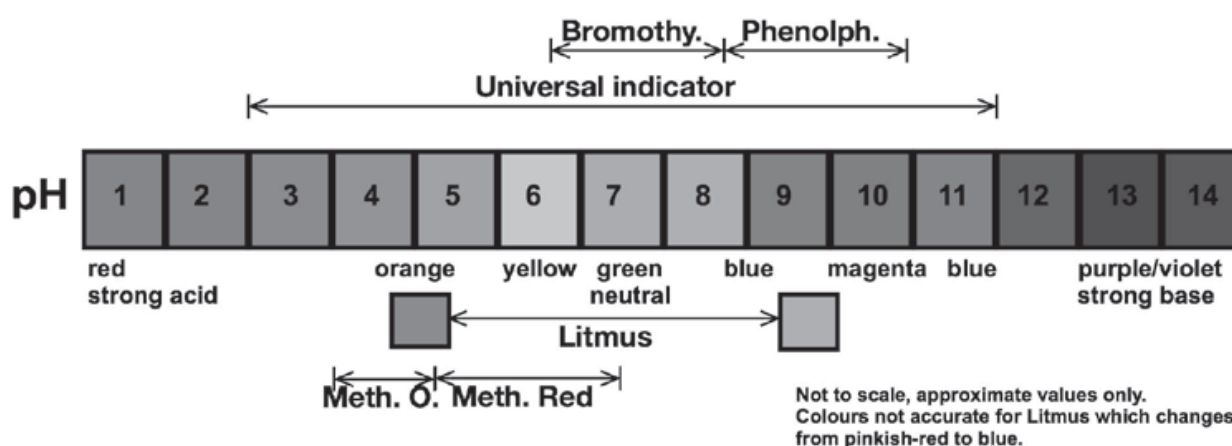
1. What will you observe if a few drops of concentrated hydrochloric acid are added to the test tube?
2. Explain your answer.

Solutions

1. The colour of the solution changes from blue to yellow.
2. Adding hydrochloric acid increases the concentration of the H^+ ions in solution. According to Le Châtelier's Principle the reverse reaction that opposes this change and decreases the $[\text{H}^+]$, will be favoured. Therefore the $[\text{HIn}]$ increases and the colour changes to blue.

The most common indicators that are used in laboratories are:

INDICATOR	pH RANGE	COLOUR CHANGE
methyl orange	3,1 - 4,4	red to orange to yellow
methyl red	4,2 - 6,2	red to yellow
litmus	4,5 - 8,3	red to blue
bromothymol blue	6,0 - 7,8	yellow to blue
phenolphthalein	8.3 - 10	pink-purple (magenta) in range, colourless outside range
universal	3-11	red (3 and below); 3-6 orange/yellow; 7 green; 8-11 blue; 11 and above, violet.



Choose the most suitable indicator for a particular titration. If you do not have Universal Indicator available, you should follow these steps:

Step by step – universal indicator

Step 1: Identify the strength of the acid and the base (pH range maximum and minimum)

Step 2: Draw a bracket to show the strength of the identified acid and base (shown as a line with arrowheads above)

Step 3: Note or mark the mid-point (centre) of the bracket (or line as shown above)

Step 4: Use the indicator table to choose the indicator that shows the range of pH around the mid-point (centre) of that bracket/line.

RESULT: You now have selected the appropriate indicator to use.

Worked example 5

Which one of the indicators given below will be the most suitable to be used in the titration of ethanoic acid against sodium hydroxide?

	INDICATOR	pH COLOUR CHANGE RANGE
A	bromothymol blue	6,0 – 7,8
B	phenolphthalein	8,3 – 10
C	methyl orange	3,1 – 4,4
D	methyl red	4,2 - 6,2

Solution

Consult the table at Sections (3) and (4) above.

We see Ethanoic Acid has a pH of about 2, 4 (1M solution), and NaOH has a pH of about 14.

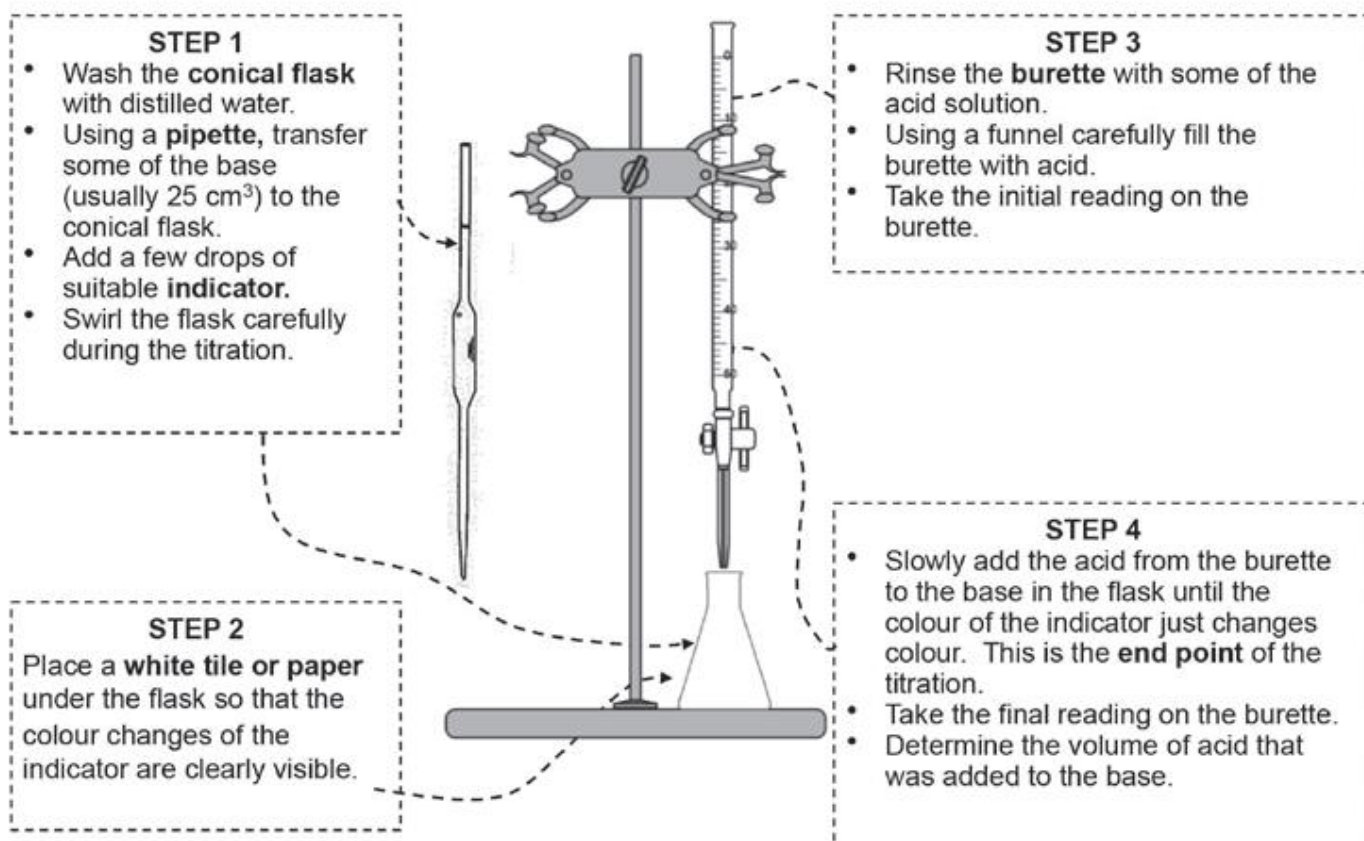
The mid-point between 2, 4 and 14 is about 5, 8, so any indicator which changes from indicating acid to base around 5,8 would do.

Answer: D; methyl red.

9. Acid-base titrations (volumetric analysis)

Titration is used to experimentally determine the concentration of an unknown acid or base. When the titration results are used to determine the concentration of the unknown solution it is called a **volumetric analysis**.

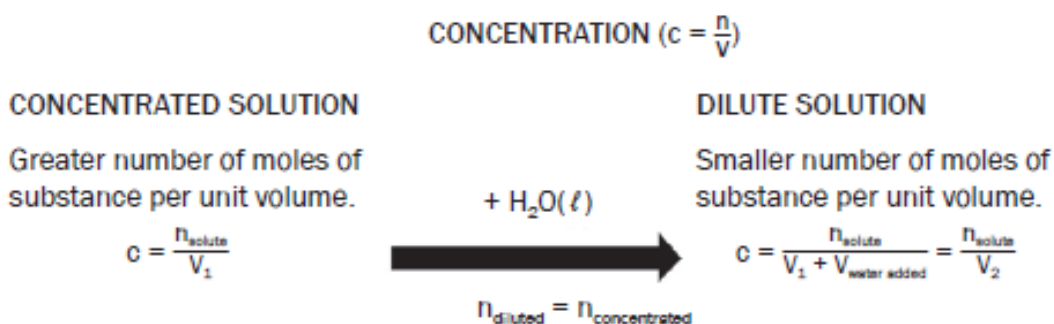
a) Method and apparatus for an acid-base titration



10. Preparing a standard solution

A standard solution has a known concentration which remains constant for a period of time.

Standard solutions are often used in laboratories and it is important to know how to prepare a standard solution.

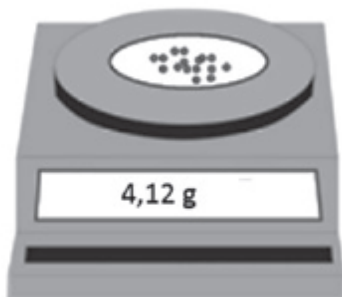


Worked example 6

Aim: To prepare a 200 cm³ NaOH standard solution with a concentration of 0,5 mol·dm⁻³.

Step 1: Calculate the mass of NaOH pellets required. $m(\text{NaOH}) = 40 + 16 + 1 = 40$ g·mol⁻¹

Step 2: Use an electronic scale (balance) to measure off ± 4,4 g NaOH.



Step 3: Note the exact mass of NaOH on the scale.

Step 4: Transfer the NaOH pellets to a volumetric flask. Add ± 100 cm³ of distilled water to the flask and seal it with a stopper. Shake the flask carefully until all the solute (NaOH) has dissolved.

Step 5: Slowly fill the flask to the calibration mark on the neck of the flask.

Step 6: Now calculate the exact concentration of the prepared solution – use the mass that was noted on the scale in Step 3.

$$\begin{aligned}n &= \frac{m}{M} \\ &= \frac{4,1}{40} \\ &= 0,103 \text{ mol}\end{aligned}$$

and

$$\begin{aligned}c &= \frac{n}{V} \\ &= \frac{0,103}{0,3} \\ &= 0,52 \text{ mol}\cdot\text{dm}^{-3}\end{aligned}$$

A standard NaOH_(aq) solution of concentration 0,52 mol·dm⁻³ has been prepared.

11. Dilution of solutions

We sometimes need to dilute a solution so that we can use it in a laboratory. We do this by taking a small amount of the solution and adding distilled water to it.

When diluting a solution, we need to know:

- the exact amount of distilled water that needs to be added as well as

- the exact concentration of the dilute solution.

In symbols:

$$c_1 V_1 = c_2 V_2$$

- c_1 - concentration 1 (mol.dm⁻³)
- V_1 - volume 1 (dm⁻³)
- c_2 - concentration 2 (mol.dm⁻³)
- V_2 - volume 2 (dm⁻³)

Remember:

When a solution is diluted, the number of moles of substance remains constant. Only the volume of the solution changes (hence n is omitted in this equation.)

WORKED EXAMPLE 7

Solution 1 has a concentration of 0,2 mol·dm⁻³. Exactly 150 cm³ of solution A is transferred to a beaker 2 and 250 cm³ of distilled water is added to the beaker.

Calculate the concentration of the diluted solution.

$$c_1 V_1 = c_2 V_2$$

$$(0,2)(150) = c_2 (400)$$

$$c_2 = \frac{(0,2)(150)}{400}$$

$$= 0,075 \text{ mol}\cdot\text{dm}^{-3}$$

The volume of the final solution (V_2) is:

$$V_2 = V_1 + V_{\text{water}}$$

$$= 150 + 250$$

$$= 400 \text{ cm}^3$$

$$400 \text{ cm}^3 = 400 \div 1000 = 0,4 \text{ dm}^3$$

12. Acid-base titration calculations

$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$	$c = \frac{n}{V}$	n : mol (mol) c : concentration (mol.dm ⁻³) V : volume (dm ⁻³)
	$c = \frac{m}{MV}$	a : acid b : base
	$n = \frac{m}{M}$	

REMEMBER:

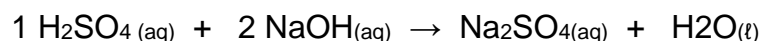
- To convert volume from cm³ to dm³ (by dividing by 1000).

Worked example 8

During a titration 20 cm³ diluted H₂SO₄ precisely neutralises 25 cm³ of a NaOH solution. If the concentration of the H₂SO₄ solution is 0,5 mol·dm⁻³, calculate the concentration of the NaOH.

SOLUTION

First write down the balanced reaction.



Find the mol ratio of acid: base: H₂SO₄: NaOH = 1: 2

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

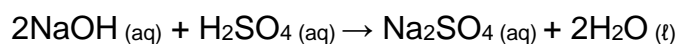
$$\frac{1}{2} = \frac{(0,5)(20)}{c_b (25)}$$

$$1. c_b (25) = (0,5)(20)(2) = 0,8 \text{ mol}\cdot\text{dm}^{-3}$$

Worked example 9

TITRATION CALCULATIONS

Eight grams (8,0 g) of sodium hydroxide are dissolved in 350 cm³ of distilled water. 15 cm³ of this solution neutralises 20 cm³ of a sulphuric acid solution. The balanced equation for this reaction is:



Calculate the concentration of the sulphuric acid solution.

Solution

STEP 1

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

$$c = \frac{8}{(40 \times 0,35)}$$

$$c = 0,57 \text{ mol}\cdot\text{dm}^{-3}$$

OR

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

$$n = \frac{8}{40} = 0,2 \text{ mol NaOH}$$

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

$$c = \frac{0,2}{0,35}$$

$$c = 0,5 \text{ mol}\cdot\text{dm}^{-3}$$

Solution**STEP 1**

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

$$c = \frac{8}{(40 \times 0,35)}$$

$$c = 0,57 \text{ mol}\cdot\text{dm}^{-3}$$

OR

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

$$n = \frac{8}{40} = 0,2 \text{ mol NaOH}$$

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

$$c = \frac{0,2}{0,35}$$

$$c = 0,5 \text{ mol}\cdot\text{dm}^{-3}$$

STEP 2

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

From the balanced equation $2 n(\text{NaOH}) : 1 n(\text{H}_2\text{SO}_4)$

$$\frac{1}{2} = (c_a \times 0,02)$$

$$(0,57 \times 0,025)$$

$$c_a = 0,36 \text{ mol}\cdot\text{dm}^{-3}$$

Worked example 10

The titration of oxalic acid with sodium hydroxide

Part 1:

Aim: To prepare a 250 cm^3 of oxalic acid standard solution with a concentration of $0,08 \text{ mol}\cdot\text{dm}^{-3}$

Solutions

Step 1

- Measure between 2, 5 and 2, 7 g of pure oxalic acid hydrate crystals $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$ into the glass beaker and weigh again.
- Add 30-60 cm^3 of distilled water to the glass beaker and dissolve the crystals.
- Transfer the solution into a clean 250 cm^3 volumetric flask.
- Rinse the beaker with 15-20 cm^3 of distilled water and pour this solution into the volumetric flask and repeat. This will ensure that all of the oxalic acid is transferred into the volumetric flask.
- Fill the volumetric flask to within about 2 cm of the mark and allow it to sit for a minute. This will allow any water clinging to the edges of the neck to drain into the flask. Using an eyedropper, fill the flask to the calibrated mark with water.
- Stopper (close) the flask and mix the solution by repeated inversion (turning upside-down) and swirling. This requires about 30 inversions and takes close to 1 minute.

Step 2

- Calculate the exact concentration of the oxalic acid solution using the mass of acid used and the volume of the volumetric flask and record the concentration of your solution on the bottle.
- If you have used the following

Mass oxalic acid crystals 2, 6 g

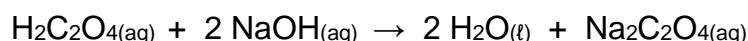
Final volume solution 250, 0 cm^3

- Using the above information to calculate the number of moles and concentration of oxalic acid crystals.

Part 2:

Procedure to perform (to do) a titration of sodium hydroxide with oxalic acid.

Aim: use a standard solution of oxalic acid to determine the concentration of sodium hydroxide



Solutions

- Measure exact 25, 00 cm^3 of the oxalic acid standard solution ($c = 0,084 \text{ mol}\cdot\text{dm}^{-3}$) into a flask and add few drops of phenolphthalein.

- In this titration the oxalic acid solution is acidic and therefore phenolphthalein will be **colourless**.
- The sodium hydroxide solution will be added drop wise (drop by drop) from a burette into the flask containing the oxalic acid and indicator.
- As the sodium hydroxide is added to the flask it will react with the oxalic acid and be neutralized.
- At the point where all of the oxalic acid is reacted, the next drop of sodium hydroxide will make the entire solution basic and it will turn pink. At this point you have completed the titration.

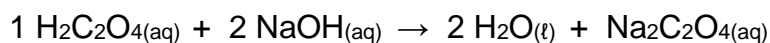
Results (If the following data and results were obtained after at least three trials)

- Volume oxalic acid solution 25,00 cm³
- Volume sodium hydroxide to titrate 19,43 cm³

Mole of sodium hydroxide reacted:

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

First write down the balanced reaction.



Find the mol ratio of acid: base ... ratio of H₂C₂O₄: NaOH = 1: 2

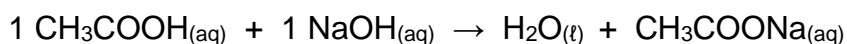
$$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$

$$\frac{1}{2} = \frac{(0,084)(25)}{c_b (25)}$$

$$1. c_b (19) = (0,084)(25)(2) = 0, 0,216 \text{ mol}\cdot\text{dm}^{-3}$$

Part 3:

In order to determine the concentration of acetic acid in the vinegar solution you will titrate it with the standardized sodium hydroxide solution. The equation for this reaction is

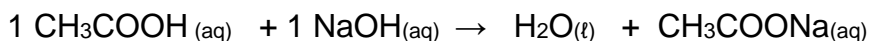


The following data was obtained during titration

- Volume vinegar solution 25,00 cm³
- Volume sodium hydroxide titrated 22,84 cm³

Calculations for determining concentration of acetic acid in vinegar

First write down the balanced reaction.



Find the mol ratio of acid: base ... $\text{CH}_3\text{COOH} : \text{NaOH} = 1 : 1$

From a balanced equation 2 n (NaOH): 1 n (H_2SO_4)

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

$$\frac{1}{1} = \frac{(c_a)(25)}{(0,216)(22,84)}$$

$$1 \cdot (0,216)(22,84) = c_a(25)$$
$$c_a = 0,197 \text{ mol}\cdot\text{dm}^{-3}$$

In order to get the best precision possible, you should repeat each titration until you get 3 trials that are within 1% of each other.

13. The Equilibrium Constant (Kc) - (The Law of Mass Action)

- The concentrations of all the compounds (solutions and gases) in a closed system in dynamic chemical equilibrium are related by a mathematical equation.
- The numerical value of this equation is called the **equilibrium constant (Kc)**.

Solids and pure liquids are omitted from the Kc expression as their concentration is [1], as multiplying by 1 has no effect.

In the hypothetical equation below the equilibrium expression for this reaction is:



$$K_c = \frac{[\text{S}]^2 \times [\text{T}]^4}{[\text{P}]^2 \times [\text{R}]^3}$$

- This is the correct way of writing the Kc expression
- The coefficients are the moles of each reactant and product in the balanced equation
- The product of the concentration of **reactants** (not to be added, but multiplied!!), raised to the power of the number of moles is the **numerator**

- The product of the concentration of **products** (not to be added, but multiplied!!), raised to the power of the number of moles is the **denominator**
- The concentrations used in the Law of Mass Action is the **[reactant]_{equilibrium}** and **[product]_{equilibrium}** (NOT initial concentrations!! i.e. the concentrations of reactants and products at equilibrium)

HINT!

K_c : equilibrium constant (no unit)

[substance] : concentration of reactant or product (in mol·dm⁻³)

mol : number of moles of each compound in the balanced reaction equation

14. K_a and K_b values

Since the ionisation of a weak acid is an equilibrium, a chemical equation and an equilibrium constant expression can be written as follows.

Remember that square brackets [] means “concentration”, or moles per dm³.



$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

The equilibrium constant for the ionisation of an acid is called the **acid ionisation constant** (K_a).

A similar expression can be written for bases:



$$K_b = \frac{[\text{OH}^-][\text{HA}^+]}{[\text{A}^+]}$$

The equilibrium constant for the ionisation of a base is called the **base ionisation constant** (K_b).

ACIDS	BASES
Ionisation of acid (HA): $HA + H_2O \rightleftharpoons H_3O^+ + A^-$	Ionisation of base (B): $B + H_2O \rightleftharpoons OH^- + BH^+ (aq)$
$K_a = \frac{[H_3O^+][A^-]}{[HA]}$	$K_b = \frac{[OH^-][BH^+]}{[B]}$ (NB: here we substituted in values from the line above!)
Strong acid \rightarrow high K_a -value (>1) Weak acid \rightarrow low K_a -value (<1)	Strong base \rightarrow high K_b -value (>1) Weak base \rightarrow low K_b -value (<1)

Examples:

$HC\ell(g) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C\ell^-(aq)$	$NH_3(g) + H_2O(l) \rightleftharpoons OH^-(aq) + NH_4^+(aq)$
	Dissociation of base: $H_2O(l)$ $NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$ $K_b = [Na^+][OH^-]$

- An acid or base's strength refers to its degree of ionisation.
- A strong acid will completely ionise in water while a weak acid will only partially ionise.
- Since there are different degrees of ionisation, there are different levels of weakness. Fortunately, there is a simple quantitative way of expressing this.

Activity 6

Do you think a strong acid will have larger or smaller K_a value? **Explain your answer.**
(3)

Activity 7

Choose the strongest base in the list below by comparing their K_b values.

	Base	K_b
A	Ammonia, NH_3	$1,8 \times 10^{-5}$
B	Hydroxylamine, $HONH_2$	$9,1 \times 10^{-9}$
C	Ethylamine, $C_2H_5NH_2$	$4,3 \times 10^{-4}$

(2)

15. The relationship between K_a and K_b for a substance

We know that the strength of a conjugate base is inversely proportional to the strength of the conjugate acid; i.e. weak acids produce strong conjugate bases, and vice versa.

ACID	CONJUGATE BASE
$\text{HA}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{A}^-(\text{aq})$	$\text{A}^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HA}(\text{aq}) + \text{OH}^-(\text{aq})$
$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$	$K_b = \frac{[\text{OH}^-][\text{HA}]}{[\text{A}^-]}$
Then follows:	
$K_a K_b = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} \times \frac{[\text{HA}][\text{OH}^-]}{[\text{A}^-]} = [\text{H}_3\text{O}^+][\text{OH}^-]$	
But:	
$[\text{H}_3\text{O}^+][\text{OH}^-] = K_w = 1 \times 10^{-14}$	

16. Auto-ionisation of water

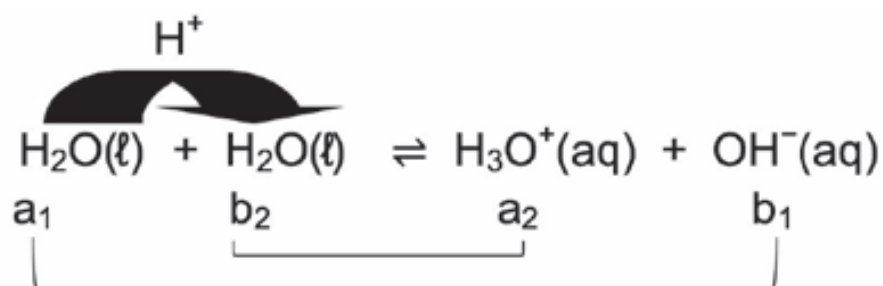
Water is an ampholyte and can react as an acid (donates a H^+) or a base (accepts a H^+).

Two water molecules can undergo **autoprotolysis or auto-ionisation**. One water molecule can act as an acid and donate a H^+ to the other water molecule, the base.

An acid : $\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$

A base : $\text{H}_2\text{O} + \text{H}^+ \rightleftharpoons \text{H}_3\text{O}^+$

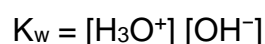
- Water is a weak acid and a weak base.
- Low % auto-ionisation occurs.
- Pure water is a weak electrical conductor.



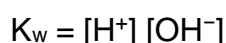
17. Equilibrium constant for water (K_w)

From the acid-base reaction for water the equilibrium expression for water can be written.





- K_w : equilibrium constant for water
- At 25°C: $K_w = 1 \times 10^{-14}$
- Water has a low percentage of ionisation with a low concentration of products. The K_w - value will be low.
- Due to the symbol H^+ often being used instead of H_3O^+ , the ionization constant (ion product) for water can also be written as:



Therefore: Ion product for water: $K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = [\text{H}^+][\text{OH}^-] = 1 \times 10^{-14}$ at 25 °C

18. The pH scale

pH of a solution is the negative logarithm of the hydronium ion concentration in a solution.

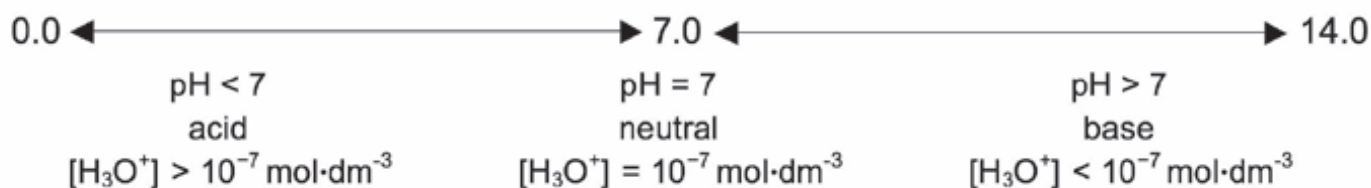
$$\text{pH} = \log [\text{H}_3\text{O}^+]$$

We know $K_w = [\text{H}_3\text{O}^+] [\text{OH}^-] = [\text{H}^+] [\text{OH}^-] = 1 \times 10^{-14}$

therefore

$$[\text{H}_3\text{O}^+] = [\text{OH}^-] = 10^{-7} \quad \text{or} \quad [\text{H}^+] = [\text{OH}^-] = 10^{-7}$$

Acid solution	Neutral solution	Base solution
$[\text{H}_3\text{O}^+] > [\text{OH}^-]$ OR $[\text{H}^+] > [\text{OH}^-]$	$[\text{H}_3\text{O}^+] = [\text{OH}^-]$ OR $[\text{H}^+] = [\text{OH}^-]$	$[\text{H}_3\text{O}^+] < [\text{OH}^-]$ OR $[\text{H}^+] < [\text{OH}^-]$
$[\text{H}_3\text{O}^+] > 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$	$[\text{H}_3\text{O}^+] = 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$	$[\text{H}_3\text{O}^+] < 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$



Worked example 11

Determine whether the following solutions are acidic, basic or neutral:

A solution with	
$[\text{H}_3\text{O}^+] = 10^{-3} \text{ mol}\cdot\text{dm}^{-3}$	1. A solution with $[\text{H}_3\text{O}^+] = 10^{-3} \text{ mol}\cdot\text{dm}^{-3}$ $10^{-3} \text{ mol}\cdot\text{dm}^{-3} > 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$ \therefore Solution is acidic
$[\text{H}_3\text{O}^+] = 10^{-12} \text{ mol}\cdot\text{dm}^{-3}$	2. A solution with $[\text{H}_3\text{O}^+] = 10^{-12} \text{ mol}\cdot\text{dm}^{-3}$ $10^{-12} \text{ mol}\cdot\text{dm}^{-3} < 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$ \therefore Solution is basic
$[\text{OH}^-] = 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$	3. A solution with $[\text{OH}^-] = 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$ $[\text{H}_3\text{O}^+][\text{OH}^-] = 10^{-14}$ $\therefore [\text{H}_3\text{O}^+] (10^{-7}) = 10^{-14}$ $\therefore [\text{H}_3\text{O}^+] = 10^{-14} \div 10^{-7} = 10^{-7}$ \therefore Solution is neutral
$[\text{OH}^-] = 10^{-4} \text{ mol}\cdot\text{dm}^{-3}$	4. A solution with $[\text{OH}^-] = 10^{-4} \text{ mol}\cdot\text{dm}^{-3}$ $[\text{H}_3\text{O}^+][\text{OH}^-] = 10^{-14}$ $\therefore [\text{H}_3\text{O}^+] (10^{-4}) = 10^{-14}$ $\therefore [\text{H}_3\text{O}^+] = 10^{-14} \div 10^{-4} = 10^{-10}$ $10^{-10} \text{ mol}\cdot\text{dm}^{-3} < 10^{-7} \text{ mol}\cdot\text{dm}^{-3}$ \therefore Solution is basic

19. pH Calculations for strong acids and bases

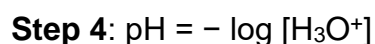
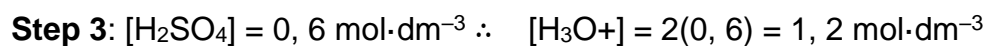
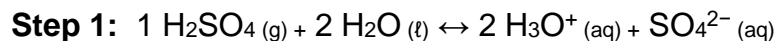
To calculate the pH of a strong acid or base, these steps should be followed:

Acid	Step	Base
0,1 mol·dm ⁻³ of HCl solution	For example:	0,5 mol·dm ⁻³ of NaOH solution
Write down the ionisation reaction for the acid. HCl + H ₂ O ⇌ 1 H ₃ O ⁺ + Cl ⁻	1	Write down the dissociation reaction for the base. 1NaOH(s) ⇌ Na ⁺ (aq) + OH ⁻ (aq)
Find the mol ratio of acid to hydronium ions 1 mol HCl : 1 mol H ₃ O ⁺	2	Find the mol ratio of base to hydroxyl ions 1 mol NaOH : 1 mol OH ⁻
Determine the [H ₃ O ⁺] [HCl] = 0,1 mol·dm ⁻³ ∴ [H ₃ O ⁺] = 0,1 mol·dm ⁻³	3	Determine the [OH ⁻] [NaOH] = 0,5 mol·dm ⁻³ ∴ [OH ⁻] = 1 (0,5) = 0,5 mol·dm ⁻³
No step 4 for acids	4	Determine the [H ₃ O ⁺] [H ₃ O ⁺][OH ⁻] = 10 ⁻¹⁴ ∴ [H ₃ O ⁺] (0,5) = 10 ⁻¹⁴ ∴ [H ₃ O ⁺] = 10 ⁻¹⁴ ÷ 0,5 = 2 × 10 ⁻¹⁴
Calculate the pH pH = - log [H ₃ O ⁺] = - log 0,1 = 1	5	Calculate the pH pH = - log [H ₃ O ⁺] = - log (2 × 10 ⁻¹⁴) = 13,7

Worked example 12

Calculate the pH of a H_2SO_4 solution of concentration $0,6 \text{ mol}\cdot\text{dm}^{-3}$.

Solutions



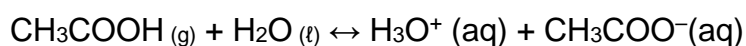
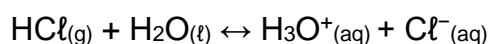
$$= -\log 1,2$$

$$= 0,08$$

20. Summary: Strong and weak acids and bases

Acids ionise in water to form ions:

Examples:



STRONG AND WEAK ACIDS	
Strong acids	Weak acids
<ul style="list-style-type: none">• High % ionisation• Donate many protons (H^+)• High $[\text{H}_3\text{O}^+]$ or $[\text{H}^+]$• Low pH• Good electric conductors• High reaction rates	<ul style="list-style-type: none">• Low % ionisation• Donate few protons (H^+)• Low $[\text{H}_3\text{O}^+]$ or $[\text{H}^+]$• Relatively low pH• Poor electric conductors• Low reaction rates
<p><i>Examples:</i></p> <p>HCl (hydrochloric acid) H_2SO_4 (sulphuric acid) HNO_3 (nitric acid)</p>	<p><i>Examples:</i></p> <p>CH_3COOH (acetic acid) $(\text{COOH})_2$ (oxalic acid) $\text{C}_6\text{H}_8\text{O}_7$ (citric acid) H_2CO_3 (carbonic acid)</p>
<p>Strong acid \rightleftharpoons weak conjugate base + H^+</p> <p>$\text{HCl} \rightleftharpoons \text{Cl}^- + \text{H}^+$</p>	<p>Weak acid \rightleftharpoons strong conjugate base + H^+</p> <p>$\text{CH}_3\text{COOH} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}^+$</p>

Bases like:

- NaOH are ionic and dissociate in water while
- NH_3 consists of covalent molecules which ionise in water forming NH_4^+ .

STRONG AND WEAK BASES	
Strong bases	Weak bases
<ul style="list-style-type: none"> High % dissociation Accept many protons (H^+) High $[OH^-]$ Very high pH 	<ul style="list-style-type: none"> Low % dissociation or ionisation Accept few protons (H^+) Low $[OH^-]$ Relatively high pH
NaOH Sodium hydroxide KOH Potassium hydroxide	NH_3 Ammonia $CaCO_3$ Calcium carbonate
strong base + $H^+ \rightleftharpoons$ weak conjugate acid $OH^- + H^+ \rightleftharpoons H_2O$	weak base + $H^+ \rightleftharpoons$ strong conjugate acid $NH_3 + H^+ \rightleftharpoons NH_4^+$

In general:

pH 1 - 2 : strong acid

pH 12 - 14 : strong base

pH 3 - 6 : weak acid

pH 8 - 11 : weak base

pH 7 : neutral

21. Summary:

Concentrated and dilute acids and bases

Concentration of an acid or a base is an indication of the number of moles of solute per unit volume. Both strong and weak acids and bases can be either concentrated or diluted.

Examples:

$1 \text{ mol}\cdot\text{dm}^{-3} \text{ HCl}_{(aq)}$: concentrated solution of a strong acid

$0,01 \text{ mol}\cdot\text{dm}^{-3} \text{ HCl}_{(aq)}$: diluted solution of a strong acid

$1 \text{ mol}\cdot\text{dm}^{-3} \text{ CH}_3\text{COOH}_{(aq)}$: concentrated solution of a weak acid

$0,01 \text{ mol}\cdot\text{dm}^{-3} \text{ CH}_3\text{COOH}_{(aq)}$: diluted solution of a weak acid

$1 \text{ mol}\cdot\text{dm}^{-3} \text{ NaOH}_{(aq)}$: concentrated solution of a strong base

$0,01 \text{ mol}\cdot\text{dm}^{-3} \text{ NaOH}_{(aq)}$: diluted solution of a strong base

$1 \text{ mol}\cdot\text{dm}^{-3} \text{ NH}_3_{(aq)}$: concentrated solution of a weak base

$0,01 \text{ mol}\cdot\text{dm}^{-3} \text{ NH}_3_{(aq)}$: diluted solution of a weak base

Structured Activities

QUESTION 1

1.1 Write down:

1.1.1 The meaning of the term diprotic acid.

(2)

1.1.2 The formula of a diprotic acid.

(1)

1.2. Magnesium hydroxide ($\text{Mg}(\text{OH})_2$) is often used as medicine to relieve an upset stomach. The pH of the $\text{HCl}_{(\text{aq})}$ in a person's stomach is 1. $\text{HCl}_{(\text{aq})}$ ionizes completely when dissolved in water.

1.2.1 Write down the term that refers to the underlined phrase. (1)

1.2.2 Calculate the concentration of the hydrochloric acid in the person's stomach. (3)

QUESTION 2 (NORTH-WEST (SEPTEMBER) 2015)

2.1 Define an acid in terms of the Brønsted-Lowry theory. (2)

2.2 Consider the reaction below:



2.2.1 Write down the formulae of the conjugate acid–base pairs in the above reaction. (2)

2.2.2 Write down the NAME of the substance that can act as an ampholyte in the above reaction. (1)

2.3 Sulphuric acid (H_2SO_4) is a strong acid.

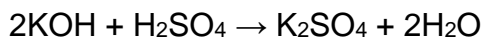
2.3.1 Explain why sulphuric acid is considered a strong acid. (2)

2.3.2 Calculate the pH of a $0,025 \text{ mol}\cdot\text{dm}^{-3}$ sulphuric acid solution. (4)

QUESTION 3 (MPUMALANGA (SEPTEMBER) 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:



3.1.1 What is a standard solution?

(1)

3.1.2 Calculate the mass of KOH which he must use to make 300 cm³ of a 0, 2 mol.dm⁻³ KOH solution.

(4)

3.1.3 Calculate the pH of the 0, 2 mol.dm⁻³ KOH solution.

(5)

3.1.4 Which one of the indicators listed in the table below should he use in this titration? Explain your answer.

INDICATOR	pH
Methyl orange	2.9 – 4.0
Methyl red	4.4 – 6.0
Bromothymol blue	6.0 – 10.0
Phenolphthalein	8.3 – 10.0

(2)

3.1.5 During the titration the learners find that 15 cm³ of the KOH solution neutralizes 20 cm³ of the H₂SO₄ solution. Calculate the concentration of the H₂SO₄ solution. (4)

ELECTROCHEMICAL CELLS

Electrochemical cells are based on Redox reactions; therefore they can't be dealt with without considering the core of their existence.

REDOX REACTIONS

A redox reaction is defined as transfer of electrons. Therefore, any transfer of electrons must have two sides, one side must be losing electrons (**donating**), the other side must be gaining electron.

There are two types of electrodes (i) an **anode** that is being oxidized always shows a decrease in mass, (ii) a **cathode** undergoing reduction always shows an increase in mass.

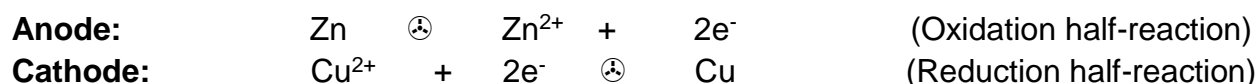
Reduction reaction

Reduction reaction is defined as gaining of electrons, which consequentially leads to a decrease in the **oxidation number**. A substance that undergoes reduction facilitates the loss of electrons of another substance. Therefore it is called an **oxidizing agent**.

Oxidation reaction

Oxidation reaction is defined as the loss of electrons, which consequentially leads to an increase in the **oxidation number**. A substance that undergoes oxidation facilitates the gain of electrons by another substance. Therefore it is called a **reducing agent**.

Example:



There are two type electrochemical cells

1. Galvanic / Voltaic cell
2. Electrolytic cell

Galvanic cell

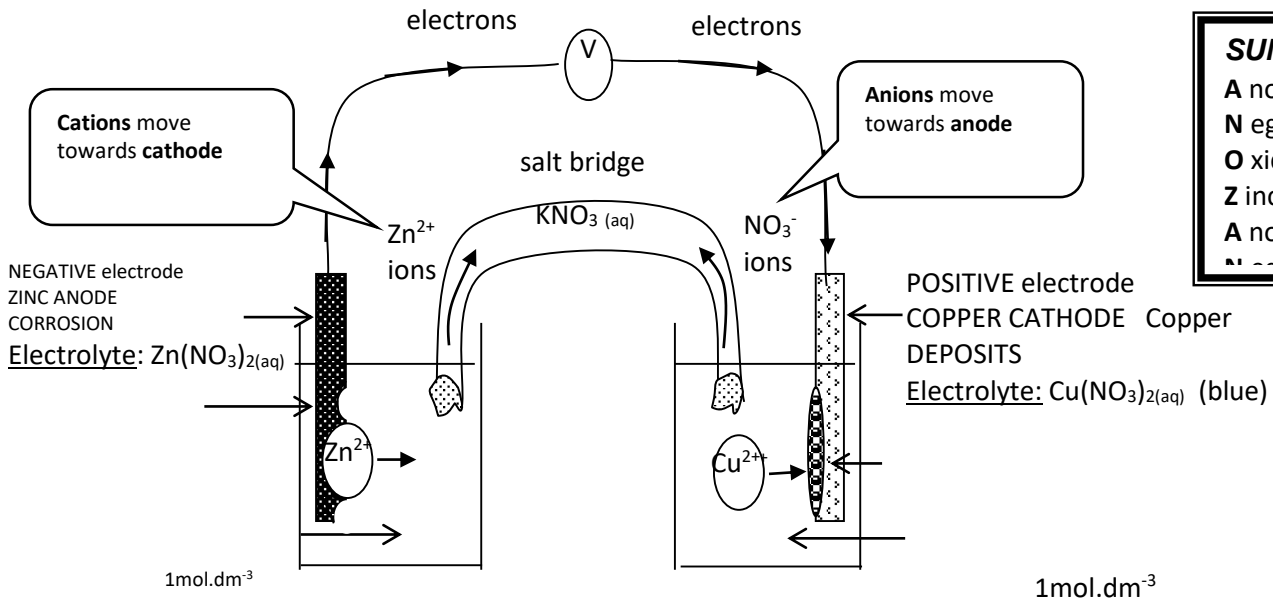
Galvanic cells are electrochemical cells that convert chemical energy into electrical energy.

A salt bridge is used to:

- (i) Complete the circuit,
- (ii) Neutralize solutions by allowing the flow of ions in between solutions

Conducting wires are used to transport electrons that are being transferred. A voltmeter is used to measure the potential difference across the cell.

The diagram below shows a standard Galvanic Cell.



SUMMARY
A node
Negative
Oxidation
Zinc
Anode
Negative

NOTE: The same observations would be made if zinc metal was placed in a solution of copper sulphate. The zinc is oxidised and corrodes, red brown deposits of copper would form, the blue solution would turn colourless and the solution would become hot (exothermic reaction).

STANDARD HYDROGEN ELECTRODE

The standard hydrogen electrode consists of;

- an inert platinum electrode to conduct electrons between the half cells
- a solution of H^+ ions of **concentration 1 mol.dm^{-3}** eg. $1 \text{ mol.dm}^{-3} \text{ HCl}$ or $0,5 \text{ mol.dm}^{-3} \text{ H}_2\text{SO}_4$

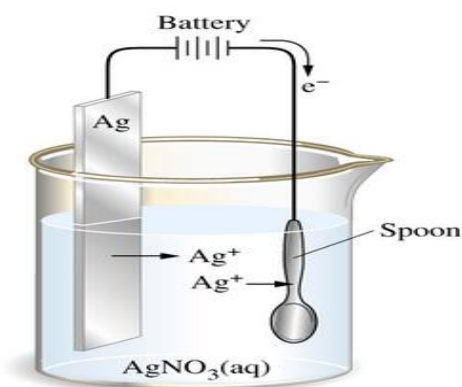
Electrolytic Cell

Electrolytic cell is an electrochemical cell in which electrical energy is converted into chemical energy.

Electro-plating

Electro-plating is the process whereby material that corrodes easily is coated with material that does not corrode easily. The the reason behind this is to mix useful properties of different substances to meet the needs of society.

The diagram below shows a simple electroplating cell



Anode: $\text{Ag} \rightarrow \text{Ag}^+ + e^-$ (silver metal is oxidised to Ag^+ ions 4anode corrodes)

Cathode: $\text{Ag}^+ + e^- \rightarrow \text{Ag}$ (silver ions are reduced to silver metal which deposits on spoon)

NOTE: The concentration of the electrolyte remains the same during the electroplating process.

Electro-refining

Electro-refining is the process whereby metals are purified from their ores. An ore (impure metal) that is mined consists of other atoms bonded to a metal of interest. Then electro-refining is used to extract that metal from others.

THE CHLOR-ALKALI INDUSTRY

Chlorine is manufactured by the electrolysis of brine (saturated sodium chloride solution).

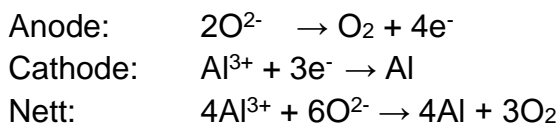
The overall reaction is:



Aluminium Extraction

Aluminium is mined as an ore called Bauxite which is washed by NaOH to produce alumina (Al_2O_3) and mostly Fe_2O_3 which is known as red mud. Then aluminium has to be separated from oxygen during extraction. The aluminium extraction cell uses carbon electrodes (both anode and cathode). After alumina has been electrolyzed it produces Al^{3+} and O^{2-} . The Al^{3+} is attracted to the negative electrode which is the cathode and it undergoes reduction there. Whereas O^{2-} is attracted to the positive electrode which is the anode and it gets oxidized there.

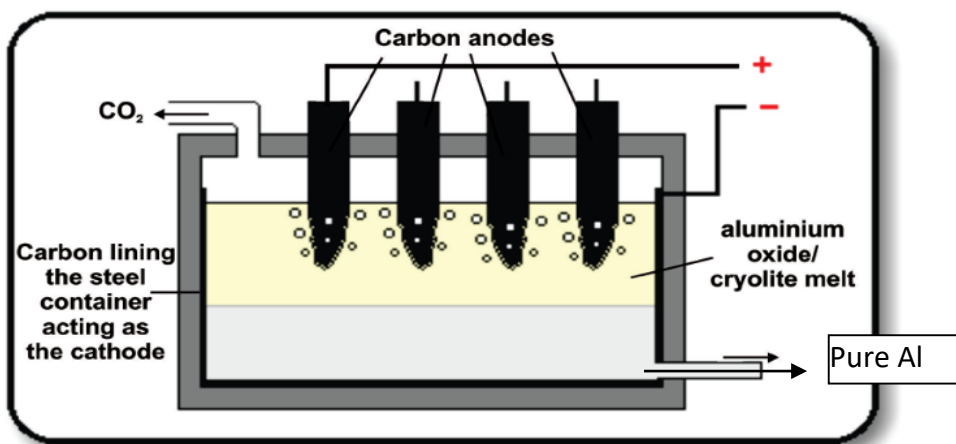
The reactions occurring in this cell are as follows:



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 $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$. This CO_2 re-joins the environment. Therefore, after some time the anode may need to be replaced.

The diagram below shows the simple representation of aluminium extraction cell.



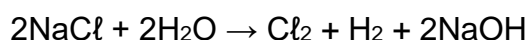
SUMMARY OF ELECTROLYTIC CELL VS VOLTAIC (GALVANIC) CELL

	ELECTROLYTIC	VOLTAIC (GALVANIC)
Appearance of simple form of cell		

	<ul style="list-style-type: none"> • Must have a cell or battery in external circuit to supply electrical energy. • Consists of 2 electrodes in the SAME solution. 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Extraction of aluminium; • purification of copper; • electroplating; • chlor-alkali process – electrolysis of brine to form chlorine, sodium hydroxide and hydrogen 	Batteries <ul style="list-style-type: none"> • Primary – zinc-carbon; lithium; mercury (not rechargeable) • Secondary – lead-acid accumulator or car battery (rechargeable)

Multiple choice

1.1 Consider the following balanced equation of a chemical reaction:



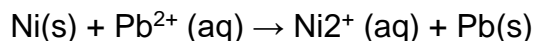
Which ONE of the following statements about the reaction is correct?

The reaction takes place in a/an ...

- A galvanic cell and absorbs energy.
- B galvanic cell and releases energy.
- C electrolytic cell and absorbs energy.
- D electrolytic cell and releases energy.

(2)

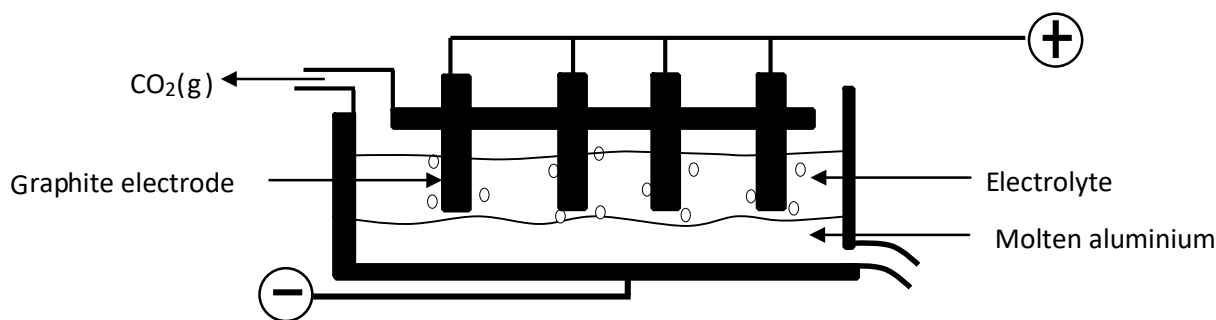
1.2 The following equation represents the reaction taking place in an electrochemical cell:



The flow of electrons through the external circuit of this cell is from

- A Pb at the anode to Ni at the cathode.
- B Pb at the cathode to Ni at the anode.
- C Ni at the cathode to Pb at the anode.
- D Ni at the anode to Pb at the cathode. (2)

1.3 A simplified diagram for the extraction of aluminium is shown below.



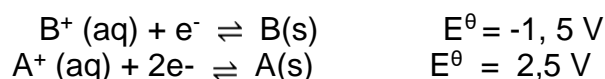
Consider the following statements regarding the process above:

- I: The electrolyte is a mixture of cryolite and aluminium oxide.
- II: $\text{O}_2(\text{g})$ is produced at the anode.
- III: The half-reaction at the cathode is $\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightarrow \text{Al}(\text{s})$.

Which of the above statements are CORRECT?

- A I and II only
- B II and III only
- C I and III only
- D I, II and III (2)

1.4 Two hypothetical half-reactions and their respective reduction potentials are shown below:



A galvanic cell is set up using the above substances.

Which ONE of the following statements is CORRECT for this galvanic cell?

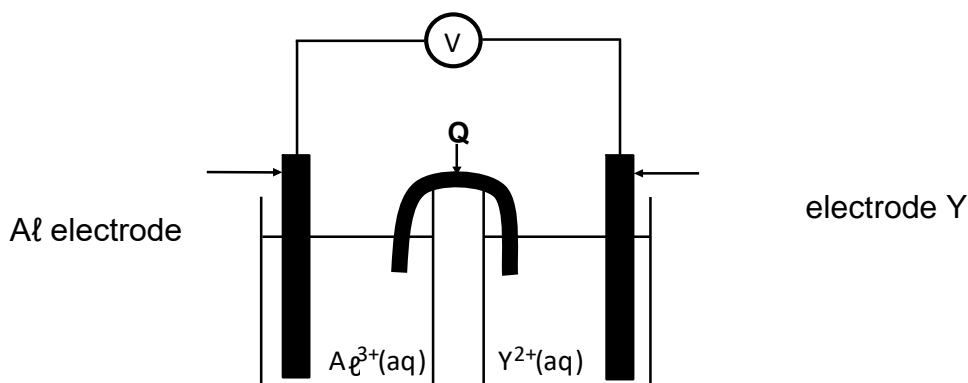
- A B(s) is the reducing agent.
- B A(s) is the oxidising agent.
- C The mass of B(s) will increase.
- D The mass of A(s) will decrease. (2)

1.5 In an electrolytic cell ...

- A the anode is the positive electrode.
- B oxidation takes place at the cathode.
- C electrons flow from the cathode to the anode.
- D the mass of the anode increases. (2)

QUESTION 2 DBE FEB-MARCH 2017

In the electrochemical cell shown below an aluminium electrode and another metal electrode, Y, are used.



2.1 Write down the:

2.1.1 Name of component Q (1)

2.1.2 Type of electrochemical cell represented above (1)

It is found that the mass of the aluminium electrode increases whilst the cell is functioning.

2.2 How will EACH of the following change while the cell is functioning? Choose from INCREASES, DECREASES or REMAINS THE SAME.

2.2.1 The concentration of Al^{3+} (aq) (1)

2.2.2 The concentration of Y^{2+} (aq) (1)

2.3 Write down the:

2.3.1 Half-reaction that takes place at electrode Y (2)

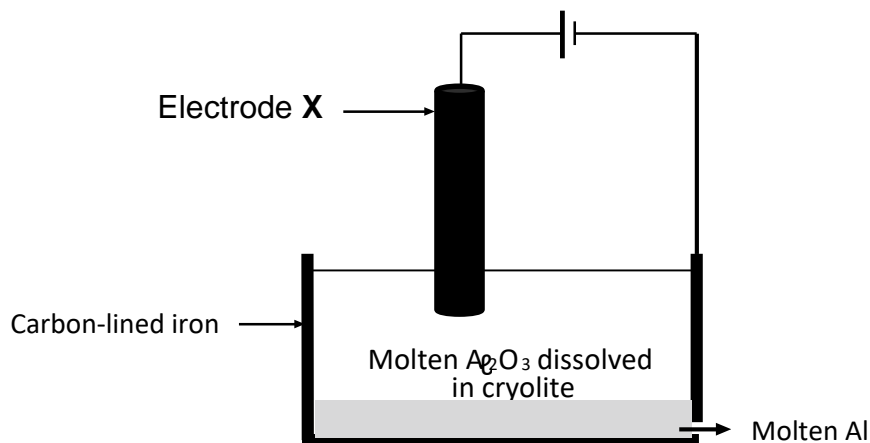
2.3.2 Cell notation of the cell (3)

2.4 The initial emf of this cell measured under standard conditions is 0,7 V.

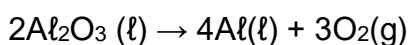
Identify metal Y by means of a calculation.(5)

QUESTION 3: DBE FEB-MARCH 2017

The simplified diagram below shows an electrolytic cell used in the industrial extraction of aluminium (Al) from aluminium oxide at temperatures as high as $1\ 000\ ^\circ C$. Electrode X is a carbon rod.



The cell reaction that takes place is as follows:



3.1 Write down the name of the ore used as a source of aluminium oxide. (1)

3.2 Which half-reaction (OXIDATION or REDUCTION) takes place at electrode X? (1)

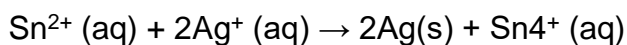
3.3 What is the function of the cryolite? (1)

3.4 Write down the reduction half-reaction. (2)

3.5 Write down a balanced equation that shows why the carbon rod, X, must be replaced regularly. (3)

QUESTION 4 DBE FEB-MAR 2018

4.1 A group of learners use the redox reaction below to construct an electrochemical cell.



4.1.1 Define a *reducing agent* in terms of *electron transfer*. (2)

4.1.2 Name a substance that should be used as electrode in the anode half-cell. (1)

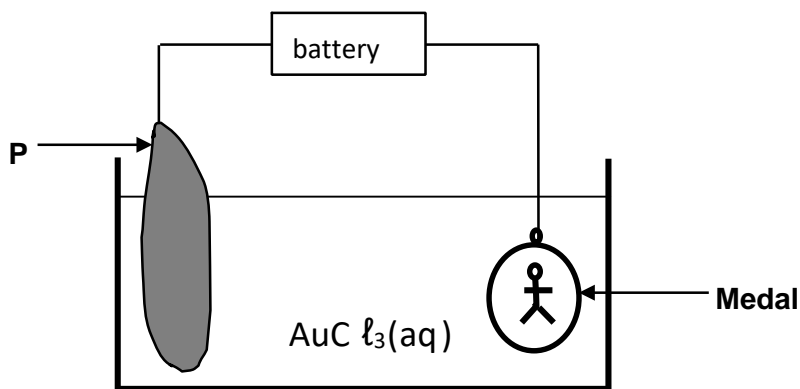
4.1.3 Write down the NAME or FORMULA of the reducing agent. (1)

4.1.4 Write down the cell notation of the cell. (3)

4.1.5 Calculate the initial emf of this cell under standard conditions. (4)

QUESTION 5 DBE MAY-JUNE 2017

The simplified diagram below represents a cell used to electroplate an iron medal with a thin layer of gold.



5.1 Is this an ELECTROLYTIC or a GALVANIC cell? (1)

5.2 Which electrode, **P** or the **Medal**, is the anode? (1)

5.3 Write down the:

5.3.1 Half-reaction that takes place at electrode **P** (2)

5.3.2 Oxidation number of gold (Au) in the electrolyte (1)

5.3.3 Energy change that takes place in this cell (1)

5.3.4 Change that occurs on electrode **P** after the cell functions for a while (1)

5.4 Besides improving appearance, state ONE other reason why the medal is electroplated. (1)

5.5 State ONE of the two possible changes that should be made to the cell above to electroplate the medal with silver instead of gold. (1)

CHEMICAL SYSTEMS

FERTILIZERS

Fertiliser is a substance that is used to make the soil fertile.

TYPES OF FERTILISERS	DESCRIPTION	EXAMPLES
Organic	Organic fertilisers are fertilisers that are manufactured by chemical processing of plants	<ul style="list-style-type: none">• urea, ammonia, ammonium phosphate, ammonium nitrate, triple superphosphates, superphosphates and NPK fertilisers
Inorganic	Inorganic fertilisers are fertilisers that are derived mainly from plant remains and animal excretions	<ul style="list-style-type: none">• plant compost,• animal manure• guano• bone meal

Why fertilisers are needed:

- a) to produce more food
- b) to fertilise soil faster than naturally.
- c) to increase the rate of food production in a given space of land
- d) Land available for agriculture decreases

Nutrients needed by plants

- There are 16 nutrients

NUTRIENTS	EXAMPLES	SOURCES OF NUTRIENTS
Mineral	Nitrogen (N)	organic sources: guano, manure inorganic sources: urea, ammonium nitrate, ammonia
	Phosphorous (P)	Organic sources: guano, bone meal Inorganic sources: superphosphates, triple superphosphates, ammonium phosphate
	Potassium (K)	Organic sources: potash Inorganic sources: potassium chloride, potassium nitrate, potassium sulphate
Non-mineral	Carbon (C)	Carbon dioxide in the atmosphere
	Hydrogen (H)	Rain
	Oxygen (O)	Rain and atmosphere

NPK ratio is the proportion of nitrogen phosphorous and potassium in a fertiliser

FUNCTIONS OF NUTRIENTS

NUTRIENTS	FUNCTIONS
Nitrogen	<ol style="list-style-type: none"> 1. Promote growth of the leaves 2. Stimulates growth of the plant
Phosphorus	<ol style="list-style-type: none"> 1. Promote growth of roots and stems
Potassium	<ol style="list-style-type: none"> 1. Improve quality of fruits and flowers

Interpretation of NPK ratio

N P K 3: 1: 2(30) 50kg

the N, P, K ratio above

- 30 percentage
- 3 parts of 6 parts is nitrogen
- 1 part of 6 parts is phosphorus
- 2 parts of 6 parts is potassium

indicates that there is:
fertiliser in the bag

Exercise 1 (Feb – March 2018)

A 10kg bag of NPK fertilizer is labelled 6 : 1 : 5 (22)

1.1 What is the meaning of NPK?

(1)

1.2 What is the meaning of (22) on the label?

(1)

1.3 Calculate the mass of potassium in the bag

(4)

Solutions to Exercise 1

1.1 The ratio of Nitrogen (N), phosphorus (P) and potassium (K) in a certain fertilizer.

(1)

1.2 Percentage fertilizer in the bag

(1)

1.3

$$\% = \frac{5}{12} \checkmark \times 22\% \checkmark$$
$$= 9.17\%$$

$$m(N) = \frac{9.17}{100} \times 10 \text{ kg} \checkmark$$
$$= 0.92 \text{ kg} \checkmark$$

(4)

INDUSTRIAL PROCESSES

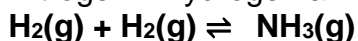
There are THREE industrial processes of manufacturing fertilisers:

- Haber process
- Contact process
- Ostwald process
-

HABER PROCESS (PRODUCTION OF AMMONIA)

- Is the industrial process of manufacturing ammonia
- Iron or iron oxide is used as a catalyst
- The chemical reaction which takes place during the Haber process is represented by the following equation.

Nitrogen + hydrogen ammonia



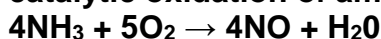
Nitrogen (N₂) is obtained through fractional distillation of air.

OSTWALD PROCESS (PRODUCTION OF NITRIC ACID)

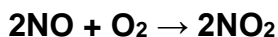
- Ostwald process is the industrial process of manufacturing nitric acid
- Platinum (Pt) is used as a catalyst in the Ostwald process.

STEP 1:

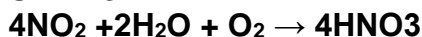
catalytic oxidation of ammonia



STEP 2:



STEP 3:



Exercise 2 (DBE Feb-March 2016)

Ammonium nitrate is an important fertilizer. It is produced by reacting nitric acid with ammonia. Both nitric acid and ammonia are prepared on a large scale in industry.

- 2.1 Write down the name of the industrial preparation of nitric acid. (1)
- 2.2 The catalytic oxidation of ammonia is one of the steps in the process named in question 2.1. Write down the NAMES or FORMULAE of the TWO products formed in this step (2)
- 2.3 Write down a balanced equation for the preparation of ammonium nitrate. (3)
- 2.4 Calculate the mass, in kilogram, of ammonium nitrate that can be made from $6,8 \times 10^4$ kg of ammonia and excess nitric acid. (3)
(One mole of ammonia produces one mole of ammonia nitrate.)
- 2.5 Ammonium nitrate is often mixed with potassium chloride and ammonium phosphate. Give a reason why it is mixed with these compounds. (1)

Solutions to Exercise 2

2.1 Ostwald process

2.2 NO / Nitrogen Monoxide

H₂O / Water

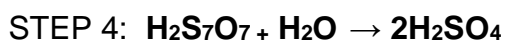
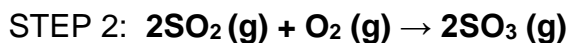
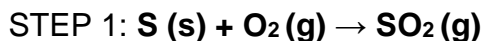
2.3 $\text{NH}_3 + \text{HNO}_3 \rightarrow \text{NH}_4\text{NO}_3$

$$\begin{aligned} 2.4 \quad n(\text{NH}_3) &= \frac{m}{M} \\ &= \frac{6,68 \times 10^7}{17} \\ &= 4 \times 10^6 \text{ mol} \\ n(\text{NH}_4\text{NO}_3) &= n(\text{NH}_3) \\ &= 4 \times 10^6 \text{ mol} \\ m(\text{NH}_4\text{NO}_3) &= nM \\ &= (4 \times 10^6)(80) \\ &= 3,2 \times 10^8 \text{ g} \\ &= 3,2 \times 10^5 \text{ kg} \end{aligned}$$

2.5 To make a NPK fertilizer / fertilisers which contain all three primary nutrients.

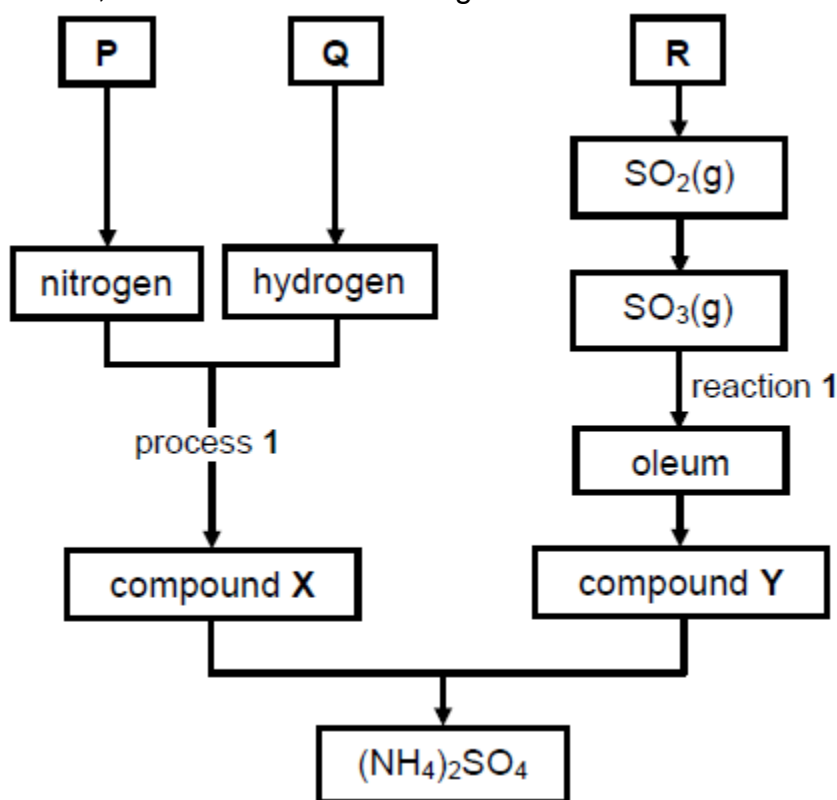
CONTACT PROCESS (PRODUCTION OF SULPHURIC ACID)

- Contact process is the industrial process of manufacturing sulphuric acid.



Exercise 3 (May – June 2016)

Chemical company produces ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$, starting from the raw materials P, Q and R, as shown in the flow diagram below.



Write down the NAME of raw material:

3.1 P (1)

3.2 Q (1)

3.3 R (1)

Write down the:

3.4 NAME of process 1 (1)

3.5 NAME of compound X (1)

3.6 FORMULA of compound Y (1)

3.7 Balanced equation for reaction 1

The company compares the nitrogen content of ammonium sulphate with that of ammonium nitrate, NH_4NO_3

3.8 Determine by performing the necessary calculations, which ONE of the two fertilisers has the higher percentage of nitrogen per mass.

(4)

3.9 Write down the name of the process that should be included in the flow diagram above if the company wants to prepare ammonium nitrate instead of ammonium sulphate.

(1)

Solutions to exercise 3

3.1 Air✓

3.2 Natural gas / Methane / Coal✓

3.3 Sulphur / Iron sulphide✓

3.4 Haber✓

3.5 Ammonia✓

3.6 H₂SO₄✓

3.7 SO₃ + H₂SO₄ ✓ → H₂S₂O₇✓✓

3.8 %N(NH₄NO₃) = $\frac{28}{80} \times 100 = 35\%$ } ✓

S %N(NH₄NO₄) = $\frac{28}{132} \times 100 = 21,21\%$ }

Ammonium nitrate (has the highest percentage of nitrogen)

3.9 Ostwald

Disadvantages of inorganic fertilisers

1. Cause eutrophication
2. Acidify ground water
3. Promotes growth of alien plants & cause blue baby syndrome

EUTROPHICATION

- Eutrophication is the process by which an ecosystem (river or dam) becomes enriched with inorganic plant nutrients especially phosphorus and nitrogen resulting in excessive plant growth.

How does eutrophication lead to dead zones?

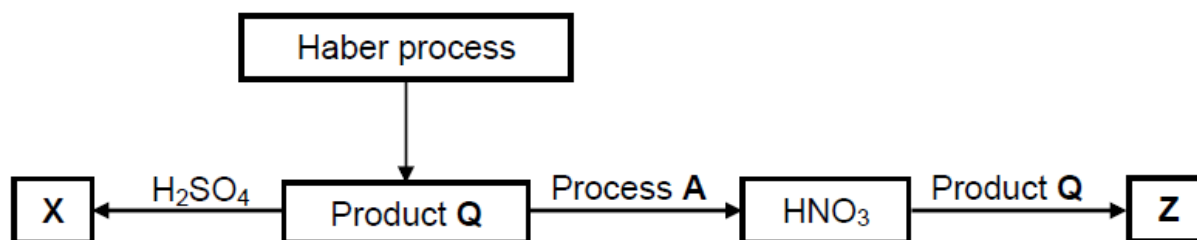
- Nitrogen-rich or phosphate fertilisers are washed into rivers or lakes which results in algae bloom. The amount of oxygen becomes depleted and aquatic organisms die.

Ways in which human accelerates eutrophication

- Over-application of fertilisers
- Emissions from vehicles
- Factory emissions
- Sewage; waste disposal systems
- Stock farming

QUESTION 1 (DBE FEB-MARCH 2018 Q10)

1.1 The diagram below shows processes involved in the production of fertilizer X and fertilizer Y



Write down the:

1.1.1 Balanced equation for the formation of product Q (3)

- 1.1.2 FORMULA of fertilizer X (1)
- 1.1.3 NAME of process A (1)
- 1.1.4 NAME of fertilizer Z (1)
- 1.2 A 10 kg bag of NPK fertilizer is labelled 6: 1: 5 (22)
- 1.2.1 What is the meaning of NPK? (1)
- 1.2.2 What is the meaning of (22) on the label? (1)
- 1.2.3 Calculate the mass of potassium in the bag (4)

QUESTION 2 (DBE JUNE 2019 Q10)

2.1 The four steps in the manufacture of an inorganic fertilizer are listed below. These steps are NOT written in the order in which they occur.

STEP I: Sulphuric acid reacts with ammonia to produce ammonium sulphate.

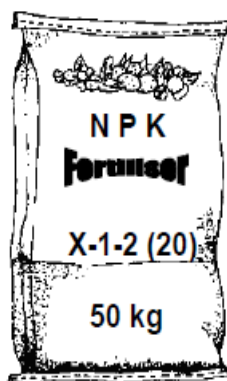
STEP II: Sulphur dioxide reacts with oxygen to produce Sulphur trioxide

STEP III: Oleum is diluted with water to produce sulphuric acid.

STEP IV: Sulphur trioxide is bubbled in concentrated sulphuric acid to produce oleum.

Write down the:

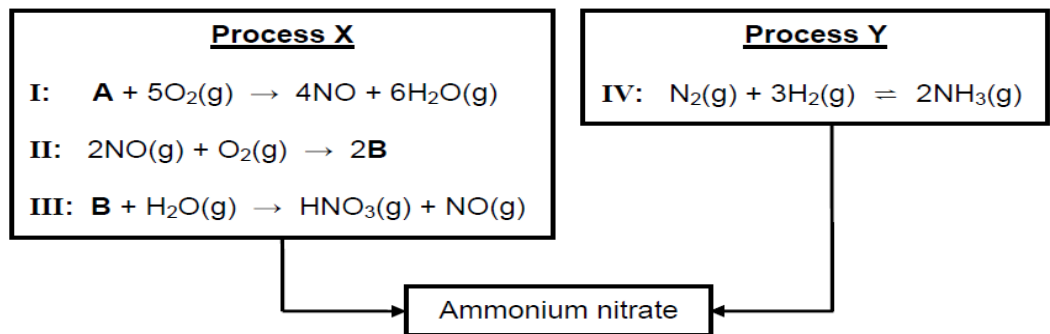
- 2.1.1 Correct order in which the steps occur in the preparation of the inorganic fertilizer by using the numbers I to IV (1)
- 2.1.2 Balanced chemical equation for step I (3)
- 2.1.3 NAME of the catalyst used in step II (1)
- 2.1.4 Balanced chemical equation for step IV (3)
- 2.1.5 Reason why Sulphur trioxide is NOT dissolved in water in step IV (1)
- 2.2 The diagram below shows a bag of NPK fertiliser. One of the numbers of the NPK ratio on the bag is labelled as X.



- If the mass of potassium in the bag is 3, 33 kg. Calculate the value of X (4)

QUESTION 3 (DBE NOV 2017)

3.1 The equations below represent two industrial processes involved in the preparation of ammonium nitrate.



Write down the:

- 3.1.1 NAME of substance A (1)
- 3.1.2 FORMULA of substance B (1)
- 3.1.3 NAME given for reaction I (1)
- 3.1.4 NAME or FORMULA of the catalyst used in reaction I (1)
- 3.1.5 Name of process X (1)
- 3.1.6 Name of process Y (1)
- 3.1.7 Balanced equation for the preparation of ammonium nitrate from the products obtained in process X and process Y (3)
- 3.2 A 15 kg bag of fertiliser contains 5% phosphorus, 10% nitrogen and 15% potassium.
Calculate the:
- 3.2.1 Mass of phosphorus in the bag (2)
- 3.2.2 Mass of filler in the bag (3)