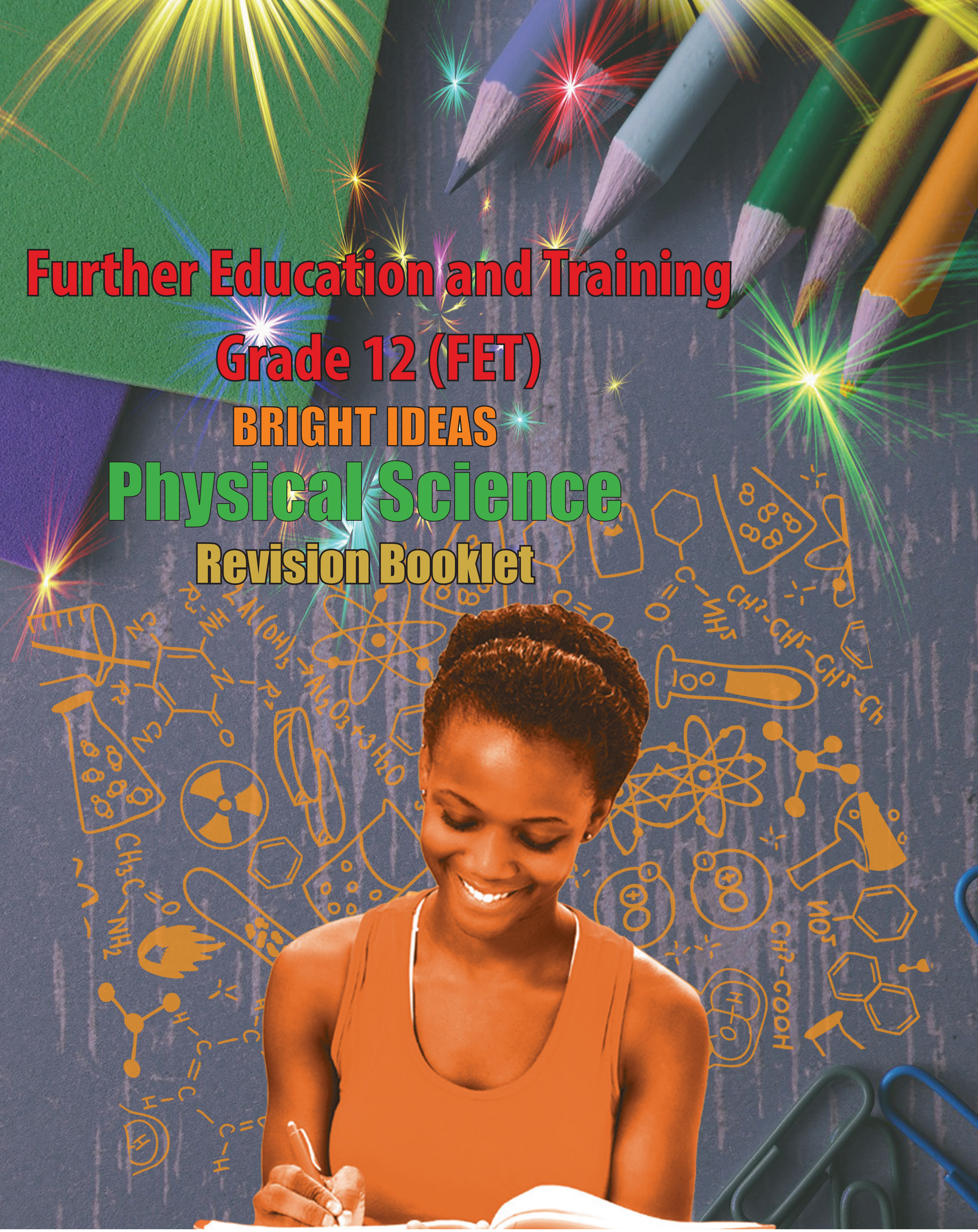
Further Education and Training

Grade 12 (FET)

BRIGHT IDEAS

Physical Science

Revision Booklet



basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Read to Lead
A Reading Nation is a Leading Nation

2030 NDP

Physical Science

Grade 12

REVISION BOOKLET

1 FOREWORD

Message from the Minister of Basic Education

Message to Grade 12 Learners from the Minister of Basic Education

Matric (Grade12) is perhaps the most important examination you will prepare for. It is the gateway to your future; it is the means to enter tertiary institutions; it is your opportunity to pursue the career of your dreams.

It is not easy to accomplish but it can be done with hard work and dedication, prioritising your time and effort to ensure that you cover as much of the curriculum content as possible in order to be well-prepared for the examinations.

I cannot stress the importance and value of revision in preparing for the examinations. Once you have covered all the content and topics, you should start working through the past examination papers, thereafter check your answers against the memoranda. If your answers are not correct, go back to the ***Mind the Gap (MTG)*** series and work through the content again. Then retest yourself, and continue with this process until you get all the answers right.

The ***Bright Idea… getting exam ready*** booklet will allow you to do this in a systemic way. It has been developed to assist you to achieve a minimum of 40% in the examinations – if you work hard and follow the advice and guidance provided. I also urge you to continue with the next section in this booklet that deals with an additional 20%, which will ensure you have covered the basics required to achieve at least a 60% pass.

Use this valuable resource which has been developed especially for YOU. Work hard, persevere, work every day, read and write every day to ensure that you are successful.

I have faith that you can do this. Remember 'SUCCESS' depends on the second letter, 'U'.

Best Wishes

MRS AM MOTSHEKGA, MP

MINISTER OF BASIC EDUCATION

DATE: 24/02/2017

2 HOW TO USE THIS REVISION BOOKLET

2.1 FOR EVERY TOPIC YOU NEED TO:

- Learn the content.
- Study the strategy you need to use to answer questions on that topic.
- Study the worked examples. First try to answer the worked examples yourself by **writing down your own solution.** Then compare your solution with the solution given in the book.
- Do the exercises **without looking at the solutions.**
- Compare your solutions with the given solutions and identify what your mistakes were (if any).
- Go back to your answer and correct any errors.
- Do another exercise. You can find more exercises in this book, previous NSC question papers, Mind the Gap (MTG) study guides, the Grade 12 Siyavula textbook and many other sources.

2.2 GENERAL STRATEGY FOR PROBLEM-SOLVING IN PHYSICS

(a) Read the whole question as many times as you need to, in order to understand what is given and what you need to find out or calculate.

- If a diagram is given, look at the diagram while reading the question and try to understand the diagram.
- If a diagram is not given, represent the problem in a rough sketch and put all the information given into the diagram, e.g. if the velocity of a car is given, write it down, e.g. $_{car}$ = 2 m·s^{-1} to the left

(b) Write the given information in symbolic form (data) using the correct scientific symbols, e.g. $_{i}$ for initial velocity, net for net force, etc.

(c) Select /choose the appropriate equation /formula /principal /law /theorem /concept.

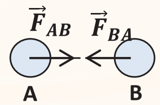
(d) Substitute the given data in the selected equation and do the calculations where calculations are required.

(e) Check that your answer makes sense and that:

- the numerical value is reasonable
- the correct units are used
- magnitude and direction (if it is a vector quantity)

3 KEY PHYSICS CONCEPTS

3.1 NEWTON'S LAWS

Newton's First Law of Motion	Newton's Second Law of Motion	Newton's Third Law of Motion	Newton's Law of Universal Gravitation
A body will remain in its state of rest or motion at constant velocity unless a non-zero resultant/net force acts on it. $\vec{F}_{net} = \vec{0}$	When a resultant/net force acts on an object, the object will accelerate in the direction of the force at an acceleration directly proportional to the force and inversely proportional to the mass of the object. $\vec{F}_{net} = m\vec{a}$	When one body exerts a force on a second body, the second body exerts a force of equal magnitude in the opposite direction on the first body.  $\vec{F}_{AB} = -\vec{F}_{BA}$	Each body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres. $Fg = \frac{Gm_1m_2}{r^2}$

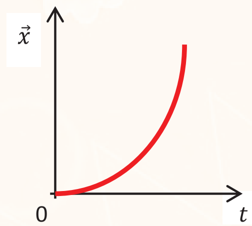
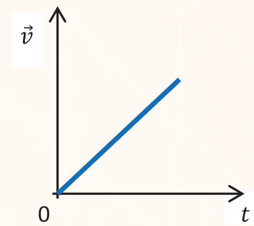
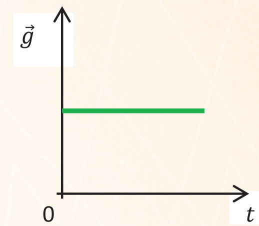
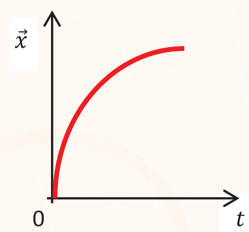
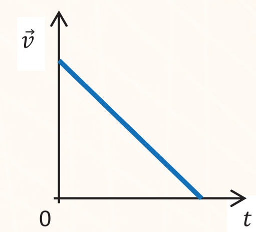
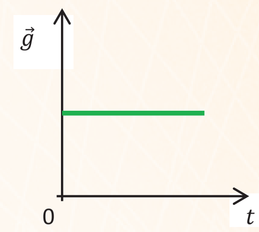
DIFFERENT TYPES OF FORCES

Normal Force	Weight	Frictional force
Force or the component of a force which a surface exerts on an object with which it is in contact, and that is perpendicular to the surface. $\vec{N}$	Weight ($(\vec{w})$) is the gravitational force that the Earth exerts on the object of mass *m*. $\vec{w} = m\vec{g}$ $\vec{g}$ - acceleration due to gravity. $\vec{g} \approx 9,8\ m/s^2$ close to the surface of the Earth. Use this equation to calculate the acceleration of any other planet: $g = \frac{GM}{r^2}$	This is force that opposes the motion of an object and which acts parallel to the surface. ➢ **Static frictional force (** f_s) is the force that opposes the tendency of motion of a stationary object relative to a surface. $f_s^{max} = \mu_s N$ ➢ ***Kinetic frictional force*** (f_k) is the force that opposes the motion of a moving object relative to a surface. *You need to know that a frictional force:* $f_k = \mu_k N$ • is proportional to the normal force • is independent of the area of contact • is independent of the velocity of motion **NOTE:** ○ If a force (F) applied to a body parallel to the surface does not cause the object to move, F is equal in magnitude to the static frictional force. ○ The static frictional force is a maximum ((f_s^{max})) just before the object starts to move across the surface. ○ If the applied force exceeds ((f_s^{max})), a resultant force accelerates the movement of the object.

3.2 MOMENTUM AND IMPULSE

Physical quantities		Newton's second law in terms of momentum	Impulse-momentum theorem	Law of conservation of lineal momentum
Momentum and change in momentum	**Impulse**			
Momentum is the product of an object mass and its velocity. Momentum is a vector quantity. $\vec{p} = m\vec{v}$ SI units $[kg \cdot m \cdot s^{-1}]$ Change in momentum $\Delta\vec{p} = \vec{p}_f - \vec{p}_f$ $\Delta\vec{p} = m\vec{v}_f - m\vec{v}_f$ $\Delta\vec{p} = m(\vec{v}_f - \vec{v}_f)$ $\Delta\vec{p} = m\Delta\vec{v}$ SI units of $\Delta\vec{p}$ $[kg \cdot m \cdot s^{-1}]$	***The impulse of a force is the product of the force acting on an object and the time the force acts on the object.*** Impulse is a vector quantity. $\overrightarrow{Impulse} = \vec{F}\Delta t$ SI units $[N \cdot s]$	***The resultant/ net force acting on an object is equal to the rate of change of momentum of the object in the direction of the resultant/net force.*** $\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$	$\overrightarrow{Impulse} = \Delta\vec{p}$ $\vec{F}_{net}\Delta t = m\Delta\vec{v}$ $\vec{F}_{net}\Delta t$ $= m\vec{v}_f - m\vec{v}_i$	*An **isolated (closed) system** in physics is a system on which the resultant/net external force is zero.* OR **When** Then The law of conservation of momentum states: ***The total linear momentum of an isolated (closed) system remains constant (is conserved).*** $\sum_{before}$ is the total momentum before collision $\sum_{after}$ is the total momentum after collision

3.3 VERTICAL PROJECTILE MOTION

VERTICAL PROJECTILE MOTION				
Projectile	**Equations of motion**			
Projectile is an object upon which the only force acting is the force of gravity. The motion of a projectile is called ***free fall.*** *Free fall* is the motion in which an object experiences negligible air resistance and constant acceleration due to gravitational force.	**Position**	**Displacement**	**Velocity**	**Acceleration**
	$\vec{y}_f = \vec{y}_i + \Delta\vec{y}$ $\Delta\vec{y}$ – Displacement, which is the change in position.	$\Delta y = v_i\Delta t + \frac{1}{2}g\Delta t^2$ $\Delta y = \frac{v_f^2 - v_i^2}{2\vec{g}}$ $\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$	$v_f = v_i + g\Delta t$ $v_f^2 = v_i^2 + 2g\Delta y$	Magnitude constant: $\vec{g} = 9{,}8\ m \cdot s^{-2}$ Direction is always downwards (towards the centre of the Earth).
		Graphs		
	Direction of motion	Position vs time	Velocity vs time	Acceleration vs time
	Vertically downwards (speed increases) (constant acceleration)			
	Vertically upwards (speed decreases) (constant acceleration)			

3.4 WORK ENERGY AND POWER. WORK-ENERGY THEOREM. LAW OF CONSERVATION OF MECHANICAL ENERGY.

Physical quantity					Work energy and the principle of conservation of energy	Law of conservation of mechanical energy
Work	**Kinetic energy**	**Potential energy**	**Mechanical energy**	**Power**		
Work done by a constant force is defined as the *scalar quantity* equal to the *product of the force multiplied by the displacement* of the point of application of the force *by the cosine of the angle* formed by the line of action of the force and the direction of the displacement. $W = F\Delta x \cos\theta$ SI unit: **joule** [J]	**Kinetic energy** is the energy an object has due its motion. $E_K = \frac{1}{2}mv^2$ SI unit: **joule** [J]	***Gravitational potential energy*** *is the energy an object has due to its position in a gravitational field relative to some reference point.* $E_p = mgh$ SI unit: **joule** [J]	**Total Mechanical energy** is equal to the sum of the gravitational potential energy plus the kinetic energy. $E_M = E_K + E_p$ SI unit: **joule** [J]	**Power** is the rate at which work is done or energy is expended. $P = \frac{W}{\Delta t}$ If the body possesses rectilinear uniform motion (v = constant), then: $P_{ave} = Fv_{ave}$ SI unit: **watt** [W]	**The work done by the resultant (net) force acting on an object is equal to the change in the kinetic energy of the object.** $W_{net} = \Delta E_K$ (work − energy theorem) $W_{net} = E_{Kf} - E_{Ki}$ $W_{net} = W_c + W_{nc}$ Using the work- energy theorem: $W_c + W_{nc} = \Delta E_K$ But: $W_{cons} = -\Delta E_p$ $-\Delta E_p + W_{nc} = \Delta E_K$ Hence: $W_{nc} = \Delta E_K + \Delta E_p$ **This equation can be used to solve conservation of energy problems and is called the principle of conservation of energy.**	**Total mechanical energy in an isolated system remains constant (is conserved).** $E_{M(initial)} = E_{M(final)}$ ***In an isolated system, only conservative forces are acting.*** ***OR*** **The total mechanical energy of an object remains constant as the object moves, provided that the net work done by external non-conservative forces is zero.** $0 = \Delta E_K + \Delta E_p$

3.5 DOPPLER EFFECT

<table>
<tr><th colspan="5">DOPPLER EFFECT</th></tr>
<tr><th colspan="2">Sound</th><th></th><th colspan="2">Light</th></tr>
<tr><th>Theory

(DEFINITION)</th><th>Equations</th><th>Applications</th><th>Red shift</th><th>Blue shift</th></tr>
<tr>
<td>The Doppler effect is a change in frequency (or pitch) of sound detected by a listener because the sound source and the listener have different velocities relative to the medium of sound propagation.

The frequency heard by the observer is higher than the frequency of the source when the source moves towards the observer and lower when the source moves away from the observer.</td>
<td>$f_L = \left(\frac{v \pm v_L}{v \pm v_s}\right) f_s$

where

$v = f\lambda$
For a stationary listener

$f_L = \left(\frac{v}{v \pm v_s}\right) f_s$

For a stationary source

$f_L = \left(\frac{v \pm v_L}{v}\right) f_s$

<u>For a source moving:</u>

• <u>away</u> $(v + v_s)$

• <u>towards</u> $(v - v_s)$

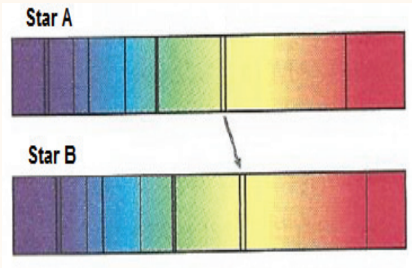
<u>Listener moving:</u>

• <u>towards</u> $(v + v_L)$

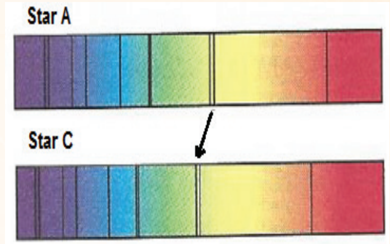
• <u>away</u> $(v - v_L)$</td>
<td>• To find the rate of blood flow (Doppler scanning)

• To see the unborn child (ultrasound scanning)

• To hear the heartbeat of a foetus (ultrasound scanning)</td>
<td>If the light source is moving away from the observer (positive velocity), then the observed frequency is lower and the observed wavelength is greater (red-shift).



Red shifts are evidence that the Universe is expanding.</td>
<td>If the source is moving towards the observer (negative velocity), the observed frequency is higher and the wavelength is shorter (blue-shift).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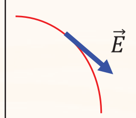
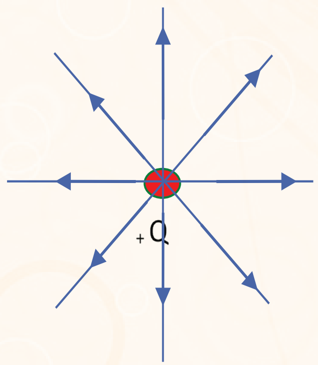
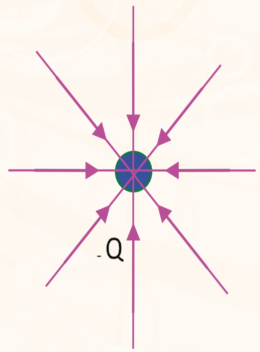
3.6 ELECTROSTATICS

ELECTROSTATICS					
Electrostatics Force	Electric field	Electric field at a point	Lines	Principle of superposition of forces	Principle of superposition of fields
Coulomb`s law The magnitude of the electrostatic force exerted by one point charge (Q) on another point charge (Q[1]) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them: $F = \frac{KqQ}{r^2}$	***Electric field* is an area of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction in which a positive test charge would move if placed at that point.**	**The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point.** $\vec{E} = \frac{\vec{F}}{q}$ **For a point charge:** $E = \frac{KQ}{r^2}$	Electric field lines are IMAGINARY LINES along which a small POSITIVE **test charge** would move. The force experienced by the positive **test charge** is always in the **direction** of the **tangent** to the field line They start on a positive **charge** and end on a negative **charge**. 	**The force that a system of point charges exerts on another point charge is equal to the vector addition of all the forces each one exerts on it.** $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + ... + \vec{F}_n$	**The electric field strength at a point due to a system of point charges is equal to the vector addition of all the electric field strengths of each one at a specific point.** $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + ... + \vec{E}_n$

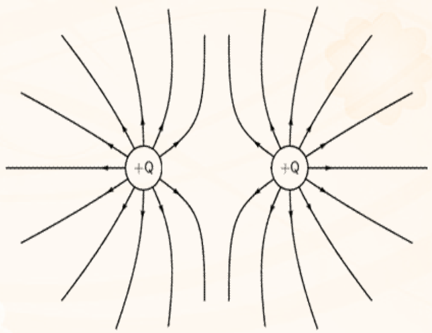
Electric field pattern



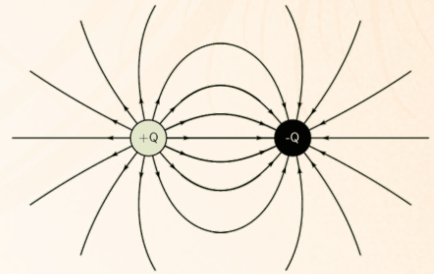
Positive point charge



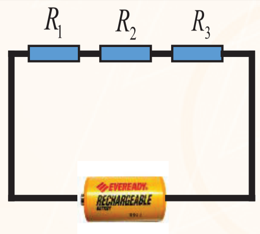
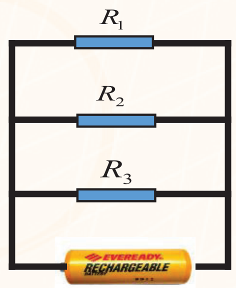
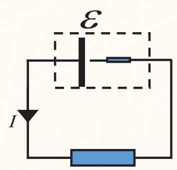
Negative point charge



Positive like charges



Unlike charges

CURRENT	*EMF &* POTENTIAL DIFFERENCE	SERIES	PARALLEL	Ohm's Law	Work	Power
The total charge that passes through a conductor per unit of time. $I = \frac{Q}{\Delta t}$	Work done (energy transferred) per unit charge to move the charge from the negative electrode to the positive electrode in the battery. $\varepsilon = \frac{W}{q}$ ***Potential defference*** is the work done per unit charge between two points in a circuit. $V = \frac{W}{Q}$	 $R_T = R_1 + R_2 + R_3$ $I_1 = I_2 = I_3$ $V_T = V_1 + V_2 + V_3$ (Resistors act as potential dividers.)	 $\frac{1}{R_E} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $V_1 = V_2 = V_3$ $I_T = I_1 + I_2 + I_3$ (Resistors act as current dividers.)	 ***The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.*** $R = \frac{V}{I}$ ***Whole circuit:*** *A real battery has internal resistance.* $I = \frac{\varepsilon}{R + r}$	General: $W = VIt$ Series: $W = I^2 R$ Parallel: $W = \frac{V^2}{R} t$ **Whole circuit:** $W = \varepsilon It$	**The rate at which electrical work is done or electrical energy is transferred.**

3.7 ELECTRIC CIRCUITS

- Strategy to Solve Problems on Electric Circuits
- Read the problem carefully as many times as needed.
- If not given, draw a circuit diagram.
- Write down the data in symbolic form.
- Indicate the conventional direction of the current from high-potential to low-potential (+ to -).
- Re-draw the circuit diagram to simplify it if necessary.
- Identify the type of connection (series/parallel).

Analysing circuits:

1 – The algebraic sum of the changes in potential in a complete transversal of any loop of a circuit must be zero. **(ε= Ir+ Ir)**

2. The sum of the currents entering any junction must be equal to the sum of the currents leaving that junction.

- **$i = i_1+i_2+\ldots+i_n$**
- Write down the formula/ equation that solves the question.
- Find the unknowns if needed (multi-concept problems).
- Do the calculations and write down the final answer.
  - Check your answer. Check if it makes sense, e.g.:
  - Is the unit correct?

Is the numerical value reasonable?

3.8 ELECTRODYNAMICS

Electrical machines

Direct current motor (DC–motor)

<u>Motors convert electrical energy into (rotational) mechanical energy.</u>

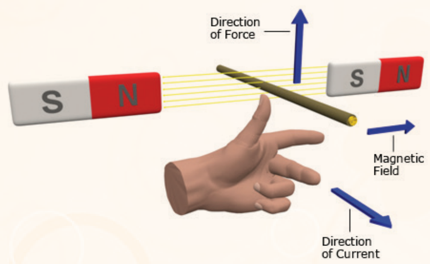
<u>Elements of the DC-motor:</u>

1. Armature.

Split-ring (commutator).

2. Carbon brushes.
3. Two poles of magnet (permanent magnets)

Fleming's left hand (motor) rule



The thumb shows the direction of the force, the first finger shows the direction of current and the second finger shows the direction of the magnetic field. The thumb, the first finger and the second finger must be at a right angle to (90^0) each other.

AC and DC Generators

<u>Generators convert mechanical energy into electrical energy.</u>

*The generator is based on the principle of "**electromagnetic induction**"*

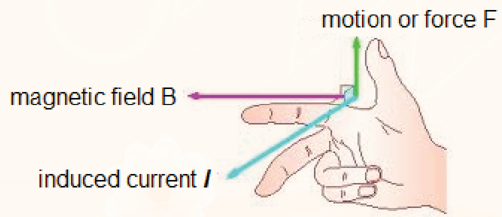
<u>Elements of the AC generator:</u>

1. Armature.
2. Slip-rings.
3. Carbon brushes.
4. Two poles of magnet (permanent magnets).

The DC generator (Dynamo)

The DC generator or dynamo is similar to the AC generator, but the slip rings are replaced by split ring (commutator) to get direct current (current that flows in one direction).

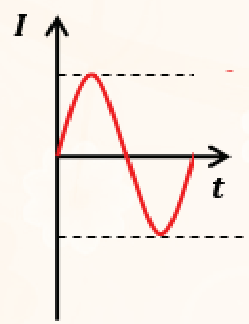
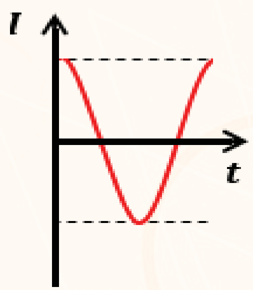
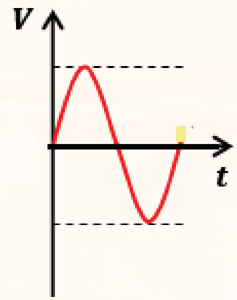
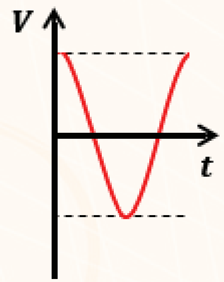
Fleming's right hand (dynamo) rule (for generators)



The thumb represents the direction of motion of the conductor.
The first finger represents the direction of the magnetic field (north to south).
The second finger represents the direction of the induced or generated current (the direction of the induced current will be the direction of conventional current - from positive to negative).

ALTERNATING CURRENT

Alternating current ***(AC) is an oscillating electric current that varies*** **sinusoidally with time,** ***reversing its direction of flow periodically.***

Advantages of AC over DC	Graphs a		rms values		Average power
	Current versus time	Voltage versus time	Current	Voltage	
• Easy to be transformed (step up or step down using a transformer). • Easier to convert from AC to DC than from DC to AC. • Easier to generate. • It can be transmitted at high voltage and low current over long distances with less energy lost. • High frequency used in AC makes it suitable for motors.	For one complete cycle  OR  	For one complete cycle  OR  	***The root-mean-square current*** ***is the value of the current in an AC circuit that will have the same heating effect as a DC circuit.*** $I_{rms} = \frac{I_{max}}{\sqrt{2}}$ where $I_{max} = \frac{V_{max}}{R}$	***The root-mean-square voltage*** ***is the value of the voltage in an AC circuit that will have the same heating effect as a DC circuit.*** $V_{rms} = \frac{V_{max}}{\sqrt{2}}$ Where $V_{max} = I_{max}R$	$P_{ave} = I_{rms}V_{rms}$ $I_{rms} = \frac{V_{rms}}{R}$ OR $V_{rms} = I_{rms}R$ OR **For series connection:** $P_{ave} = (I_{rms})^2R$ For parallel connection: $P_{ave} = \frac{V_{rms}^2}{R}$

3.9 PHOTOELECTRIC EFFECT

OPTICAL PHENOMENA				
ENERGY RADIATION	PHOTOELECTRIC EFFECT		SPECTRA	
	Theory	Einstein's equation	Absorption	Emission
The energy radiated by hot objects is liberated in the form of separate packets of energy called quanta. A quantum of energy is called photon. The energy of a photon is: **The energy of the radiation is where N is $E = Nhf$ the number of photons emitted.** **The power of the radiating sources:** $P = \frac{\Delta N}{\Delta t} hf$	**Photoelectric effect:** This is the process whereby electrons are ejected from a metal surface when light of a suitable frequency is incident on that surface. ***Threshold frequency*** **(** f **)** is the minimum frequency of light needed to emit electrons from a certain metal surface. ***Work function*** **(** W **)** is the minimum energy that an electron in the metal needs to be emitted from the metal surface. **Effect of intensity on the photoelectric effect.** *The number of electrons emitted per unit time is proportional to the intensity of incident light.* **Effect of frequency on the photoelectric effect.** *The maximum kinetic energy of the photoelectrons is linearly proportional to the frequency of the incident radiation.* **Significance of the photoelectric effect.** *The photo-electric effect establishes the quantum theory and illustrates the particle nature of light.*	**$E = W_o + E_{k(max)}$** **Where** **OR** $E = \frac{hc}{\lambda}$ **Maximum kinetic energy (** $E_{K(\max)}$) $E_{K(\max)} = \frac{m_e v_{\max}^2}{2}$ **Work function** $W_0 = h f_0$ OR $W_0 = \frac{hc}{\lambda_0}$	An atomic absorption spectrum is formed when certain frequencies of electromagnetic radiation that pass through a medium (e.g. a cold gas) are absorbed.	An atomic emission spectrum is formed when certain frequencies of electromagnetic radiation are emitted due to an atom's electrons making a transition from a high-energy state to a lower energy state.

4 REVISION QUESTIONS- SET 1

4.1 NEWTON'S LAWS

Strategies for problem-solving questions on Newton's Laws

Step 1: Read the problem as many times as needed.

Step 2: Sketch the problem, if necessary.

Step 3: Draw a force diagram for the situation.

Step 4: Draw a free-body diagram and resolve the forces into component on the Cartesian plane.

Step 5: List all the given information and convert these to SI units, if necessary.

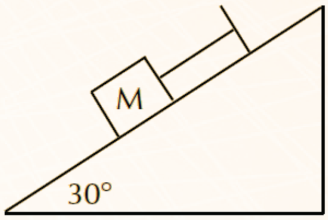
Step 6: Determine which physical principle can be used to solve the problem.

Step 7: Use the principle to solve the question, often by substituting numerical values into an appropriate equation.

Step 8: Check that the question has been answered and that the answer makes sense.

Worked Example 1

A block of mass M is held stationary by a rope of negligible mass. The block rests on a frictionless plane that is inclined at 30º to the horizontal.



1.1 State Newton's first law of motion in words.

1.2 Draw a free-body diagram that shows all the forces acting on the block.

1.3 Calculate the magnitude of the gravitational force of the block when the force in the rope is 8 N.

1.4 Now the rope is cut and the block slides down on the inclined plane, reaching the horizontal rough surface and then continuing to move with constant acceleration of magnitude 1,5 m·s^{-2}.

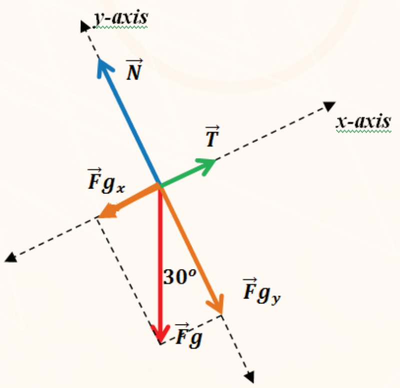
1.4.1 State Newton's second law of motion in words.

1.4.2 Calculate the acceleration of the block while it is sliding down the inclined plane.

1.4.4 Calculate the coefficient of kinetic friction between the block and the surface.

Solutions for Worked Example 1

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



1.3 To calculate the gravitational force, we can use the parallel component:

$F_{gx} = Fg\sin\theta$

We do not have the component, but we can calculate this by applying Newton's second law in the x direction. We are going to calculate only the magnitude, because the direction is known.

On the x-axis:

$\vec{F}_{Rx} = m\vec{a}_x$

$T - F_{gx} = 0$

$T - Fg\sin\theta = 0$

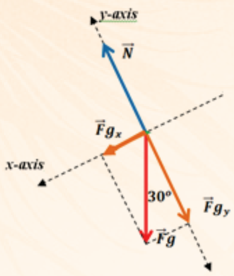
$8 - \vec{F}g\sin 30^o = 0$

$Fg = \frac{8}{\sin 30^o}$

$Fg = 16\,N$

1.4.1 If a resultant force acts on a body, it will cause the body to accelerate in the direction of the resultant force. The acceleration of the body will be directly proportional to the resultant force and inversely proportional to the mass of the body.

1.4.2 Free body diagram, coordinate system and components.



Applying Newton's second law of motion

$\vec{F}_R = m\vec{a}$

Applying it in the x direction

$\vec{F}_{gx} = m\vec{a}$

$mgsin30^o = m\vec{a}$

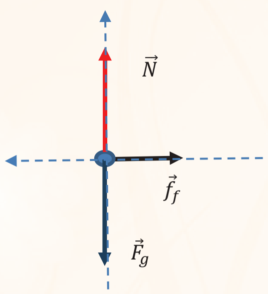
$\vec{a} = gsin30^o$

$\vec{a} = 9{,}8\ sin30^o$

$\vec{a} = 4.9\ \mathrm{m} \cdot s^{-2}$

1.4.3

Free body diagram



Applying Newton's second law of motion

$\vec{F}_R = m\vec{a}$ (1)

There is only one force acting on the block, which is the frictional force:

$\vec{F}_{fx} = m\vec{a}$ (2)

$\mu_K N = ma$ (3)

The normal force is unknown and we need to calculate it.

Working in the y-direction:

In the vertical direction, the acceleration is zero, therefore we can apply Newton's first law of motion.

$\vec{F}_{net(y)} = \vec{0}$ $\quad \vec{N} + \vec{F}_g = \vec{0}$

Taking as positive the y-positive direction

$N - F_g = 0 \quad N - mg = 0$

$\therefore\ N = mg$ **(4)**

Substituting 4 in 3:

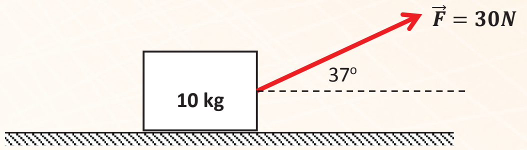
$\mu_K mg = ma$ Hence $\mu_K g = a$

Substituting

$\mu_K(9{,}8) = 1{,}5 \quad \mu_K = 0{,}153$

Exercise 1

A block of mass 10 kg is pulled to the right at constant velocity with a force of magnitude 30 N that acts at an angle of 37° with the horizontal.



1.1 Draw a free-body diagram with all the force action on the block. Use a Cartesian plane and represent the component of the force.

1.2 Calculate the magnitude and direction of the normal force.

1.3 Calculate the coefficient of friction.

1.4 The force is removed and the block comes to rest after a time. Calculate the acceleration of the block after the force has been removed if the frictional force remains constant.

Exercise 2

A block, of mass 20 kg, is pulled upwards by force $\vec{F}$ along a plane with an incline 30° to the horizontal. It accelerates along the incline plane at 2 m·s^{-2}. The surface of the incline exerts a friction force on the block.

2.1 Draw a diagram showing all the forces acting on the block (force diagram) as it moves up the incline. Also draw a free-body diagram for the block. Represent the forces on the Cartesian plane and resolve the gravitational force into components.

2.2 Calculate the component of the gravitational force exerted on the block parallel to the incline.

2.3 Calculate the normal force.

2.4 Calculate the magnitude of the friction force if the magnitude of is equal to 200 N.

2.5 Calculate the coefficient of kinetic friction for the block.

4.2 MOMENTUM AND IMPULSE

Momentum and impulse problem solving strategy

1 Read the problem as many time as you need to; then draw a sketch or diagram of the situation described if not provided.

2 From the reading, collect the data and write it in symbol form (not only numbers are part of the data) e.g. the object starts moving from rest means the initial speed is zero.

3 Draw a free body diagram for each object and clearly define the system you are going to work with.

- If possible, choose a system that is isolated ($\vec{F}_{net} = \vec{0}$) and closed (m = constant). If the interactions are sufficiently short and intense you can ignore external forces.
- If it is not possible to choose an isolated system, try to divide the problem into parts (scenarios).

4 Select the law (principle), theorem, equation or formula that will answer your question.

- If the mathematical representation is based in the law of conservation of momentum $\left(\sum \vec{p}_{initial} = \sum \vec{p}_{final}\right)$, write it in component form.

5 Substitute the values into the equation or formula (the system of units must be homogeneous).

6 Check your answer

- Is the value of the answer reasonable?
- Is the unit correct?

Worked example 1

Trolley A, with a mass of 120 kg, is moving at 20 m·s^{-1} ; it collides head-on with trolley B, with a mass of 150 kg, moving at 30 m·s^{-1} in the opposite direction. If A rebounds at 25 m·s^{-1}:

1.1 State the law of conservation of momentum in words.

1.2 Calculate the rebound velocity of B.

1.3 Calculate the impulse of the force exerted by trolley B on trolley A.

Solution:

Data

m_A = 120 kg

$\vec{v}_{iA} = 20 \text{ m} \cdot s^{-1}$ to the right

m_B = 150 kg

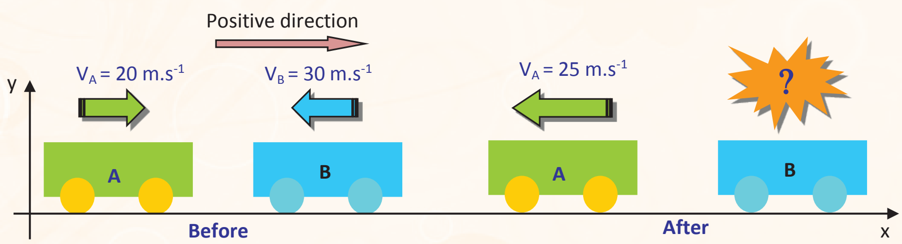
$\vec{v}_{(before)B} = 30 \text{ m} \cdot s^{-1}$ to the left

$\vec{v}_{A(after)} = 25 \text{ m} \cdot s^{-1}$ to the left

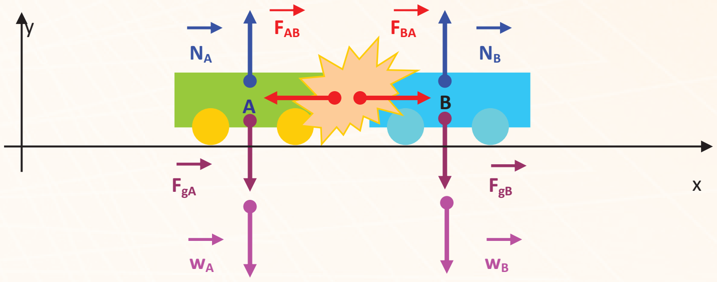
$\vec{v}_{(after)B} = ?$

1.1 The total linear momentum of an isolated system is constant.

1.2 When we work in Physics it is very important to represent a problem using a diagram; here we are working with vector quantities, so it is important to indicate direction with all elements (positive or negative)



In order to find the velocity of trolley B after the collision, the law of conservation of momentum must be applied. Learners' attention must be addressed to the general characteristics of this kind of problem, i.e. when an interaction between two bodies takes place. Firstly, we have to identify which bodies we are going to consider as our “system”. This is a very important step, since momentum is only conserved in ***closed*** and ***isolated systems***. In this problem, trolleys A and B integrate the system. Once we have identified the bodies of the system, we have to identify the interaction between the bodies of the system and the interaction with external bodies. Learners know that when we have any kind of interaction, a force will appear (as a measurement of the intensity of any particular interaction). During the collision, the two trolleys interact with the surface where they move on, with the Earth and, of course, with each other. The forces acting on each trolley are represented in the next diagram:



The forces $\vec{F}_{AB}$ and $\vec{F}_{BA}$ are the forces exerted by the trolleys on each other during the interaction, so they are internal forces. The forces $\vec{N}_A$ and $\vec{N}_B$ are so-called “normal forces”, that is, the reaction forces exerted by the surface where the trolleys move on. These two forces are in equilibrium with the gravitational force applied by the Earth on trolleys A and B, $\vec{F}_{gA}$ and $\vec{F}_{gB}$. Finally, forces $\vec{w}_A$ and $\vec{w}_B$ are the forces applied by the trolleys on the horizontal surface (sometimes called weights). All the external forces ($\vec{N}_A$, $\vec{N}_B$, $\vec{F}_{gA}$ and $\vec{F}_{gB}$) are in equilibrium, so there is no net external force acting on the trolleys. We can then say that:

$$\sum \vec{F}_{ext} = \vec{0}$$

Since: $\sum \vec{F}_{ext} = \frac{\Delta\vec{p}}{\Delta t}$

Then:

$$\Delta\vec{p}_{net} = \vec{0}$$
$$\vec{p}_{Tafter} - \vec{p}_{Tbefore} = \vec{0}$$
$$\vec{p}_{Tbefore} = \vec{p}_{Tafter}$$
$$\vec{p}_{A(before)} + \vec{p}_{B(before)} = \vec{p}_{A(after)} + \vec{p}_{B(after)}$$
$$m_A\vec{v}_{A(after)} + m_B\vec{v}_{B(before)} = m_A\vec{v}_{A(after)} + m_B\vec{v}_{B(after)}$$

When substituting the data given in the problem, we will have:

$$(120)(20) + (150)(-30) = (120)(-25) + 150\vec{v}_{B(a}$$
$$2400 - 4500 = -300 + 150\vec{v}_{B(after)}$$
$$\vec{v}_{B(after)} = +6\, m \cdot s^{-1}$$

Since the answer is positive, we can say that trolley **B** will move in the original direction of trolley **A** before the collision.

$\vec{v}_{fB} = 6\, m \cdot s^{-1}$ in the original direction of trolley **A**

1.3

m_A = 120 kg

$\vec{v}_{iA} = 20\ \mathrm{m} \cdot s^{-1}$ to the right

$\vec{v}_{A(after)} = 25\ \mathrm{m} \cdot s^{-1}$ to the left

$\boldsymbol{Impulse} = ?$

Let's take positive to the right:

$$Impulse = \Delta p$$

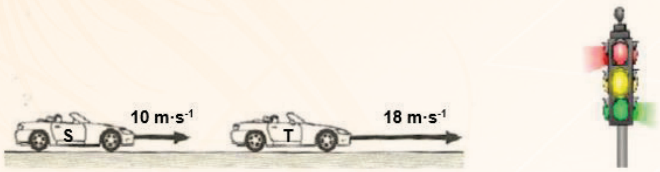
$$Impulse = m(v_f - v_i)$$

$$Impulse = 120\,(-25 - 20)$$

$$Impulse = -5400\ N \cdot s$$

$$Impulse = 5400\ N \cdot s\ \text{ to the left}$$

Worked Example 2



Two cars (S and T) are travelling on a straight road. They approach a robot at velocities of 10 m·s^{-1} East and 18 m·s^{-1} East, respectively, as shown in the sketch below. Ignore the effect of friction.

Car T suddenly stops and car S collides with car T. After the collision, the two cars move off together as a unit. The combined mass of each car with the driver is 1500 kg.

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

2.2 Calculate the speed of the two cars immediately after the collision. (4)

Research has shown that a force greater than 85 000 N during a collision may cause fatal injuries. The collision described above lasts for 0,08 s.

2.3 Determine, by means of calculations, whether the collision above could result in a fatal injury.(4)

The cars have crumple zones, seat belts, air bags and padded interiors that can reduce the chance of death or serious injury during accidents.

2.4 Use principles of Physics to explain how air bags can reduce the risk of injury or death.

Solution

2.1 The total linear momentum of an isolated and closed system remains constant in magnitude and direction. **OR** In an isolated system, the total linear momentum of a system before a collision/interaction is equal to the total linear momentum of the system after the collision.

2.2 *What to look for:*

(i) *In which direction are the cars travelling?*

(ii) *What is the mass of each car?*

(iii) *Is there a possibility of the cars moving together or moving separately after the collision?*

(iv) *What will happen to the speed of the cars after collision?*

(v) *What is the most appropriate equation for the scenario?*

The general equation for conservation of momentum is:

$$\sum \vec{p}_{before} = \sum \vec{p}_{after}$$

However, from the problem statement the two cars were moving separately before collision but moved together as a unit after the collision so the most appropriate equation to use is:

$$m_s v i_s + m_T v_i i_T = (m_s + m_T) v_{f(ST)}$$
$$(1500)(10)+(1500)(0) = v_{f(ST)} (1500+1500)$$
$$v_{f(ST)} = 5\ m \cdot s^{-1}$$

2.3 *In order to prove that the accident was fatal, the net force has to be calculated using the equation:*

$$\vec{F}_{net}\Delta t = m\Delta\vec{v}$$

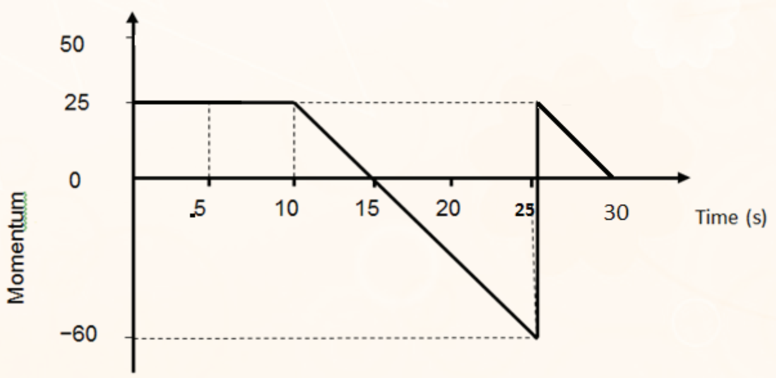
According to the problem statement, if the answer obtained exceeds 85 000 N, then the accident was fatal. If not, then the accident was not fatal. The mass and velocity of either of the cars before and after collision can be used.

$$\vec{F}_{net}\Delta t = m\Delta\vec{v}$$
$$\vec{F}_{net}(0{,}08) = 1500\ (5\text{-}0)$$
$$\vec{F}_{net}(0{,}08) = 7500$$
$$\vec{F}_{net} = \frac{7500}{0{,}08}$$
$$\vec{F}_{net} = 93\ 750\ N$$

In both cases, is greater than 85 000 N, so the accident will be fatal.

1.4 The magnitude of the impact during the collision depends on the relationship between the F_{net} and the time of collision when the momentum is constant. When the air bag inflates during the collision, the contact time of the passenger or driver with the air bag is longer than without air bag and thus the force on the passenger or driver is reduced according to the equation (F_{net} =), because Δp is constant for the collision.

The momentum versus time graph is shown in the graph below for a car initially moving horizontally towards the EAST. Is shown below.



1.1 Define momentum. (2)

1.2 What is the value of the initial momentum? (1)

1.3 In which time interval is the momentum of the car constant. (1)

1.4 At what time (s) did the car stop? (3)

1.5 Compare the direction in which the car is moving from: 0 to10 s; 10 to 15 s; and 15 to 25 s. (2)

1.6 There are many reasons for the change in momentum. Give any two possible reasons that could have caused the momentum of the car to change from 10 s to 20 s. (2)

1.7 Define impulse of a force. (2)

1.8 Calculate the change in momentum of the car from the starting point to 15s. (3)

[16]

4.3 VERTICAL PROJECTILE MOTION

PROJECTILE MOTION PROBLEM SOLVING STRATEGY

Step 1: Read the problem as many times as you need to, then draw a sketch of the situation (translate the words into a sketch).

Step 2: List all the given information and convert it to SI units, if necessary.

Step 3: Draw a free-body diagram.

- If the only force acting on the object is the gravitational force, then it is a projectile and the equations of uniformly accelerated motion can be used.

Step 4: Select the formula or equation that will be used to answer the question. In some cases, more than one equation is needed to calculate the answer.

Step 5: Substitute numerical values into an appropriate equation.

Step 6: Check your answer once you have and answer, check if it makes sense:

- Does it has the correct unit?
- Is the numerical value reasonable?

Exercise 1

A boy is standing on top of a building. He throws a ball vertically upwards from a position 3.5 m above the ground, with an initial velocity of 10 $m \cdot s^{-1}$. Ignore the effects of air resistance and answer the following questions:

1.1 What is the magnitude and direction of the acceleration of the ball?

1.2 Calculate the maximum height above the ground that the ball reaches.

1.3 What was the velocity of the ball at its maximum height?

1.4 Calculate the time taken by the ball to reach its maximum height.

1.5 How much time did the ball take to reach its maximum position and return to the position from which it was thrown?

1.6 Calculate the total time taken by the ball to reach the ground.

1.7 Calculate the velocity with which the ball hits the ground.

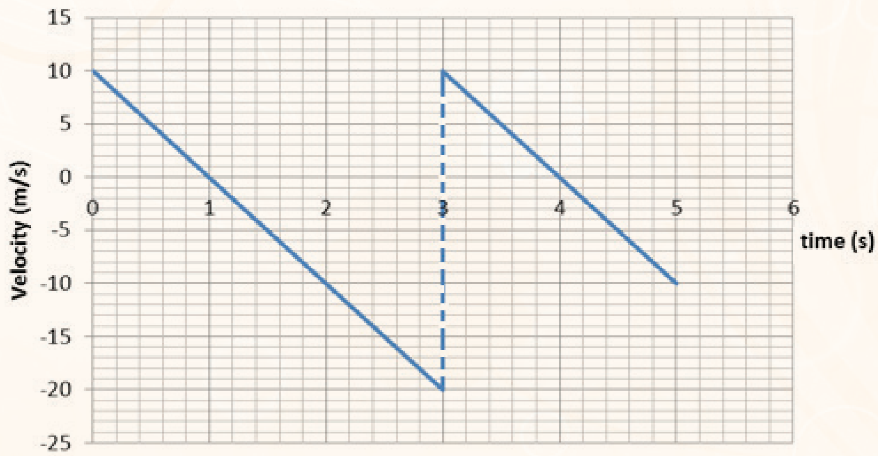
1.8 Draw a rough sketch of the velocity-time graph. Show relevant points on the velocity and time axis.

1.9 Draw a position-time graph.

Exercise 2

A boy is standing on the top of a building and throws a tennis ball vertically upwards. The graph below shows the velocity of the ball from the moment it is thrown until it hits the ground for the second time. Ignore air resistance.

Graph of velocity versus time



2.1 Describe the motion of the tennis ball in words.

2.2 What is the initial velocity of the tennis ball?

2.3 Calculate the height of the building.

2.4 Is the collision of the tennis ball with the ground elastic or inelastic? Explain.

2.5 Draw the position-time graph.

4.4 WORK ENERGY POWER

PROBLEM-SOLVING STRATEGY FOR WORK ENERGY POWER

STEP 1: Read and model the situation

- Read the problem as many time as you need to, in order to understand it.
- Draw a sketch of the situation (if not given) and identify which objects are parts of the system. Some problems may need to be sub-divided into two or more parts (scenarios).

STEP 2: Visualize

Draw a free-body diagram that show all the forces acting on the object (objects). Identify the type of force acting on the object (conservative or non-conservative)

STEP 3: Solve

- Collect the data and write it in symbol form.
- Select the equation, law (principle) or theorem that you can apply to solve the problem.
- If the system is *isolated* and *non-dissipative,* then the total mechanical energy is conserved:

  $E_{Ki} + E_{Pi} = E_{Kf} + E_{Pf} = E_M = constant$

- If there are *non-conservative* forces acting (**external** or **dissipative**), then use equation:

  $W_{non-conservative} = \Delta E_K + \Delta E_p$

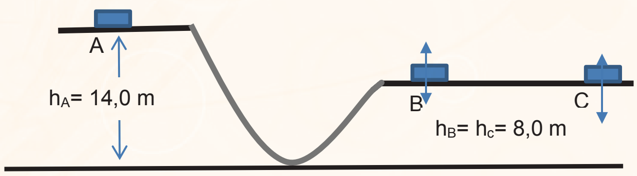
- For both conservative and non-conservative forces acting, you can use the work energy theorem:

  $W_{net} = \Delta E_K$

- Kinematics equations and some other laws must be used with some problems.
- Substitute the values in the selected equation.

WORKED EXAMPLE

1. The sketch below shows a 2,0 kg block sliding from A to B along a frictionless surface. When the block reaches B, it continues to slide along a horizontal surface (BC), where a kinetic frictional force acts on the block. As a result, the block slows down, coming to rest at C. The kinetic energy of the block at A is 40,0 J; the height of A and B is 14,0 m and 8,0 m above the ground, respectively.



1.1. Is the total mechanical energy of the block conserved as the block goes from A to B? Why or why not?

1.2. When the block reaches point B, has its kinetic energy INCREASED, DECREASED or REMAINED THE SAME? Provide a reason for your answer.

1.3. Calculate the speed of the block when it reaches B.

1.4. Is the total mechanical energy of the block conserved as the block goes from B to C? Justify your answer.

1.5. How much work does the kinetic frictional force do during the BC segment of the trip?

SOLUTION:

STEP 1: Read and Model

There is a sketch of the situation, so we do not need to draw the sketch.

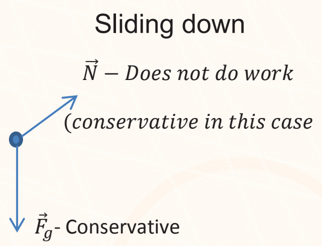
The block is interacting with the surface and the Earth.

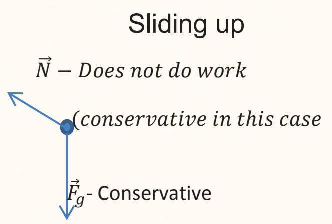
System: block-surface-Earth

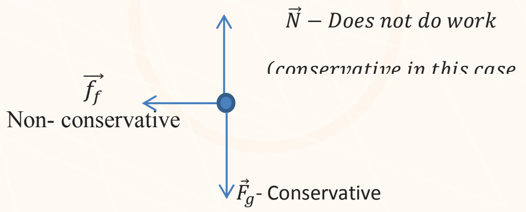
STEP 2: Visualize

Free-body diagram

Part 1 (from A to B) the only two forces acting are gravitational force and normal force.







From A to B there are \only conservative forces acting therefore the system is isolated.

Part 2 Sliding on a horizontal surface (from B to C)

From B to C the frictional force is acting on the block which is not conservative therefore the system is not isolated.

STEP 3: Solve

Data

m= 2,0 kg

E_{KA}= 40 J

h_A= 14,0 m

$h_B = h_c = 8,0$ m

v_B-?

W_{ff}-?

1.1. The total mechanical energy is conserved if the net work done by the non- conservative forces is zero, or only conservative forces act on the object, or W_{nc} = 0J. Only two forces act on the block during its trip from A to B: the gravitational force, which is conservative; and the normal force, which is conservative in this case. Thus, we conclude that W_{nc} = 0 J, with the result being that the total mechanical energy is conserved during the AB part of the trip.

1.2. As we have seen, the total mechanical energy is the sum of the kinetic and gravitational potential energy, and it remains constant from A to B. Therefore, as one type of energy decreases, the other must increase, in order for the sum to remain constant. Since B is lower than A, the gravitational potential energy at B is less than that at A. As a result, the kinetic energy at B must be greater than that at A.

1.3. From A to B, total mechanical energy is conserved.

$$E_{Ki} + E_{Pi} = E_{Kf} + E_{Pf} = E_M = constant$$
$$E_{KA} + mgh_A = \frac{1}{2}mv_B^2 + mgh_B$$
$$E_{KA} + mgh_A = \frac{1}{2}mv_B^2 + mgh_B$$

$$40 + (2 \times 9{,}8 \times 14) = \frac{1}{2} \times 2 \times v_B^2 + (2 \times 9{,}8 \times 8)$$
$$40 + 274{,}4 = v_B^2 + 156{,}8$$
$$314{,}4 - 156{,}8 = v_B^2$$
$$v_B^2 = 157{,}6$$
$$v_B = \sqrt{157{,}6}$$

$v_B = 12{,}55$ m·s^{-1}

1.4. During the trip from B to C, the frictional force acts on the block. This force is non-conservative and does work on the block, consequently. The net work done by the non–conservative force is not zero (W_{nc}), so the total mechanical energy is not conserved during the BC part of the trip.

1.5. During the BC part, the total mechanical energy is not conserved, because a kinetic frictional force is present.

$$W_{nc} = \Delta E_M$$
$$W_{nc} = \Delta E_K + \Delta E_p$$
$$W_{nc} = (E_{KC} - E_{KB} + mg(h_C - h_B)$$
$$W_{nc} = (\frac{1}{2}mv_C^2 - \frac{1}{2}mv_B^2 + mg(h_C - h_B)$$
$$W_{nc} = (\frac{1}{2}2 \times 0^2 - \frac{1}{2}2 \times (12{,}55)^2 + 2 \times 9{,}8 \times (8-8)$$
$$W_{nc} = 0 - (12{,}55)^2 + 0$$
$$W_{nc} = -157{,}50\,J$$

The work done by frictional force is –157,50 J, because this force points in the opposite direction of the displacement.

Alternative solution:

Applying the work energy theorem:

$$W_{net} = \Delta E_K$$
$$W_{ff} + W_{Fg} + W_N = (E_{KC} - E_{KB})$$
$$W_{ff} + mg\cos 90^0 + N\cos 90^0 = (\frac{1}{2}mv_C^2 - \frac{1}{2}mv_B^2)$$
$$W_{ff} + 0 + 0 = (\frac{1}{2}2 \times 0^2 - \frac{1}{2}2 \times (12,55)^2$$
$$W_{nc} = 0 - (12,55)^2$$
$$W_{nc} = -157,50\,J$$

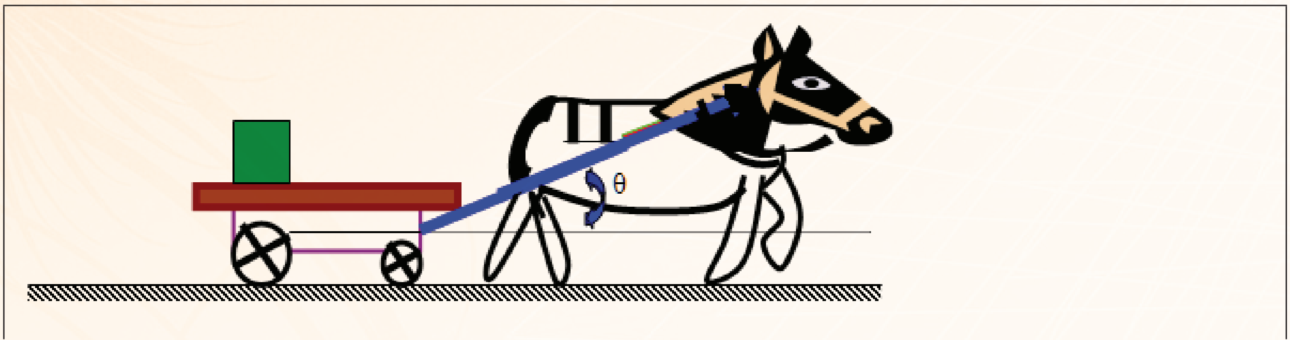
The work done by frictional force is –157,50 J, because this force points in the opposite direction of the displacement.

STEP 4: ***Assess***

The results have the correct units for speed (m·s^{-1}) and for work (J), they are reasonable and answer the questions.

Exercise 1

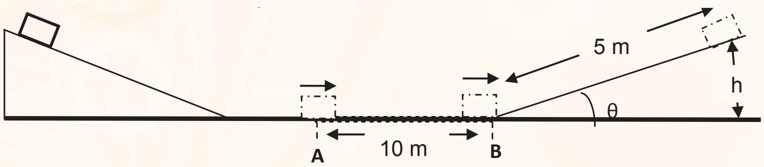
A donkey pulls a cart of mass 600 kg from rest along a horizontal road. The donkey applies a constant force of magnitude 191,7 N at an angle of 30° to the horizontal. The cart accelerates and reaches a speed of 3 $m.s^{-1}$ in 5 minutes. The average frictional force that acts on the cart is 160,02 N. Ignore the effect of the rotation of the wheels of the cart.



1.1	State the *work-energy theorem* in words.	**(2)**
1.2	Use the WORK-ENERGY THEOREM to calculate the distance covered by the cart in 5 minutes.	**(5)**
1.3	Calculate the power developed by the donkey in 5 minutes.	**(3)**
	The donkey now applies a force of the same magnitude on the cart, during the same time period and over the same distance, but at a SMALLER ANGLE to the horizontal.	
1.4	How does the power developed by the donkey now compare to the power developed by the donkey in QUESTION 1.3? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. Give a reason for the answer. (No calculations are required.)	**(2)**
		[12]

Exercise 2

A 2 kg block, initially at 4 m height, is released and slides downhill from rest on a frictionless ramp, and then moves along a horizontal surface. It then moves on a 10 m length rough horizontal surface with coefficient of kinetic friction μ_k =0,2, until reaches a rough ramp with the same coefficient of friction and slides on it for 5 m until it stops.



State the *law (principle) of conservation of mechanical energy* in words.

2.1. Use ENERGY CONSIDERATIONS to calculate the speed of the block at the bottom of the ramp.

2.2. State the *work energy theorem* in words.

2.3. Use the WORK ENERGY THEOREM to calculate the speed of the block when passing position **B**.

2.4. Use the LAW OF CONSERVATION OF ENERGY to calculate the height reached by the block until it comes to rest.

2.5. Calculate the angle at θ.

4.5 DOPPLER EFFECT

Worked Example

A man is standing on a pavement when he hears an ambulance approaching. The siren of the ambulance is emitting a wave sound with a frequency of 500 Hz. The ambulance is moving at a constant speed of 30 $m \cdot s^{-1}$. Calculate the frequency of the sound the man hears. Take the speed of the sound in the air as 340 $m \cdot s^{-1}$.

Solution

$$f_L = \left(\frac{v \pm v_L}{v \pm v_s}\right) f_s$$

$$f_L = \left(\frac{340+0}{340-30}\right) \times 500$$

$$f_L = 1{,}10 \times 500$$

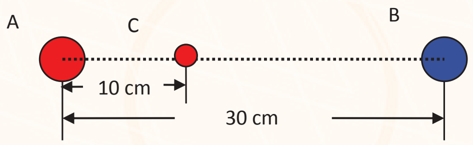
$$f_L = 550 Hz$$

4.6 ELECTROSTATICS

Worked example

QUESTION 1 (Question 3 - Spring School material, Northern Cape)

Two identically charged spheres (**A** and **B)** are 30 cm apart, with a charge of $+3 \times 10^{-4}$ C and -2×10^{-4} C, respectively. A small positive charge (**C)** of $+10^{-8}$ C is placed 10 cm from sphere **A,** as shown in the diagram below.



1.1 State *Coulomb's law* in words.

1.2 Calculate the magnitude of the force exerted on the small positive charge **C** by charge **A**.

1.3 Calculate the magnitude of the force exerted on the small positive charge **C** by charge **B**.

1.4 Calculate the magnitude of the resultant force exerted on the small positive charge **C**.

1.5 Define *electric field at* a point in words.

1.6 Calculate the magnitude of the electric field at point **C**, 10 cm from **A,** as a result of charge **A**.

1.7 Now the small charge **C** is removed. Calculate the resultant electric field at a point situated at the centre point between **A** and **B.**

1.8 Charge **C** makes contact with charge **B** until the total charge between **B** and **C** is distributed. Calculate the new charge on **C**.

SOLUTION

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

1.2 Data

$Q_A = +3x10^{-4}$ C
$q_c = +10^{-8}$ C
r_{AC} = 10 cm =10 x 10^{-2} m
k = $9x10^9 N \cdot m^2 \cdot C^{-2}$
F_{AonC} = ?

$$F_{AonC} = \frac{KQ_A q_C}{(r_{AC})^2}$$

$$F_{AonC} = \frac{9x10^9 \times 3\times10^{-4} \times 10^{-8}}{(10\times10^{-2})^2}$$

$$F_{AonC} = \frac{27\times10^{-3}}{100\times10^{-4}}$$

F_{AonC} = 0, 27x10^1N = 2,70 N

1.3 Data

$Q_B = -2$ x 10^{-4} C

$q_c = +10^{-8}$ C
r_{BC} = 20 cm = 20 x 10^{-2} m
k = $9\times10^9 N \cdot m^2 \cdot C^{-2}$
F_{AonC} = ?

$$F_{BonC} = \frac{KQ_B q_C}{(r_{BC})^2}$$

$$F_{BonC} = \frac{9x10^9 \times 2\times10^{-4} \times 10^{-8}}{(20\times10^{-2})^2}$$

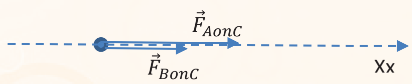
$$F_{BonC} = \frac{18\times10^{-3}}{400\times10^{-4}}$$

F_{BonC} = 0,045x10^1 N = 0,45 N

1.4 There are two electrostatic forces acting on point charge C; the gravitational force is ignored because it is too small in comparison to the electrostatics forces, therefore we must apply the principle of superposition of forces.

$\vec{F}_R = \vec{F}_{AC} + \vec{F}_{BC}$ (it is a vector equation)

We must draw a free body diagram showing the electrostatic forces acting on the point charge and choose the positive direction.



Working with the magnitudes of the forces:

$F_R = F_{AC} + F_{BC}$

Substitution:

F_R = 2,70 N + 0,45 N

$_R$ = 3,15 N

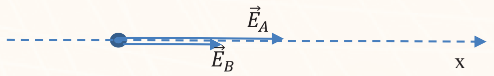
2.3 The electric field at a point is the electrostatic force experienced per unit of positive charge placed at that point.

2.3 $E = \frac{F}{q}$ $E = \frac{2,7}{10^{-8}}$ E = 2,7 x 10^8 N·C^{-1}

1.7 Each charge has an electrostatic field around it, therefore there are two electric fields at the point, and we must apply the principle of superposition of fields.

$\vec{E}_R = \vec{E}_A + \vec{E}_B$ (it is a vector equation)

We must draw the vector electric field of each charge at a point.



Both electric filed vectors point in the same direction, therefore we add them together:

$E_A = \frac{KQ_A}{r^2}$ $E_A = \frac{9x10^9\,Nm^2C^{-2}x3x10^{-4}\,C}{(15x10^{-2}\,m)^2}$ $E_A = \frac{27x10^5\,Nm^2C}{225x10^{-4}\,m^2}$

E_A = 0,12 x 10^9 = 1,2 x 10^8 N·C^{-1} to the right

$E_B = \frac{KQ_B}{r^2}$ $E_B = \frac{9x10^9\,Nm^2C^{-2}x2x10^{-4}\,C}{(15x10^{-2}\,m)^2}$ $E_B = \frac{18x10^5\,Nm^2C}{225x10^{-4}\,m^2}$

E_B = 0,08 x 10^9 = 0,8 x 10^8 to the right

E_R = 1,2 x 10^8 + 0,8 x 10^8

E_R = 2 x 10^8 N·C^{-1} to the right

1.8 Since the system is isolated, then we must apply the law of conservation of charge.

$Q_{net} = Q_c + Q_B = constant$

After being in contact ($Q_c = Q_B = Q$)

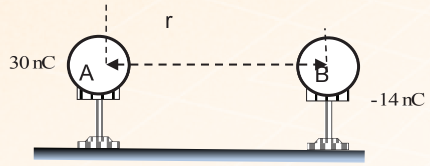
$Q_c + Q_B = 2Q$

$Q = \frac{Q_c + Q_B}{2}$

$Q_c = \frac{(1\times10^{-8})+(-2\times10^{-4})}{2} = \frac{0,0001\times10^{-4} - 2\times10^{-4}}{2} = \frac{1,9999\times10^{-4}}{2}$ = - 1,00 x10^{-4} C

Exercise 1

Two small, identical metal spheres (**A** and **B**), carrying charges of +30nC and -14nC, respectively, are mounted on insulated stands; these are placed at a certain distance **r** from each other, as shown below.



1.1. Define *electric field* in words.

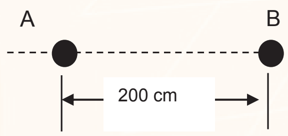
1.2. Sphere **B** is moved and makes contact with sphere **A**. It is then moved back to its original position. The magnitude of the electrostatic force between them is now 6,4 x 10^{-4} N.

1.2.1 Sketch the field pattern surrounding the charges.

1.2.2 Calculate the magnitude of the charge on each sphere after contact.

1.3. Determine the original distance between the spheres.

Exercise 2



Two small objects (**A** and **B**) are equally positively charged; these are placed in a vacuum, as shown in the figure below.

Charge **B** repels charge **A** with an electrostatic force of 3,0 x 10^{-6} N.

2.1 State *Coulomb's law* in words.

2.2 What is the magnitude of the electrostatic force that A exerts on **B**?

2.3 Draw the resultant electric field lines of the electric field around charges **A** and **B**.

2.4 Calculate the magnitude of charge **A** and **B**.

2.5 Calculate the electric field strength at a point in the centre of charge **A** and **B**.

4.7 ELECTRIC CIRCUITS

STRATEGY TO SOLVE PROBLEMS ON ELECTRIC CURRENT

- Read the problem carefully, as many times as you need to.
- If not given, draw a circuit diagram.
- Write down the data in symbolic form.
- Indicate the conventional direction of the current, from high-potential to low-potential (+ to -).
- Re-draw the circuit diagram to simplify it, if necessary.
- Identify the type of connection (series/parallel).
- Analysing circuits:

1 – The algebraic sum of the changes in potential in a complete transversal of any loop of a circuit must be zero **(ε= Ir+ Ir).**

2. The sum of the currents entering any junction must be equal to the sum of the currents leaving that junction:

$$i = i_1 + i_2 + \ldots + i_n$$

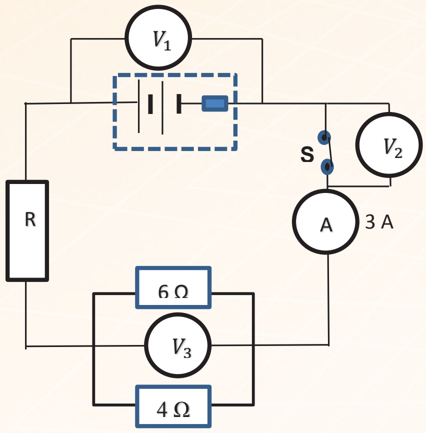
- Write down the formula/ equation that solves the question.
- Find the unknowns, if needed (multi-concept problems).
- Do the calculations and write down the final answer.
- Check your answer. Check if it makes sense, i.e.:

\- Is the unit correct?

\- Is the numerical value reasonable?

WORKED EXAMPLE

In the circuit diagram below, the voltmeter V_1 reads 12 V when switch **S** is open. When switch **S** is closed, the reading drops to 10 V. The resistance of the Ammeter and the wires is negligible.



1.1 What is the reading of the ammeter when the switch is open?

1.2 What is the emf of the battery?

1.3 What is the reading of voltmeter 2?

1.4 Calculate the equivalent resistance of the resistors connected in parallel.

1.5 Determine the reading of voltmeter 3?

1.6 Calculate the internal resistance of the battery?

1.7 Determine the total resistance of the circuit?

1.8 What is the resistance of the resistor R?

1.9 How would the reading of voltmeter V_2 change if the 6 Ω resistor is removed from the circuit? Write down INCREASE, DECREASE or REMAIN THE SAME. Explain your answer.

SOLUTION

1.1. Zero (when the circuit is open there is no flow of charges therefore no current in the

1.2. 12 V (when there is no electric current flowing in the circuit, the reading of the voltmeter connected across the terminals of the battery is equal to the *emf* of the battery, because there is no energy dissipated.

1.3. Zero (there is current in the circuit, but the resistance is negligible: V=IR=(I)(0)=0 V)

1.4. The resistors of 6 Ω and 4 Ω are connected in parallel

Where there are two resistors we can solve in the following way

$$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{(6)(4)}{6+4} = 2{,}4\ \Omega$$

$$\frac{1}{R_P} = \frac{1}{6} + \frac{1}{4} = \frac{5}{12}$$

$$R_P = 2{,}4\ \Omega$$

1.5 $V_p = IR$

$V_p = 3 \times 2{,}4$

$V_p = 7{,}2\ V$

The reading of the voltmeter 3 is 7,2 V.

1.6 $\varepsilon = V_{ext} + V_{int}$

$V_{int} = \varepsilon - V_{ext}$

$Ir = \varepsilon - V_{ext}$

$3r = 12 - 10$

$r = 0{,}67\ \Omega$

1.7 $\varepsilon = IR_{total}$

$12 = 3R_{total}$

$R_{total} = 4\ \Omega$

1.8

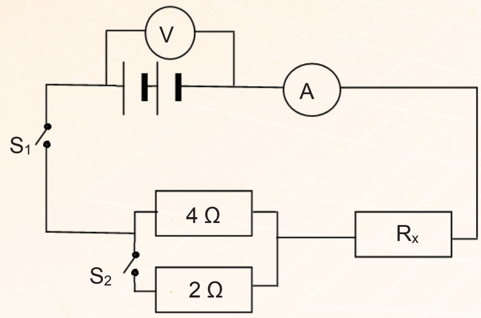
Option 1	Option 2
$R_T = R_{ext} + r$	$V_{unknown} + V_2 = V_1$
$R_{ext} = R_{unknown} + R_P$	$IR_{unknown} + 7{,}2 = 10$
$R_T = R_{unknown} + R_P + r$	$3R_{unknown} + 7{,}2 = 10$
$4 = R_{unknown} + 2{,}4 + 0{,}67$	$R_{unknown} = 0{,}93\ \Omega$
$R_{unknown} = 0{,}93\ \Omega$	

1.8 INCREASE

If the bulb of 6 Ω is removed, the total resistance of the circuit increases, then the reading of the ammeter decreases, because the current decreases due to the increasing external resistance; but the reading of the voltmeter increases, because the drop of potential in the internal resistance also decreases; but the emf of the battery is constant, according to $V_{load} = \varepsilon - V_{int} = \varepsilon - Ir$.

Exercise 1

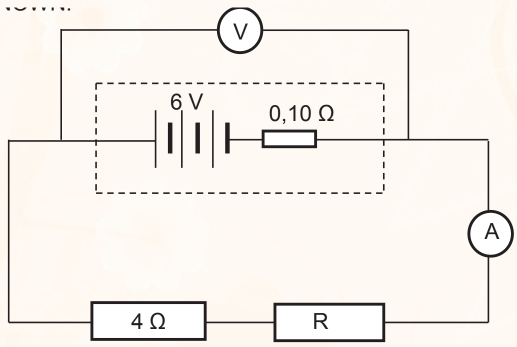
Three resistors (2 Ω, 4 Ω and R_x) are connected to a battery, as shown in the circuit diagram below. With switch S_1 open and S_2 closed, the reading on the voltmeter is 10 V. With both switches closed, the reading on the voltmeter is 8 V and the ammeter is 1 A.



1.1	WRITE DOWN THE VALUE OF THE EMF OF THE BATTERY.		(1)
1.2	CALCULATE THE:		
	1.2.1 RESISTANCE OF THE UNKNOWN RESISTOR R_x.		(7)
	1.2.2 INTERNAL RESISTANCE OF THE BATTERY.		(3)
1.3	HOW WILL THE READING ON THE VOLTMETER BE AFFECTED IF THE SWITCH S_1 IS CLOSED WHILE S_2 IS OPENED. WRITE DOWN ONLY INCREASES, DECREASES OR REMAINS THE SAME. BRIEFLY EXPLAIN THE ANSWER.		(4) [15]

Exercise 2

In the circuit diagram below, the emf of the battery is 6 V and its internal resistance is 0,10 Ω. The resistance (R) is UNKNOWN.



2.1 Explain the term *internal resistance.* (2)

2.2 Write down an equation for the terminal potential difference using the values given. (2)

2.3 Draw a sketch graph of terminal potential difference versus current. Indicate the following in the graph: (3)

- The value of the emf.
- The current at which the terminal potential difference is zero.

2.4 The energy dissipated in 4 Ω resistance is 40 J; the energy dissipated in resistance R is 60 J.

Calculate:

2.4.1 Resistance R (4)

2.4.2 Total current in the circuit (3)

2.4.3 Reading of the voltmeter (3)

2.5 A 7 Ω resistor is now connected in parallel to the 4 Ω resistor. How will this action affect the reading of the voltmeter? Write down only INCREASES, DECREASES or REMAINS THE SAME.

Briefly explain your answer.

(4)

[21]

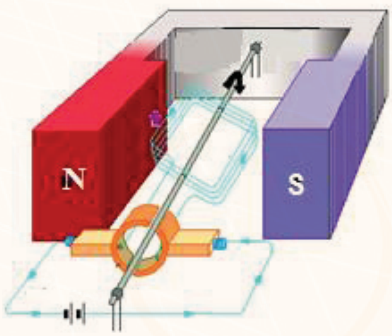
4.8 ELECTRODYNAMICS

Problem Solving Strategy for Electrodynamics

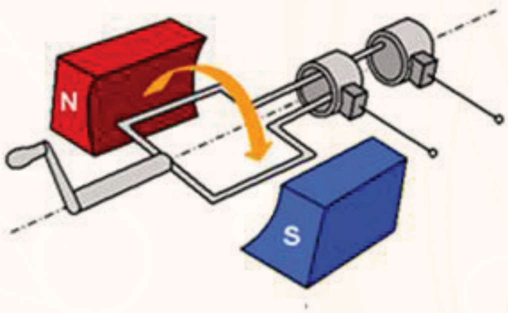
- With electrical machines, look at the energy conversions to identify the type of electrical machine.
- Re-draw the circuit diagram to simplify it, if necessary.
- Identify the type of connection (series/parallel).

Worked example

The simplified diagrams below represent an electric motor and a generator.



X



Y

1.1 Which ONE of the diagrams above represents a simplified diagram of an electric motor? Give a reason for your answer.

1.2 What type of generator (AC or DC) is represented in the simplified diagrams above? Give a reason for your answer.

1.3 State ONE method of increasing the induced emf of this generator.

1.4 WRITE DOWN ONE USE OF ELECTRIC MOTORS.

1.5 THE MAXIMUM POTENTIAL DIFFERENCE PRODUCED BY THIS GENERATOR IS 12 V AND THE FREQUENCY IS 50 HZ.

1.1. SKETCH A GRAPH OF THE INDUCED POTENTIAL DIFFERENCE VERSUS TIME.

1.5.2. CALCULATE THE INDUCED RMS POTENTIAL DIFFERENCE.

1.5.3. CALCULATE THE AVERAGE POWER DISSIPATED IF A 5 Ω RESISTOR IS CONNECTED TO THIS GENERATOR.

SOLUTION

1.1 X. It converts electrical energy into mechanical energy.

1.2 AC generator.✓ It has slip rings.✓

W

1.3 ANY ONE of the following:✓

Increasing the speed/frequency of rotation

Increasing the number of coils

Increasing the strength of the magnetic field

Insert a soft iron core

1.4 ANY ONE of the following:✓

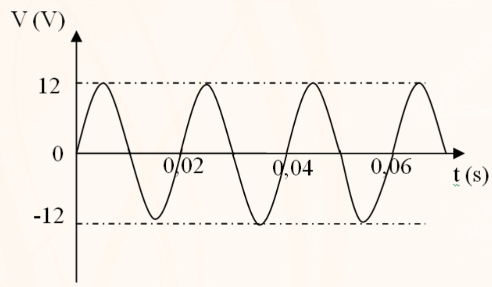
Pumps

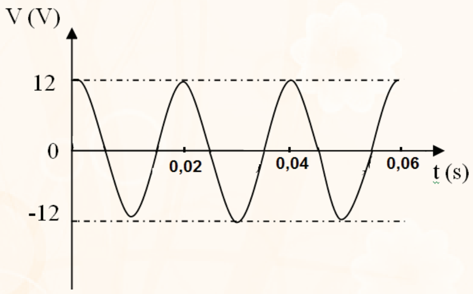
Fans

Compressors

Hair dryers

1.5.1





1.5.2

$$V_{rms/wgk} = \frac{V_{max/maks}}{\sqrt{2}} \checkmark$$

$$V_{rms/wgk} = \frac{12}{\sqrt{2}} \checkmark$$

$$V_{rms/wgk} = 8{,}49 \text{ V} \checkmark$$

1.5.3

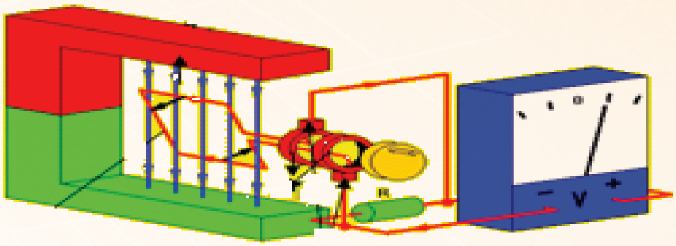
$$P_{ave/gem} = \frac{V^2_{rms/wgk}}{R} \checkmark$$

$$P_{ave/gem} = \frac{(8{,}49)^2}{5} \checkmark$$

$$P_{ave/gem} = 14{,}42 \text{ W} \checkmark$$

Exercise 1

A team of grade 12 learners conducted a practical investigation to investigate the relationship between the root mean square value of voltage generated and the frequency of rotation of the armature of the generator using the device shown in the figure below.



The following table shows the results obtained.

Frequency Hz)	0	10	20	30	40	50
V_{rms}(V)	0	1	2	3	4	5

1.1. What type of generator was used by the learners during the practical investigation? Give a reason for your answer.

1.2. Write an investigative question for this investigation.

1.3. What could the learner's hypothesis have been for this experiment?

1.4. What is the dependent variable in this experiment?

1.5. Use the data to draw a graph on the graph paper provided.

1.6. Write the conclusion for the results obtained.

1.7. Calculate the root mean square value of the voltage when the amplitude of the voltage is 5 V.

1.8. If a resistor of 5 Ω is connected to the generator, determine the root mean square value of the current through the resistor when the frequency of rotation of the armature is 50 Hz.

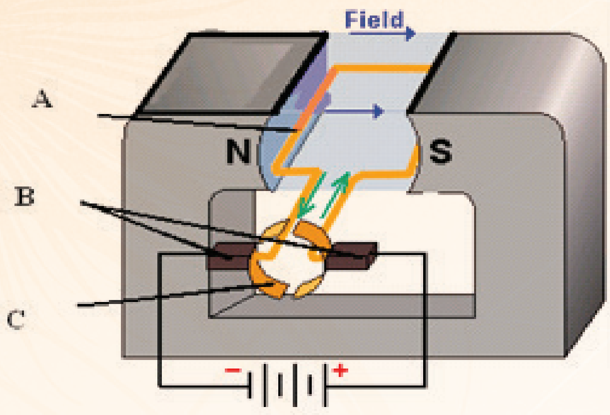
1.9. Calculate the average power dissipated through the resistor when the frequency of rotation of the armature is 50 Hz.

1.10. Draw the graph of instantaneous voltage vs time when the armature rotates with constant frequency of 50 Hz.

1.11. List the advantages of alternating current (AC) over direct current (DC).

Exercise 2

The diagram below shows one of the electrical machines studied in class.



2.1 Is this electrical machine a DC motor or a DC generator? Give a reason for your answer.

2.2 What is the direction of rotation of the loop: clockwise or anti-clockwise?

2.3 Label the parts of this electrical machine indicated by **A**, **B** and **C**.

2.4 Write three applications of this electrical machine.

5 REVISION QUESTIONS - SET 2 (MASTER AN ADDITIONAL 20%)

5.1 NEWTON'S LAWS

Exercise 1

Two blocks of the same materials are connected by a light, inelastic rope. Block A has a mass of 5 kg; block B has a mass of 3 kg. Another rope is fixed to block B and a force ($\vec{F}$) of 100N is applied horizontally. The blocks are moving along a horizontal frictionless surface.

1.1 Draw separate labelled free-body diagrams of all the force's action on the blocks.

1.2 Calculate the acceleration of the blocks.

1.3 Calculate the magnitude of the tension in the rope.

The two blocks are now pulled over another surface and the blocks experience friction. The blocks accelerate at 8,972 $m{\cdot}s^{-2}$. The force exerted by the rope on block A is 62,5 N.

1.4 Calculate the kinetic coefficient of friction for block A.

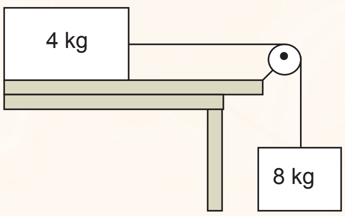
1.5 If the two blocks have the same surface area, will block B have a different coefficient of friction? Explain your answer.

1.6 Calculate the frictional force exacted by the surface on block B.

1.7 Name two action-reaction pairs in the system.

Exercise 2

A 4 kg block on a horizontal, rough surface is connected to an 8 kg block by a light inextensible string that passes over a frictionless pulley, as shown below. The coefficient of kinetic (dynamic) friction between the block of 4 kg and the surface is 0,6.



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

2.2 Write down Newton's second law of motion in words.

2.3 Calculate the acceleration of the system.

2.4 Calculate the magnitude of the tension in the string.

2.5 Calculate the magnitude of the frictional force that acts on the 4 kg block.

2.6 Calculate the apparent weight of the 8 kg block.

2.7 How does the apparent weight of the 8 kg block compare with its true weight? Write down only, GREATER THAN, EQUAL TO or LESS THAN.

2.8 How does the apparent weight of the 4 kg block compare with its true weight? Write down only, GREATER THAN, EQUAL TO or LESS THAN.

Exercise 3

ZACUBE-1 IS THE FIRST SOUTH AFRICAN SATELLITE. IT WAS DESIGNED AND BUILT BY POSTGRADUATE STUDENTS, FOLLOWING THE CUBESAT PROGRAMME AT THE FRENCH SOUTH AFRICAN INSTITUTE OF TECHNOLOGY (F'SATI), **IN COLLABORATION WITH THE SOUTH AFRICAN NATIONAL SPACE AGENCY (SANSA). ZACUBE-1 WAS LUNCHED ON** 21 NOVEMBER 2013 AND **IS ORBITING AT A HEIGHT OF 600 KM FROM THE SURFACE OF EARTH**. **WEIGHING 1.2 KG, THIS CUBESAT IS ABOUT** 100 TIMES SMALLER THAN SPUTNIK **- THE FIRST SATELLITE LAUNCHED INTO SPACE IN 1957.**

3.1 **STATE *NEWTON'S LAW OF UNIVERSAL GRAVITATION* IN WORDS.** **(2)**

3.2 How would the magnitude of the gravitational force exerted by the Earth on ZACUBE-1 compare with the magnitude of the gravitational force exerted by the Earth on Sputnik, if both satellites were orbiting at the same height?

Write down only LARGER THAN, SMALLER THAN or THE SAME. Explain the answer. **(4)**

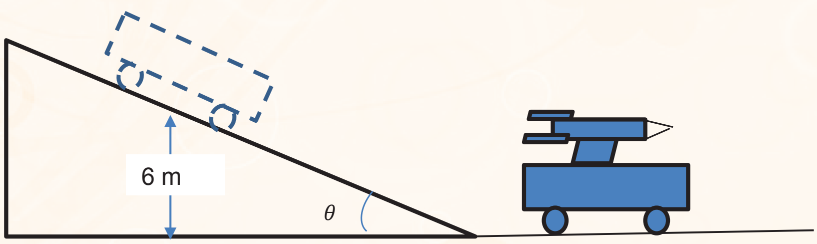
3.3 **CALCULATE THE GRAVITATIONAL FORCE EXERTED BY THE EARTH ON THE SATELLITE ZACUBE-1.** **(5)**

3.4 **CALCULATE THE HEIGHT THE SATELLITE MUST BE ORBITING AT FOR THE VALUE OF THE ACCELERATION DUE TO GRAVITY TO BE 25% OF THE GRAVITATIONAL ACCELERATION ON THE SURFACE OF THE EARTH.** **(6)** **[17]**

5.2 MOMENTUM AND IMPULSE

Exercise 1 (Integration of: Law of Conservation of Momentum, Newton's Laws and Equations of Motion)

The sketch below shows a missile launcher of mass 4800 kg at rest on a frictionless horizontal surface next to the base of a smooth inclined plane. It fires a rocket of mass 100 kg horizontally, and recoils up the inclined plane, rising to a height of 6 m.



1.1. State the *law of conservation of linear momentum* in words.

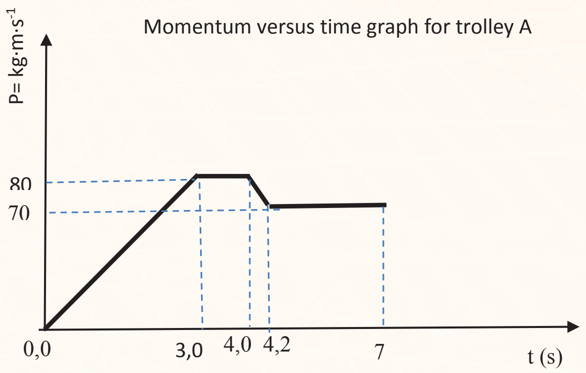
1.2. Why is the system formed by the missile launcher and the rocket is said to be isolated?

1.3. Calculate the initial speed of the rocket.

Answer: $520{,}32\ m \cdot s^{-1}$

Exercise 2

A constant force to the right is applied to Trolley A; it has a mass 10 kg during 3 s and starts moving from rest on a horizontal frictional surface. After the 3 s, the trolley moves with constant velocity and collides with Trolley **B,** which has a mass of 8 kg and is at rest. After the collision, the two trolleys stick together and move as a system. The graph below shows how the momentum of Trolley **A** changes with time just before and after the collision.



2.1 Define the term impulse of a force in words.

2.2 Use the information in the graph to calculate:

2.2.1 The impulse of the force exerted on the trolley during the three first seconds.

2.2.2 Velocity of Trolley A before the collision.

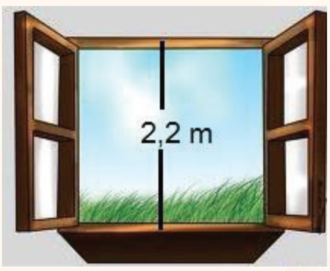
2.2.3 Velocity of the system formed by Trolley A and B after the collision.

2.2.4 The average force exerted by trolley B on trolley A during the collision.

5.3 VERTICAL PROJECTILE MOTION

Exercise 1

A falling stone takes 0,28 s to travel past a window that is 2,2 m in height. Ignore air friction.



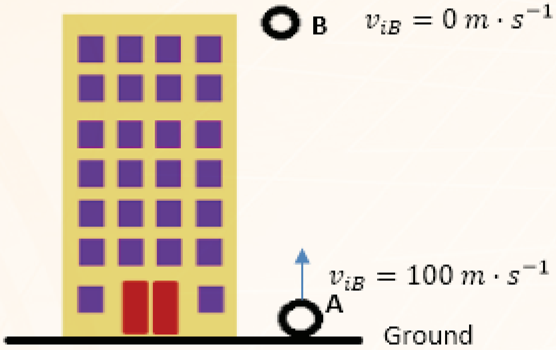
1.1. From what height above the top of the window was the stone dropped?

1.2. Draw the position vs time graph for the motion of the stone for the period of time from when it was dropped until it reached the base of the window.

1.3. Draw the velocity vs time graph for the motion of the stone for the period of time from when it was dropped until it reached the base of the window.

Exercise 2

A very small rocket (**A**) is launched vertically upwards with an initial velocity of 100 $m.s^{-1}$. At the same time, a stone (**B**), which is initially at a height of 150 m, is dropped from the top of the very high building. Ignore air resistance.



2.1 Calculate the velocity of stone **B** when it hits the ground.

2.2 Calculate the time taken for **A** and **B** to pass each other.

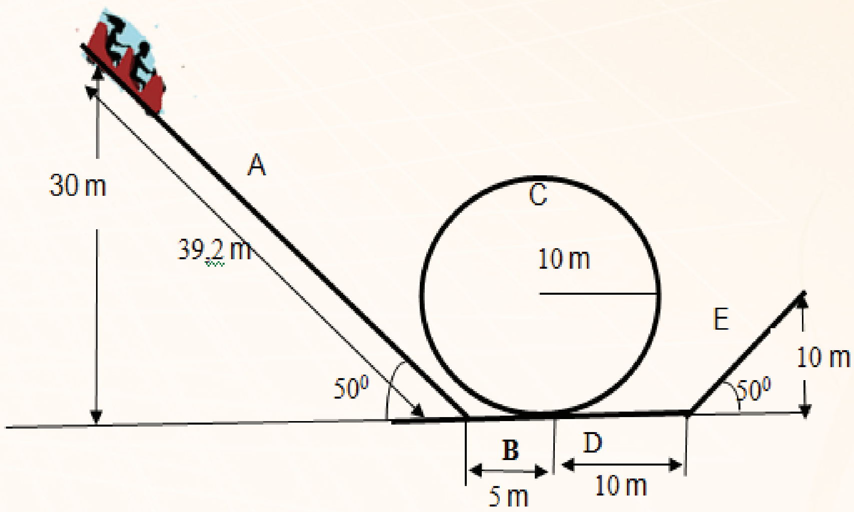
2.3 Calculate the fly time of the small rocket (**A**).

2.4 Draw the velocity versus time graph for the motion of the small rocket (**A**) from the moment it is launched until it strikes the ground. Indicate the respective values of the intercepts on your velocity-time graph.

5.4 WORK ENERGY POWER

QUESTION 1

THE DIAGRAM BELOW ILLUSTRATES A ROLLER-COASTER TRACK. SECTIONS A, B AND C ARE FRICTIONLESS. THERE IS FRICTION ON SECTIONS D AND E. THE SLED HAS A TOTAL MASS OF 24,7 KG AND IS AT REST AT THE TOP LEFT POSITION.



1.1 **How does the total mechanical energy of the sled at the top left position compare to the total mechanical energy of the sled at the end of section D. Write down GREATER THAN, LESS THAN or EQUAL TO. Then explain your answer.** **(3)**

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

1.3 The speed of the sled at the beginning of section B is 24,25 $m \cdot s^{-1}$; the speed of the sled at the end of section D is 18 $m \cdot s^{-1}$. **(4)**

1.3.1 Use the work-energy theorem to calculate the frictional force that acted on the sled in section D. (5)

1.3.2 Use the LAW OF CONSERVATION OF ENERGY (ENERGY PRINCIPLE) to calculate the minimum length of section E required for the sled to come to rest, if it has the same frictional force as calculated in 1.3.1. (6)

[16]

5.5 DOPPLER EFFECT

EXERCISE 1

The siren of a stationary police car emits sound waves at a frequency of 620 Hz. A stationary listener watches the police car approaching him at constant velocity on a straight road. Assume that the speed of sound in air is 340 $m \cdot s^{-1}$.

1.1 How does the wavelength of the sound waves heard by the listener compare to the wavelength of the sound produced by the siren of the police car when it approaches the listener? Write down LONGER THAN, SHORTER THAN or EQUAL TO. Then explain your answer. **(4)**

1.2 Name the phenomenon observed in QUESTION 1.1. **(1)**

1.3 Calculate the wavelength of the sound waves detected by the stationary listener if the police car moves toward him at a speed of 110 $km \cdot h^{-1}$. **(6)**

1.4 **HOW WILL THE ANSWER TO QUESTION 7.3 CHANGE IF THE POLICE CAR MOVES AWAY FROM THE LISTENER AT 120 $KM \cdot H^{-1}$? WRITE DOWN INCREASES, DECREASES OR REMAINS THE SAME.** **(1)**

1.5 **WRITE DOWN ONE APPLICATION OF THE DOPPLER EFFECT IN MEDICINE.** **(1)**

[13]

5.6 ELECTROSTATICS

Exercise 1

A group of grade 12 learners obtained the following set of values when investigating Coulomb's law.

Distance between charges (m)	Electrostatic force (N)
1	1600
2	400
4	100
8	25

1.1 **WRITE DOWN AN INVESTIGATIVE QUESTION FOR THIS INVESTIGATION.** **(2)**

1.2 **WRITE DOWN THE DEPENDENT VARIABLE.** **(1)**

1.3 **WRITE DOWN ONE CONTROLLED VARIABLE IN THIS INVESTIGATION.** **(1)**

1.4 **USING THE RESULTS IN THE TABLE ABOVE, PLOT A GRAPH OF ELECTROSTATIC FORCE VERSUS DISTANCE BETWEEN THE CHARGES.** **(2)**

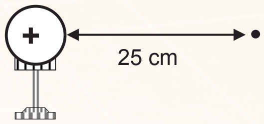
1.5 WRITE DOWN A CONCLUSION FOR THIS INVESTIGATION. (2)

1.6 TWO SMALL IDENTICAL POSITIVELY CHARGED SPHERES ARE USED IN THIS INVESTIGATION.

1.6.1 DRAW THE ELECTRIC FIELD PATTERN FOR THE SYSTEM OF THE TWO CHARGED SPHERES. (2)

1.6.2 CALCULATE THE MAGNITUDE OF THE CHARGES USED IN THIS INVESTIGATION. (4)

1.6.3 ONE OF THE CHARGES IS REMOVED AND THE OTHER ONE IS MOUNTED ON AN INSULATED STAND, AS SHOWN IN THE SKETCH BELOW. CALCULATE THE ELECTRIC FIELD AT A POINT 25 CM FROM THE CHARGE.



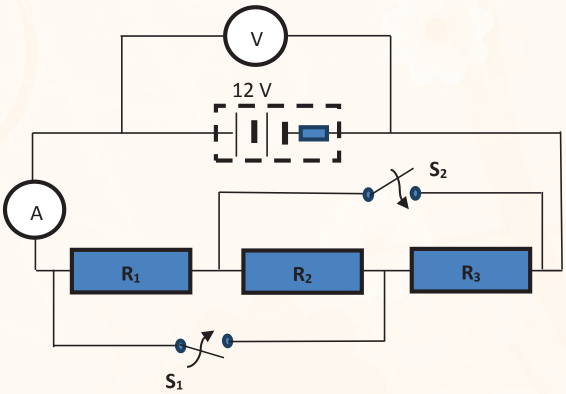
(3)

[19]

5.7 ELECTRIC CIRCUITS

Exercise 1

In the circuit diagram, below the *emf* of the battery is 12 V and the internal resistance is 0,4 Ω. The ammeter reading is 3 A. The resistance of the three resistors is the same. Ignore the resistance of the wires.



1.1 WRITE DOWN TWO DIFFERENCES BETWEEN ELECTROMOTIVE FORCE (EMF) AND TERMINAL POTENTIAL DIFFERENCE. (2)

1.2 STATE *OHM'S LAW* IN WORDS. (2)

1.3 CALCULATE THE CURRENT PASSING THROUGH RESISTOR R_2. (6)

1.4 DETERMINE THE READING OF THE VOLTMETER. (3)

1.5 HOW WILL THE READING ON THE VOLTMETER BE AFFECTED IF SWITCHES S_1 AND S_2 ARE CLOSED?

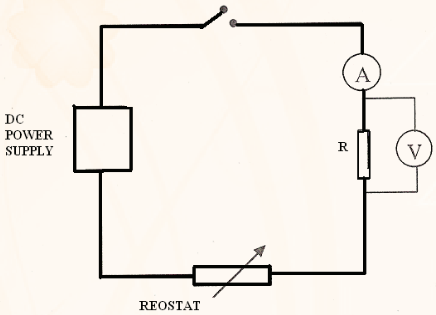
WRITE DOWN INCREASES, DECREASES OR REMAINS THE SAME.

THEN EXPLAIN THE ANSWER.

(4)
[17]

Exercise 2

Thabo is a grade 12 learner. He is investigating the relationship between potential difference and current using a resistor with unknown resistance. He sets up the circuit shown in the diagram. Thabo adjusts the current in the circuit using the rheostat. He takes the ammeter reading while the voltmeter is disconnected. He then measures the potential difference across the unknown resistor for each current value I. From the readings taken from the ammeter and voltmeter, he could complete the following table.



Experiment number	Current (A)	Potential difference (V)
1	0,02	6
2	0,04	12
3	0,06	18
4	0,08	24

2.1. Write a possible investigative question for this practical investigation.

2.2. What could Thabo's hypothesis have been for this investigation?

2.3. What is:

2.3.1. the dependent variable

2.3.2. the independent variable?

2.4. Plot a graph of current vs. potential difference with the experimental data collected.

2.5. Calculate the gradient of the graph.

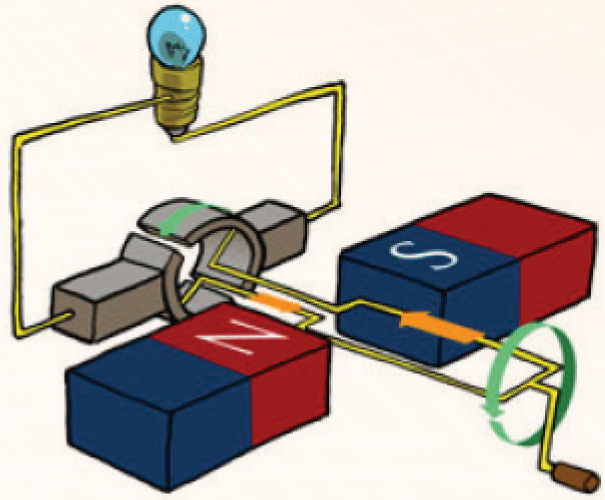
2.6. What quantity does the gradient of the graph represent?

2.7. Write a conclusion for this investigation.

5.8 ELECTRODYNAMICS

Exercise 1

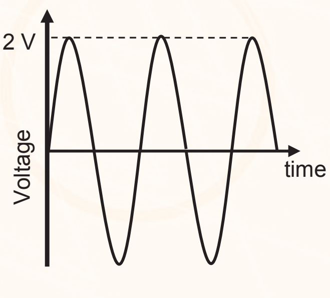
The diagram below represents an electrical machine; P is a split ring (commutator).



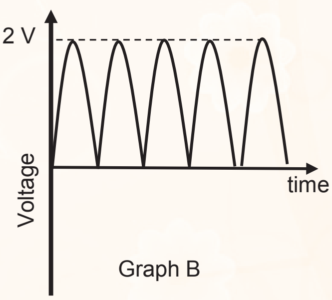
1.1 Identify the type of electrical machine and write down the energy conversion that takes place in this electrical machine. (2)

1.2 Explain the function of the component P. (2)

1.3 The split ring (commutator) is replaced by slip rings. Which ONE of the following voltage-time graphs (Graph A or Graph B) corresponds with the above change?



Graph A



Graph B

Explain your answer. (3)

1.4 The light bulb shown in the circuit dissipates energy of 6 J per second. An identical light bulb is connected in parallel to it. Calculate the rms current in the circuit under the new conditions. Assume the emf remains unchanged. (5)

[12]

5.9 PHOTOELECTRIC EFFECT

Exercise 1

The work function of potassium is 3,52 x 10^{-19} J. An electromagnetic radiation strike on the surface of this metal produces the photoelectric effect. The maximum kinetic energy of the electrons ejected is 4,20 x 10^{-19} J.

1.1 Define work function.

1.2 Define photoelectric effect.

1.3 Calculate:

1.3.1 The frequency of the incident radiation.

1.3.2 The wavelength of the incident radiation.

1.3.3 The threshold/cut-off frequency.

1.4 The intensity of the incident radiation on the metal plate is increased, whilst maintaining a constant frequency. State and explain what effect this change has on the following:

1.4.1 kinetic energy of the emitted photo-electrons

1.4.2 number of photo-electrons emitted.

6 CHECK YOUR ANSWERS - SET 1

6.1 NEWTON'S LAWS

Exercise 1

1.1

1.2 $\vec{F}_{net} = m\vec{a}$

Applying Newton's second law on the y-direction.

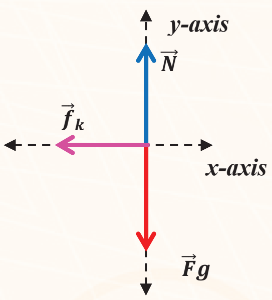
y-axis. <u>(upwards as positive</u>

$\vec{F}_{Ry} = m\vec{a}_y$

$\vec{N} + \vec{F}_{Ay} + \vec{F}g = 0$

$N + F\sin 37^o - mg = 0$

$N = mg - F\sin 37^o$



1.3 $f_k = \mu_k N$ OR $\mu_k = \frac{f_k}{N}$

To calculate the frictional force, we apply Newton's second law in the x-direction.

x-axis. (Right as positive)

$\vec{F}_{Rx} = m\vec{a}_x$

$\vec{f}_k + \vec{F}_{Ax} = 0$

$-f_k + F\cos 37^o = 0$

$f_k = F\cos 37^o$

$f_k = 30\cos 37^o$

$f_k = 23{,}96\ N$

$\mu_k = \frac{f_k}{N} = \frac{23{,}96}{79{,}95} = 0{,}31$

1.4.1

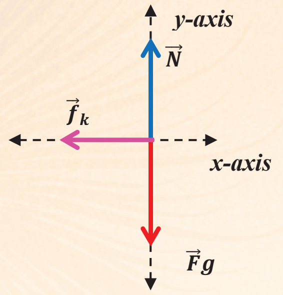
We apply Newton's second law in the x direction.

x-axis (Right as positive)

$\vec{F}_{Rx} = m\vec{a}_x$

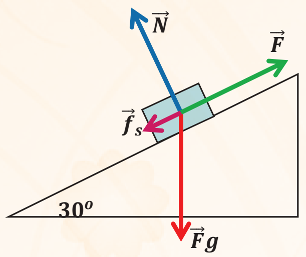
$\vec{f}_k = m\vec{a}_x$

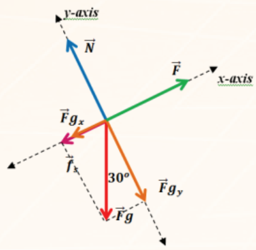
$-23{,}96 = 10\vec{a}_x$



Exercise 2

2.1





2.2 $F_{gx} = Fg \sin\theta$

We do not know the magnitude of the gravitational force, but we can calculate it.

$Fg = mg = (20)(9{,}8) = 196\ N$

Now we can calculate the component:

$Fgx = Fg \sin 30^o = 196 \sin 30^o = 98\ N$

2.3

We apply Newton's second law in the y-direction.

$\vec{F}_{Ry} = m\vec{a}_y$

$\vec{N} + \vec{F}_{gy} = 0$

$N - F_{gy} = 0$

$N - Fg \cos 30^o = 0$

$N = Fg \cos 30^o$

2.4 We apply Newton's second law in the x-direction.

$\vec{F}_{Rx} = m\vec{a}_x$

$\vec{F} + \vec{F}_{gx} + \vec{F}_f = m\vec{a}_x$

$200 + (-98) + \vec{F}_f = (20)(2)$

$102 + \vec{F}_f = 40$

$\vec{F}_f = 40 - 102$

2.5 $f_k = \mu_k N$ OR $\mu_k = \frac{f_k}{N}$

$\mu_k = \frac{62}{169{,}7} = 0{,}365$

6.2 SOLUTIONS: MOMENTUM AND IMPULSE

Exercise 1 Solutions

1.1 Momentum is the product of an object's mass and its velocity.

1.2 25 $kgm.s^{-1}$ [Read the graph; initial momentum is where the graph starts].

1.3 From 1s to 10 s the graph is a horizontal line – there is no increase or decrease; the slope of the graph is zero.

1.4 At 15 s, 25 s and 30 s [These points correspond to the 0 value for both the x and y axis.]

1.5 From 0-15 s the object is moving in the same direction (East); then it stops at 15 s; BUT it moves in the opposite direction from 15s to 25 s.

1.6 The object could have decelerated, stopped and changed direction. / The object could have collided with another object at 10s, and stopped for 5 s from 10-15 s, then moved in the opposite direction from 15-25 s.

1.7 The product of the force acting on an object and the time the force acts on the object.

1.8 $\boldsymbol{F}\text{net}\,\Delta t = \Delta \boldsymbol{p}$ [using the values from the graph]

$\boldsymbol{F}\text{net}\,\Delta t = 0\text{-}25$

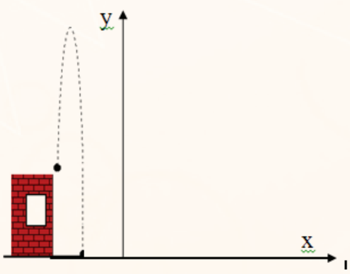
$= -25\ kgm.s^{-1}$

Impulse = 25 $kgm.s^{-1}$ to the West

6.3 VERTICAL PROJECTILE MOTION

Exercise 1 Solutions

It is important to make a sketch of the situation and to select positive direction. In this case, let's use positive direction upwards. If a drawing is not provided, drawing the situation will help in solving the problem.



1.1 a =g= 9,8 ($m.s^{-2}$) downwards.

1.2 $H = h_i + \Delta \mathbf{y}$

$v^2 = v_i^2 + 2g\Delta y$

At the maximum height, the velocity of the projectile is zero:

$0^2 = (10)^2 + 2(-9,8)\Delta y$

$-100 = -(19,6)\Delta y$

$\Delta y = 5,10$ m

H = 3,5 + 5,10 = 8,60 m

1.3 Zero. [The ball makes a turn, here so it stops momentarily.]

1.4 The time required is from point 0 of projection to the maximum height where the stone turns back towards the ground and the $v_f = 0$ m.s^{-1}

$v_f = v_i + g\Delta t$

$0 = 10 + (-9,8)\Delta t$

$-10 = (-9,8)\Delta t$

$\Delta t = 1,02$ s

1.5 *Time taken from the point of projection the maximum height and the time from the maximum height the point of projection are* equal

$t = t_{up} + t_{down}$

$t_{up} = t_{down}$ when the ball reaches the projection point

$t = 2t_{up}$

t = 2 x 1,02 = 2,04 s

1.6 *The total time for the motion of the stone is the time taken by the stone from the point of projection to the maximum height, plus the time for the stone from the maximum height to the ground.*

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

From the maximum height to the ground:

$-8,60 = (0 \times \Delta t) + \frac{1}{2}(-9,8)\Delta t^2$

$-8,60 = -4,9\Delta t^2$

$\Delta t = \sqrt{\frac{8,60}{4,9}} = \sqrt{1,76} =$

$\Delta t = 1,33$ s

$t_t = t_1$ (upwards) + t_2 (downwards)

$t_t = 1,02 + 1,33 = 2,35$ s

1.7 $v_f = v_i + g\Delta t$

$v_f = 0 + (-9,8)1,33$

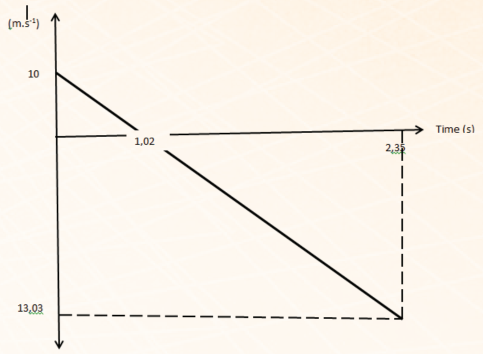
$v_f = 0 - 13,03$

$v_f = -13,03$ m.s^{-1}

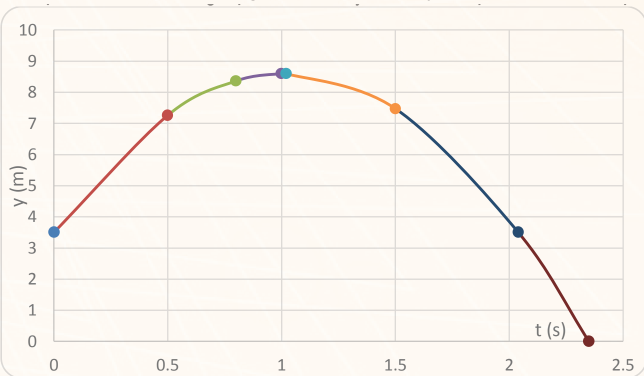
$v_f = 13,03$ (m.s^{-1}) downwards

The time taken by the object to go up is less than the time taken for it to come down from the maximum height. Therefore, the area of the triangle representing motion of the stone up will be less than the area of the triangle representing the object moving from maximum height to the ground.

1.8



1.9 The position vs time graph is actually a mind-map of the actual path travelled by the object.



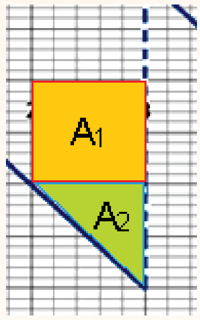
Exercise 2

Solution:

2.1

- From 0 to 1 s, the velocity of the ball decreases from 10 m·s^{-1} to zero, and the acceleration of the ball is constant.
- From 1 to 2 s, the velocity of the ball increases from zero to (– 10 m·s^{-1}) with constant acceleration. At 2 s, the ball is at the point of projection.
- From 2 to 3 s, the velocity of the ball increases from (– 10 m·s^{-1}) to (– 20 m·s^{-1}). At 3 s, the ball hits the ground and bounces back.
- From 3 to 4 s, the velocity of the ball decreases to zero at the maximum height.
- From 4 to 5 s, the velocity of the ball increases with constant acceleration, until it hits the ground for the second time.

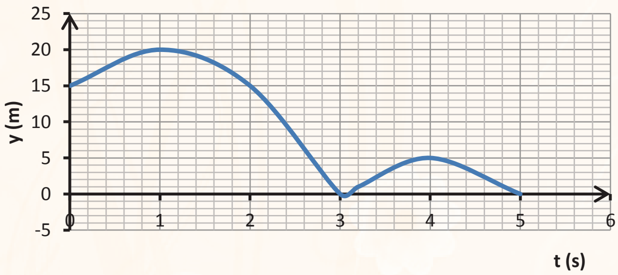
2.2 10 m·s^{-1} upwards

2.3 **Option 1**	**Option 2**
$H = \|\Delta y\|$ $H = \left(\frac{v_f + v_i}{2}\right)\Delta t$ $H = \left(\frac{-20 + (-10)}{2}\right)(3-2)$ $H = 15\ m$	 $H = A = A_1 + A_2 = bh + \frac{1}{2}bh$ $H = (1)(-10) + \frac{1}{2}(1)(-10)$ $H = -10 + (-5) = 15\ m$

2.4 Inelastic, because after bouncing, the speed of the ball is less than the speed it hits the ground then kinetic energy is not conserved.

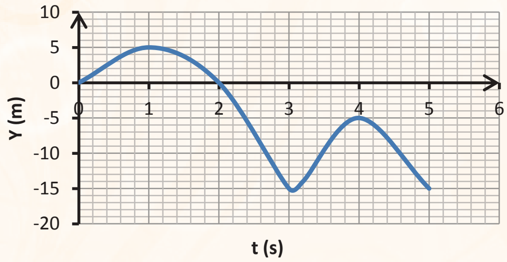
2.5

Position vs. time (taking ground as level zero)



Or

Position vs. time (taking top of building as level zero)



6.4 WORK ENERGY POWER

Exercise 1

1.1 The net (total) work (done on an object/particle) is equal to✓ the change in kinetic energy (of the object/particle).✓

1.2 Data

m = 600 kg

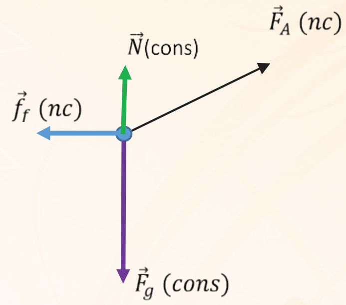
F_A = 191,7 N

Θ = 30^0

f_f = 160,02 N

Δx = ?

Free-body diagram



The work-energy theorem can be applied for both conservative and non-conservative forces:

$W_{net} = \Delta E_K$ ✓

$W_{fr} + W_A + W_g + W_N = \Delta E_K$

$$f_f \Delta x \cos 180^0 + F\Delta x \cos 30^0 + F_g\Delta x \cos 90^0 + N\Delta x \cos 90^0 = \frac{mv_f^2}{2} - \frac{mv_i^2}{2}$$

✓160,02 Δx (-1) +✓(191,7) Δx (cos 30^0) + 0 + 0 = $\frac{600(3)^2}{2} - \frac{600(0)^2}{2}$ ✓

(-160,02+ 166.017...) Δx= 2700

(5,997...) Δx =2700

Δx = 450,22 m✓

1.3 Power is the rate at which work is done: $P = \frac{W}{\Delta t}$ ✓

$$P = \frac{F\Delta x\cos\theta}{\Delta t}$$

We must convert minutes into seconds:

5 minutes = 300 s

$$P = \frac{191{,}7 \times 450{,}22 \times \cos 30^o}{300}$$ ✓

P = 249,03 W✓

Alternative answer
P=F v ✓
P=191,7 cos 30^0 $\left(\frac{3+0}{2}\right)$)✓
P = 249,03 W✓

1.4 Greater than✓

The work done will be greater.✓

As θ decreases, cos θ increases; therefore, the horizontal component will be greater.✓

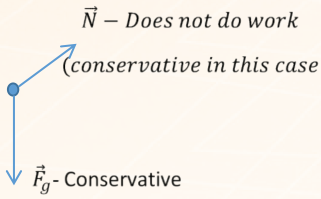
Exercise 2

2.1 The total mechanical energy (the sum of gravitational potential energy and kinetic energy) in an isolated system remains constant.

2.2 From top to bottom of the inclined plane:

Data

Free body diagram



m= 2 kg

hi= 4 m

h_f= 0 m

v_i= 0 m·s^{-1}

g= 9,8 m·s^{-2}

v_i=?

Only conservative energy acting on the object, the system is isolated therefore mechanical energy is conserved.

$$E_M = constant$$

We can apply the principle of conservation of mechanical energy to solve the problem:

$$E_{Mi} = E_{Mf}$$
$$E_{Ki} + E_{Ki} = E_{Ki} + E_{Ki}$$
$$\frac{mv_i^2}{2} + mgh_i = \frac{mv_f^2}{2} + mgh_f$$

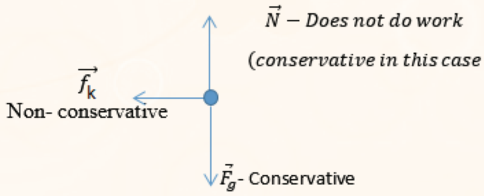
$$\frac{2 \times 0^2}{2} + 2 \times 9{,}8 \times 4 = \frac{2v_f^2}{2} + 2 \times 9{,}8 \times 4$$

$$0 + 78{,}4 = v_f^2 + 0$$
$$v^2 = 78{,}4$$
$$v = \sqrt{78{,}4} \quad v = 8{,}85 \text{ m·s}^{-1}$$

2.3 The net/total work done on an object is equal to the change in the object's kinetic energy.

2.4 From A to B.

Data:



μ_k = 0,2

Δx = 10 m

$v_{i=}$ 8,85 m·s^{-1}

$v_{i=}$

The work energy theorem can be applied to both conservative and non-conservative forces.

$$W_{net} = \Delta E_k$$

$$W_{fr} + W_{Fg} + W_N = E_{kf} - E_{ki}$$

$$f_K \Delta x \cos 180^0 + F_g \cos 90^0 + N \cos 90^0 = E_{kf} - E_{ki} \quad \mu_K N \Delta x(-1) = \frac{mv_f^2}{2} - \frac{mv_i^2}{2}$$

$$-\mu_K mg.\Delta x = \frac{mv_f^2}{2} - \frac{mv_i^2}{2}$$

$$-\mu_K g.\Delta x = \frac{v_f^2}{2} - \frac{v_i^2}{2}$$

$$v_f^2 = (v_i^2 - 2\mu g.\Delta x)$$

$$v_f^2 = (8{,}85)^2 - 2 \times 0{,}2 \times 9{,}8 \times 10)$$

$$v_f^2 = 78{,}32 - 39{,}2$$

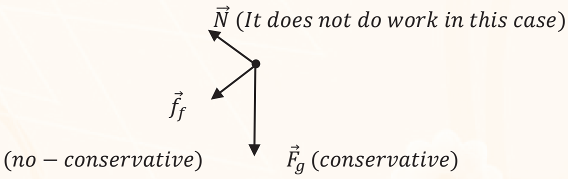
$$v_f = \sqrt{39{,}12}$$

$$v_f = 6{,}25 m.s^{-1}$$

2.5. From bottom to top.

Data:

$v_i = 6{,}25 m.s^{-1}$



m = 2 kg

h_i = 0 m

h_f = ?

When there are non-conservative forces acting on a system, we can apply the principle of conservation of energy (law of conservation of energy).

$$W_{non-conservative} = \Delta E_K + \Delta E_p$$

$$f_f \Delta x \cos 180 = (E_{Kf} - E_{Kf}) + (E_{Pf} - E_{Pi})$$

$$\mu N \Delta x \cos 180 = \left(\frac{mv_f^2}{2} - \frac{mv_i^2}{2}\right) + (mgh_f - mgh_i)$$

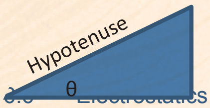
$$\mu mg \Delta x \cos 180 = \left(\frac{mv_f^2}{2} - \frac{mv_i^2}{2}\right) + (mgh_f - mgh_i)$$

$$0{,}2 \times 2 \times 9{,}8 \times 5(-1) = \left(\frac{2 \times 0^2}{2} - \frac{2 \times (6.25)^2}{2}\right) + (2 \times 9{,}8 \times h_f - 2 \times 9{,}8 \times 0)$$

$$-19.6 = 0 - 39{,}0625 + 19{,}6h$$

h = 0,99 m

2.6



Opposite side

$$\sin\theta = \frac{Opposite\ side}{hypotenuse}$$

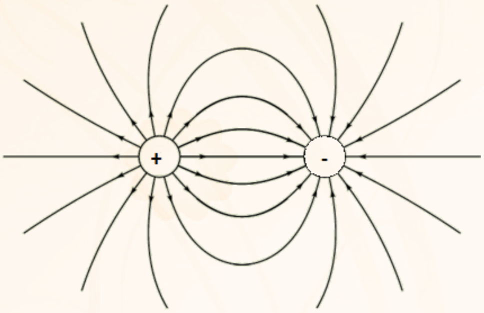
$$h = \Delta x \sin\theta$$
$$0{,}99 = 5\sin\theta$$
$$\sin\theta = 0{,}198$$
$$\theta = 11{,}45^0$$

6.5 ELECTROSTATICS

Exercise 1

1.1 *Electric field* is a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.

1.2.1



1.2.2 The system is isolated, so we must apply the law of conservation of charge:

$$Q_{net} = Q_1 + Q_2 = constant$$

After being in contact ($Q_1 = Q_2 = Q$

$$Q_1 + Q_2 = 2Q$$

$$Q = \frac{Q_1 + Q_2}{2}$$

(Charge on each) Q = $\frac{30nC - 14nC}{2} = \frac{16nC}{2} = 8nC = 8\times10^{-9}\,C$

1.3. To calculate the electrostatic force exerted by one charge on the other we must apply the mathematical expression of Coulomb's law:

$$F_E = \frac{kQ_A \times Q_B}{r^2}$$

$$6{,}4\times10^{-4} = \frac{9\times10^9 \times 8\times10^{-9} \times 8x10^{-9}}{r^2}$$

r = 0,03 m

Because the charges are equal, we can also solve this in the following way:

$F_E = \frac{kQ_A \times Q_B}{r^2}$ Q_A=Q_B $F_E = \frac{kQ^2}{r^2}$

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

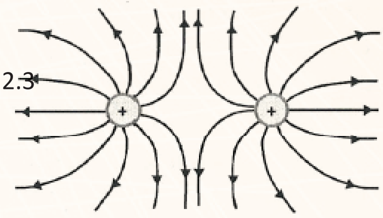
r = 0,03 m

Exercise 2

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

2.2 According to Newton's third law, when one body exerts a force on a second body, the second body exerts a force of equal magnitude in the opposite direction on the first body, therefore:

2.3



2.4

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

$Q_A = Q_B = Q$

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

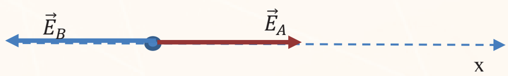
$$3{,}0\times10^{-6} = \frac{(9{,}0\times10^{9})Q^2}{2^2}$$

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

$Q_A = Q_B = 3{,}65 \times 10^{-8}$ C

2.5

We must draw the electric field vectors at the middle point:



$\vec{E}_R = \vec{E}_A + \vec{E}_B$ (It is a vector equation.)

The vectors are pointing in different directions and positive is taken in the positive direction of the X axis; therefore:

$$E_R = E_A - B_B$$

The magnitude of the charges are equal and the distance from the charge to the middle point are the same; hence:

$E_A = B_B$

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

$E = \frac{9 \times 10^9 \times 3{,}65 \times 10^{-8}}{1^2}$

$E_R = 328{,}5 - 328{,}5$

$E_R = 0\ \mathrm{N \cdot C^{-1}}$

6.6 ELECTRIC CIRCUITS

Exercise 1

1.1 When switch S_1 is open, there is no flow of charges, and the current in the circuit is zero; therefore, the voltmeter reads the emf of the battery, which is 10 V.

1.1.1 Resistors 2 Ω and 4 Ω are connected in parallel and both are connected in series with the resistor R_x.

$R_{ext} = R_x + R_{parallel}$ (1)

$R_{ext} = R_x + \left(\frac{R_1 R_2}{R_2 + R_1}\right)$ ✓ (2)

We have to calculate the equivalent external resistance and the equivalent resistance for the parallel connection.

$R_{ext} = \frac{V}{I}$ ✓ $R_{ext} = \frac{8}{1}$ ✓ $R_{ext} = 8\ \Omega$

$\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_p} = \frac{1}{2} + \frac{1}{4}$ ✓

$R_{parallel} = 1{,}33\ \Omega$

We have only two resistors in parallel, so we can use:

$R_{parallel} = \left(\frac{R_1 R_2}{R_2 + R_1}\right)$

$R_{parallel} = \left(\frac{2 \times 4}{4 + 2}\right) = 1{,}33\ \Omega$

Substituting the values of the external resistance and equivalent resistance in parallel in equation 1.

✓$8 = R_x + 1{,}33$✓

$R_x = 8 - 1{,}33 = 6{,}67\ \Omega$✓

1.2.2 $\varepsilon = V_{ext} + Ir$✓

$10 = 8 + 1r$✓

$r = 2\ \Omega$✓

1.3 INCREASES✓

Total resistance increases.✓

Current in the circuit decreases. ✓

The drop of potential within the battery (V_i= Ir) decreases, but the emf remains constant; therefore, according to the equation (V_{ext} = ε- Ir), the voltage increases.✓

Exercise 2

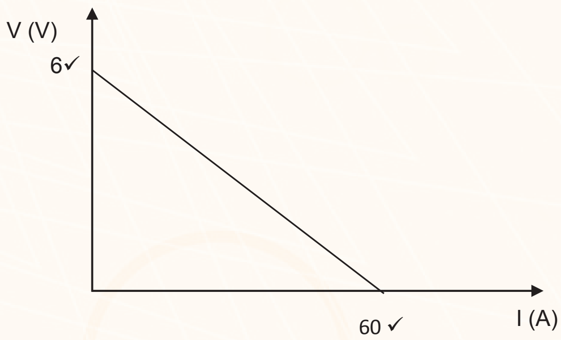
2.1 When current flows through a voltage source (battery/generator), a resistance to current flow arises✓ due to the resistance of the materials (chemicals/conductors) from which the source is made.✓

2.2 $\varepsilon = V_{ext} + Ir$✓

$6 = V_{ext} + I(0,10)$

$V_{ext} = 6 - (0,10)I$✓

2.3



To calculate the current at which terminal potential difference is zero, we need to substitute V_{ext} with zero in the equation.

$V_{ext} = 6 - (0,10)I$

$0 = 6 - (0,10)I$

$I = \frac{6}{0,1} = 60$ A

2.4.1 Resistors 4 Ω and R_x are connected in series, therefore the current is the same for both.

$W = I^2R\Delta t$ ✓ (1)

For the resistor of 4 Ω

$W_4 = I^2R\Delta t = 40$ (2)

$\underline{I^2(4)\Delta t = 40}$✓ (3)

$I^2 = \frac{10}{\Delta t}$ (4)

The current and the time are the same, therefore for resistor R_x :

$W_R = I^2R\Delta t$ (5)

Substituting 4 in 5

10)Δt = 60 ✓

$R_R = 6\ \Omega$✓

2.4.2 $\varepsilon = I(R_{ext}+r)$ ✓ (1)

Alternative solution

As the current and the time are the same for both resistors, we can solve the problem as follows:

$W = I^2R\Delta t$✓

$$\frac{W_4}{W_R} = \frac{I^2R_4\Delta t}{I^2R_R\Delta t^2}$$

$$\frac{40}{60}✓ = \frac{I^2(4)\Delta t}{I^2R_R\Delta t}✓$$

To calculate the emf, we need to know the value of the external resistance, as the resistors are connected in series:

$R_s = R_4 + R_R$ (3)

$R_s = 4 + 6 = 10\ \Omega$

Substituting the value of the total resistance I series in (1)

6 = I(10+ 0,10)✓

I = 0,594 A✓

2.4.3 We need to calculate the value of the terminal potential, as we have all the data.

$V_{ext} = IR_{ext}$✓

V_{ext} = (0,594)(10) ✓

V_{ext} = 5,94 V✓

6.7 ELECTRODYNAMICS

Exercise 1

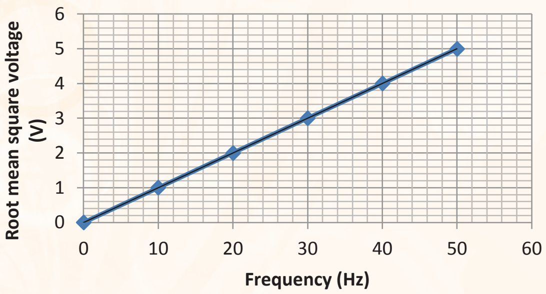
1.1. AC generator/alternator. It has slip-rings.

1.2. What is the relationship between the root mean square voltage and the frequency of rotation of the armature /coil of the generator?

1.3. The root mean square voltage generated increases/decreases when the frequency of rotation of the armature /coil of the generator increases/decreases.

1.4. Root mean square voltage.

1.5.



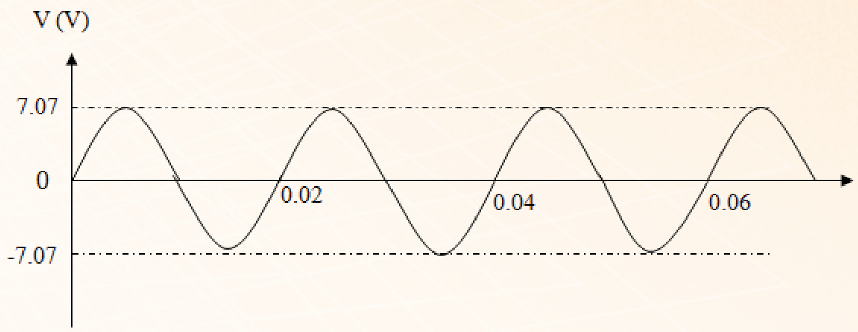
1.6. The root mean square voltage generated is directly proportional to the frequency of rotation of the armature /coil of the generator.

1.7 $V_{rms} = \frac{V_{max}}{\sqrt{2}} = \frac{5}{\sqrt{2}} = 3{,}54V$

1.8 $I_{rms} = \frac{V_{rms}}{R} = \frac{5}{5} = 1A$

1.9. $P_{ave} = I_{rms}V_{rms}$ = 1 x 5 = 5 W

1.10. $V_{max} = \sqrt{2}V_{rms} = \sqrt{2} \times 5- = 7,07\,V$



1.11 **ADVANTAGES OF AC OVER DC**

- Easy to be transformed (step up or step down using a transformer).
- Easier to convert from AC to DEC than from DC to AC.
- Easier to generate.
- It can be transmitted at high voltage and low current over long distances with less energy lost.
- High frequency used in AC makes it suitable for motors.

Exercise 2

2.1 DC motor. Electrical energy is converted into mechanical energy.

2.2 Clockwise.

2.3 A - Armature

B - Carbon brushes

C - Split ring commutator (commutator)

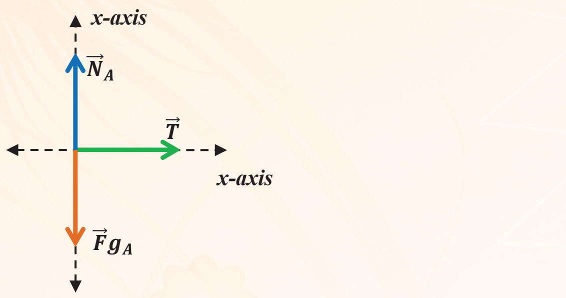
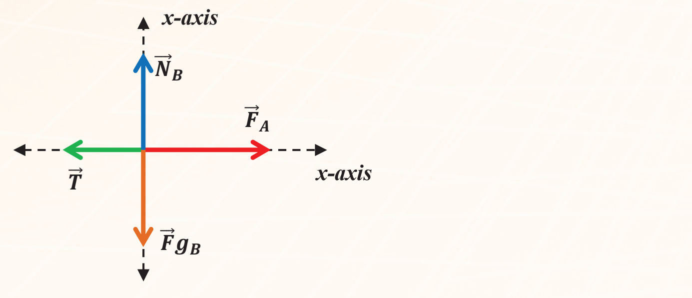
2.4 Electric motors are used in pumps, fans, compressors, etc.

7 CHECK YOUR ANSWERS - SET 2

7.1 NEWTON'S LAWS

SOLUTIONS

1.1

1.1 Free-body diagram for block A:	Free-body diagram for block B:
	

1.2

We apply Newton's second law to each object:

$\vec{F}_R = m\vec{a}$

x-axis (right positive)

<u>For block A</u>

$T = m_A a$

<u>For block B</u>

$F_A - T = m_2 a$

<u>Solving the system</u>

$T + F_A - T = m_1 a + m_2 a$

$F_A = (m_1 + m_2)a$

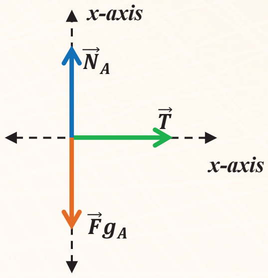
$100 = (5 + 3)\ a$

$\vec{a}_x = 12{,}5 m \cdot s^{-2}$ to the right

1.3 To calculate the magnitude of the tension, we can use block A or block B.

(Using A)

x-axis (right positive)



x-axis (right positive)

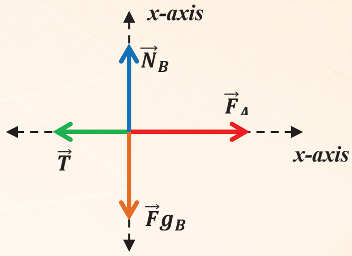
$\vec{F}_{RxA} = m_A\vec{a}_x$

$T = m_A\vec{a}_x$

$T = (5)(12{,}5) \qquad T = 62{,}5N$

(Using B)

x-axis (right positive)



x-axis (right positive)

$\vec{F}_{RxB} = m_B\vec{a}_x$

$F_A - T = m_B\vec{a}_x$

$100 - T = (3)(12{,}5)$

$-T = 37{,}5 - 100 \qquad T = 62{,}5N$

1.4

<u>Data:</u>

$a = 8{,}972m \cdot s^{-2}$

$T = 62{,}5N$

$\mu_k = ?$

$f_k = \mu_k N$

$\mu_k = \frac{f_k}{N}$

We must calculate the frictional force and the normal force.

<u>Calculating the frictional force:</u>

x-axis

$\vec{F}_{RxA} = m_A\vec{a}_x$

$T - f_k = m_A a$

$62{,}5 - f_k = (5)(8{,}972)$

$-f_k = 44{,}86 - 62{,}5$

$f_k = 17{,}64N$

<u>Calculating the normal force:</u>

y-axis

$\vec{F}_{RyA} = m_A\vec{a}_y$

$\vec{N} + \vec{F}_g = 0$

$N - Fg = 0$

$N = Fg = mg = (5)(9{,}8) = 49N$

$\mu_k = \frac{f_k}{N} = \frac{17{,}64}{49} = 0{,}355$

1.5

No, the boxes are made of the same material.

1.6

$f_k = \mu_k N$

$\vec{N} + \vec{F}_g = 0$

$N - Fg = 0$

$N = Fg = mg = (3)(9{,}8) = 29{,}4N$

We must calculate the normal force:

$\vec{F}_{RyB} = m_B \vec{a}_y$

Now we can calculate the frictional force:

$f_k = (0{,}355)(29{,}4) = 10{,}44$ to the left.

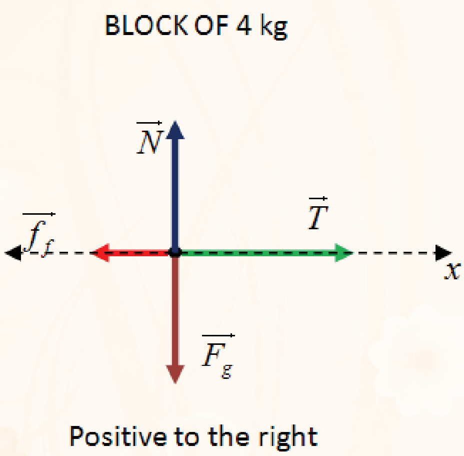
1.7

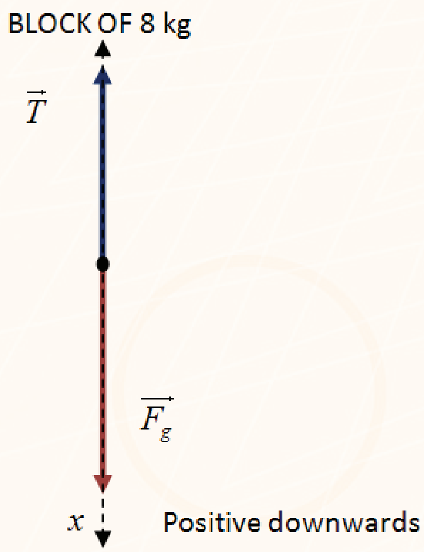
The force from box A downward on the floor (weight); and the force upwards from the floor on box A (normal force).

The force from block A to the left by the rope on block B; and the force to the right by the rope on block A.

QUESTION 2

2.1





Let's take positive in the direction of motion.

2.2 If a resultant force acts on a body, it will cause the body to accelerate in the direction of the resultant force. The acceleration of the body will be directly proportional to the resultant force and inversely proportional to the mass of the body.

2.3 Let's apply Newton's second law of motion to each block.

$$\sum \vec{F} = m\vec{a}$$

Block of 4 kg (A)

In the x direction:

$$T - f_f = m_A a$$

$$T - \mu N = m_A a$$

Block of 8 kg (B)

In the y direction:

$$-T + F_g = m_B a$$

$-T + m_B g = m_B a$ (Equation 2)

In the Y direction

$N - F_g = 0$

$N = F_g = mg$

$T - \mu m_A g = m_A a$ (Equation 1)

$$T - \mu m_A g - T + m_B g = m_A a + m_B a$$

$$-\mu m_A g + m_B g = (m_A + m_B)a$$

$$-(0{,}6)(4)(9{,}8) + (8)(9{,}8) = (4+8)a$$

$$54.88 = 12a$$

$$a = 4{,}57\ \text{m·s}^{-2}$$

2.4

Using equation 2	Using equation 1
$-T + m_B g = m_B a$ $-T = 8 \times 4{,}57 - 8 \times 9{,}8$ T = 41.84 N	$T - \mu m_A g = m_A a$ $T - (0{,}6)(4)(9{,}8) = (4)(4.57)$ $T = (0{,}6)(4)(9{,}8) + (4)(4.57)$ $T = 41.80$ N

2.5. $f_f = \mu N$

$f_f = \mu m g$

$f_f = 0{,}6 \times 4 \times 9{,}8$

$f_f = 23.52$ N

2.6

$-T + m_B g = m_B a$

$T = -8 \times 4{,}57 + 8 \times 9{,}8$

Apparent weight = T = 41.84 N

2.7 Less than.

2.8 Equal to.

Exercise 3

3.1 Each particle in the universe attracts every other particle with a gravitational force that is directly proportional to the product of their masses✓ and inversely proportional to the square of the distance between their centres✓. (2)

3.2 Smaller than.✓

The distance is the same as well as the mass of the Earth in both cases✓. The magnitude of the gravitational force exerted on the satellites is directly proportional to the mass of the satellites. ✓The mass of ZACUBE-1 is smaller than the mass of Sputnik.✓ (4)

3.3 $F = \frac{GMm}{r^2}$ ✓

$$F = \frac{6{,}67\times10^{-11}\times6\times10^{24}\times1{,}2}{(6{,}38\times10^{6}+600\times10^{3})^2}$$ ✓ ✓

F = 9,85 N ✓ Towards the Earth.✓ (5)

3.4 On the surface of the Earth.

On the surface of the Earth.

$F = \frac{GmM}{R^2}$ ✓

$mg = \frac{GmM}{R^2}$ (1) OR/OF $R^2 g = GM$

A height h.

$F_1 = \frac{GmM}{(R+h)^2}$ ✓

$mg_1 = \frac{GmM}{(R+h)^2}$ (2) OR/OF $(R+h)^2 g_1 = GM$

From (1) and (2)

$\frac{g_1}{g} = \frac{R^2}{(R+h)^2}$ ✓(3)

$\frac{g_1}{g}$ = 0,25

$0{,}25 = \frac{R^2}{(R+h)^2}$ ✓ OR/OF $\frac{1}{4} = \frac{R^2}{(R+h)^2}$ ✓ → $(R+h)^2 = 4R^2$

From (3) we get✓ $R^2 + 2Rh + h^2 = 4R^2$

$h^2 + 2Rh + \left(R^2 - \frac{R^2}{0{,}25}\right) = 0$ $h^2 + 2Rh - 3R^2 = 0$

$h = -R \pm \frac{R}{\sqrt{0{,}25}}$ $(h - R)(h + 3R) = 0$

$h = -R + \frac{R}{0{,}5}$

$h = -3{,}38 \times 10^6 + \frac{3{,}38\times10^6}{0{,}5}$ $(h - R)(h + 3R) = 0$

$h = R = 3{,}38 \times 10^6$ m✓ $\therefore h = R$ or $-3R$ (6)

[17]

7.2 MOMENTUM AND IMPULSE

Exercise 1

1.1. The total linear momentum of an isolated/a closed system remains constant (is conserved).

1.2. The resultant/net external force is zero.

1.3

$$\sum \vec{F}_{ext} = \vec{0}$$

Therefore: $\Delta \vec{p} = \vec{0}$

Hence:

$$\sum \vec{p}_{after} - \sum \vec{p}_{before} = \vec{0}$$

$$\sum \vec{p}_{before} = \sum \vec{p}_{after}$$

$$(\vec{p}_r + \vec{p}_b)_{before} = (\vec{p}_r + \vec{p}_b)_{after}$$

$$m_L\vec{v}_{L(before)} + m_R\vec{v}_{R(before)} = m_L\vec{v}_{L(after)} + m_R\vec{v}_{R(after)}$$

$$m_L 0 + m_R 0 = 4800\vec{v}_{L(after)} + 100\, v_{R(after)}$$

$$0 = 4800\vec{v}_{L(after)} + 100\, v_{R(after)}$$

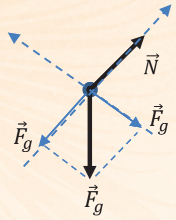
We have two unknowns, so we need to calculate the speed of the missile launcher after the rocket was fired.

Using equations of motion

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

We do not know the acceleration of the launcher on the inclined plane, therefore we must calculate it.

The free-body diagram for the missile launcher moving on the inclined plane is:



$\vec{F}_{net} = m\vec{a}$

In the x direction

$\vec{F}_{gx} = m\vec{a}_x$

$-F_g \sin\theta = ma$

$-mg\sin\theta = ma$

$a = -g\sin\theta$

$v_f^2 = v_i^2 + 2(-g\sin\theta)\Delta x$

$h = \Delta x \sin\theta$

$v_f^2 = v_i^2 - 2gh$

$0^2 = v_i^2 - 2gh$

$v_i^2 = 2gh$

$v_i^2 = 2(9{,}8)6$

$v_i = 10.84\ m \cdot s^{-1}$

In the x direction

Now we can calculate the initial speed of the rocket:

Exercise 2

Solution

2.1 *Impulse* is the product of the resultant/net force (force) acting on an object and the time the resultant/net force (force) acts on the object.

2.2 Data

$\vec{F} = 10\ N\ to\ the\ right$

Δt= 3 s

Impulse -?

Let's take positive to the right

$Impulse = F\Delta t$

$Impulse = +10 \times 3$

$Impulse = +30\ N \cdot s$

$Impulse = 30\ N \cdot s$ to the right

2.3 Data

$\vec{p} = 80\ k \cdot m \cdot s^{-1}$
$m = 10\ kg$
$\vec{v} = ?$

Let's take positive to the right:

$\vec{p} = m\vec{v}$

$+80 = 10\vec{v}$

$\vec{v} = +8\ m \cdot m^{-1}$

to the right

2.4 Data

$m_A = 10\ kg$
$m_B = 8\ kg$
$\vec{v}_{A(before)} = 8\ m \cdot s^{-1}$ to the right
$\vec{v}_{B(before)} = 0$
$\vec{v}_{AB} = ?$

For this problem, we are going to select right as positive.

$\sum \vec{F}_{ext} = \vec{0}$

$\Delta\vec{p}_{net} = \vec{0}$
$\vec{p}_{T(after)} - \vec{p}_{T(before)} = \vec{0}$
$\vec{p}_{T(before} = \vec{p}_{T(after)}$
$\vec{p}_{A(before)} + \vec{p}_{B(before)} = \vec{p}_A(after) + \vec{p}_{B(after)}$
$m_A\vec{v}_{A(before)} + m_B\vec{v}_{B(before)} = m_A\vec{v}_{A(after)} + m_B\vec{v}_{B(after)}$

After the collision, the two trolleys move together as one object; therefore, the velocity is the same:

$m_A\vec{v}_{iA} + m_B\vec{v}_{iB} = \vec{v}_{fAB}(m_A + m_B)$
$(10)(+8) + (8)(0) = \vec{v}_{fAB}(10 + 8)$
$+80 = \vec{v}_{fAB}(18)$
$\vec{v}_{fAB} = \frac{80}{18}$
$\vec{v}_{fAB} = +4{,}44\ m \cdot s^{-1}$.
$\vec{v}_{fAB} = 4{,}44\ m \cdot s^{-1}$ to the right.

2.5 We can apply Newton's second law in terms of momentum:

$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$

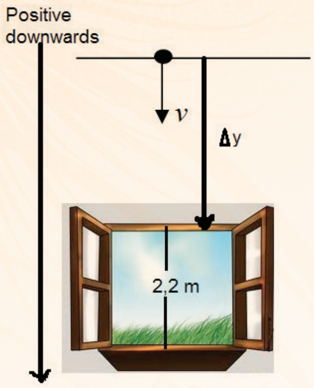
$$\vec{F}_{net} = \frac{p_f - p_i}{\Delta t}$$
$$\vec{F}_{net} = \frac{70 - 80}{0{,}2}$$
$$\vec{F}_{net} = \frac{-10}{0{,}2}$$
$$\vec{F}_{net} = -50\ N$$

$$\vec{F}_{net} = 50\ N\ to\ the\ left$$

7.3 VERTICAL PROJECTILE MOTION

Exercise 1

1.1



$$\Delta y = v_{iA}\Delta t + \frac{1}{2}g\Delta t^2$$

$$2,2 = v_i(0,28) + \frac{1}{2}(9,8)(0,28)^2$$

2,2 – 0,38 = v_i (0,28)

v_i = 6,5 m·s^{-1}

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

$$(6,5)^2 = 0^2 + 2(9,8)\Delta y$$

$$(6,5)^2 = 0^2 + 2(9,8)\Delta y$$

y = 2,16 + 2,2

1.2.

y = 2,16 + 2,2

y = 4,3 m downwards

$$2,16 = 0\Delta t + \frac{1}{2}(9,8)\Delta t^2$$

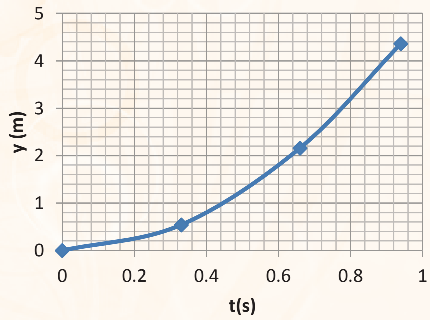
$$\Delta t^2 = \sqrt{\frac{2 \times 2,16}{9,8}}$$

Δt = 0,66 s

$\Delta t_{total} = \Delta t_1 + \Delta t_2$

Δt_{total} = 0,66 + 0,28

Δt_{total} = 0,94 s



1.4

$v_f = v_i + g\Delta t$

$v_{f1} = 0 + 9{,}8 \times 0{,}66$

$v_{f1} = 6{,}5 m \cdot s^{-1}$

$v_{f2} = 0 + 9{,}8 \times 0{,}944$

$v_{f2} = 9{,}21\, m \cdot s^{-1}$

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

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

Exercise 2

Positive downwards

2.1

Option 1	Option 2
$\vec{v}_f^2 = \vec{v}_i^2 + 2\vec{g}\,\Delta\vec{y}$ $\vec{v}_f^2 = 0^2 + (2)(9{,}8)(150)$ $\vec{v}_f^2 = 2940$ $\vec{v}_f = 54{,}22\, m \cdot s^{-1}$ downwards	$\vec{v}_f = \vec{v}_i + \vec{g}\Delta t$ $\Delta t = \sqrt{\frac{2\Delta y}{g}}$ $\Delta t = \sqrt{\frac{2x150}{9{,}8}} = 5{,}53 s$ v_f = 0+ 9,8 x5,53 v_f = 54,22 m.s-1 downwards

2.2

Option 1

When the two objects meet their position is the same:

$y_A = y_B$

$y_{Ai} + v_{iA}\Delta t + \frac{1}{2} g\Delta t^2 = y_{Bi} + v_{iB}\Delta t + \frac{1}{2} g\Delta t^2$

Level zero at the projecting point of A (reference point).

$0 + 100\Delta t + \frac{1}{2} x9{,}8x\Delta t^2 = 150 + 0\Delta t + \frac{1}{2} x9{,}8x\Delta t^2$

$100\Delta t = 150$

$\Delta t = 1{,}5\, s$

Option 2

150 = $|\Delta y_A| + |\Delta y_B|$ 150 = the addition of the absolute values of the displacements of A and B.

150 = $| v_{iA}\Delta t + \frac{1}{2} g\Delta t^2 | + |$

$v_{iB}\Delta t + \frac{1}{2} g\Delta t^2 |$

150 - $v_{iB}\Delta t + \frac{1}{2} g\Delta t^2$ =

$v_{iA}\Delta t + \frac{1}{2} g\Delta t^2$

$100\Delta t = 150$

$\Delta t = 1{,}5\, s$

2.3

Option 1

$\vec{v}_f = \vec{v}_i + \vec{g}\Delta t$

$100 = -100 + 9{,}8\,\Delta t$

$\Delta t = 20{,}41\ s$

Option 2

$\Delta y = v_{iA}\Delta t + \frac{1}{2}g\Delta t^2$

$0 = -100\Delta t + \frac{1}{2}9{,}8\Delta t^2$

$0 = -100\Delta t + 4{,}9\Delta t^2$

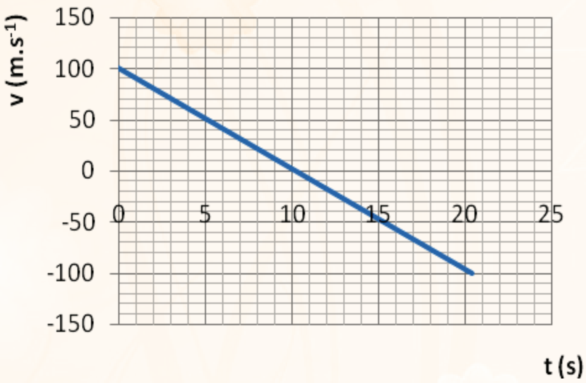
$100\Delta t = 4{,}9\Delta t^2$

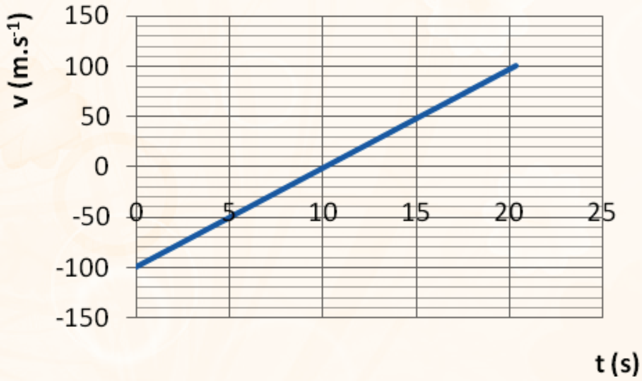
$\Delta t = 20{,}41$ s

2.4

Positive upwards

Positive downwards





7.1 WORK ENERGY POWER

EXERCISE 1

1.1 Greater than.✓

There is friction (non-conservative) force acting;✓ mechanical energy is not conserved. (3)

1.2 The net work done on an object is equal to the change in the kinetic energy of the object. ✓✓ (2)

1.3

1.3.1 $W_{net} = E_f - E_i$ ✓ (5)

$$F_{net}\Delta x\cos\theta = \frac{1}{2}m(v_f^2 - v_i^2)\checkmark$$

$$\checkmark F_{net}(10)\cos 180^0 = \frac{1}{2}(24,7)(18^2 - 24,25^2)$$

$$\therefore F_{net} = 326,12N = frictional\ force / wrywingskrag \checkmark$$

1.3.2

$$W_{nc} = \Delta E_K + \Delta E_P \checkmark$$

$$f \times \Delta x\cos\theta = \frac{1}{2}m(v_f^2 - v_i^2) + mg\Delta h \checkmark$$

$$326,12 \times \Delta x\cos 180^0 \checkmark = \frac{1}{2}(24,7)(0 - 18^2) \checkmark + 24,7(9,8)(\Delta x\sin 50^0)\checkmark$$

$$-326,12\ \Delta x = -4001,4 + 185,4287\ \Delta x$$

$$\therefore \Delta x = 7,82\ m \checkmark$$

(6) **[16]**

7.2 DOPPLER EFFECT

Exercise 1

1.1. Lower than✓

As the speed of sound is constant ✓wavelength is inversely proportional to frequency✓ and frequency is higher.✓

OR

Lower than✓

When v is constant ✓λ $\frac{1}{\alpha}$ f✓ and frequency is higher✓.

OR (4)

Lower than✓

As frequency heard is higher,✓ the wavelength is smaller, because when the speed of sound is constant,✓ wavelength and frequency are inversely proportional.✓

1.2 Doppler effect (1)

1.3 **Option 1** (6)

$$f_l = \left(\frac{v_{sound} \pm v_{listener}}{v_{sound} \pm v_{source}}\right) f_s \checkmark$$

$$f_l = \left(\frac{340 + 0}{340 - 30.56}\right) \checkmark \text{ x } 620 \checkmark$$

$f_l = 681{,}23$ Hz

$v = f\lambda \checkmark$

$340 = 681{,}23\lambda \checkmark$

$\lambda = 0{,}50$ m✓

Option 2

$$f_l = \left(\frac{v_{sound}}{v_{sound} \pm v_{source}}\right) f_s \checkmark$$

$$f_l = \left(\frac{340}{340 - 30.56}\right) \checkmark \text{ x } 620 \checkmark$$

$f_l = 681{,}23$ Hz

$v = f\lambda \checkmark$

$340 = 681{,}23\lambda \checkmark$

$\lambda = 0{,}50$ m✓

$340 = 681.23\lambda \checkmark$

$\lambda = 0{,}50$ m✓

7.3 ELECTROSTATICS

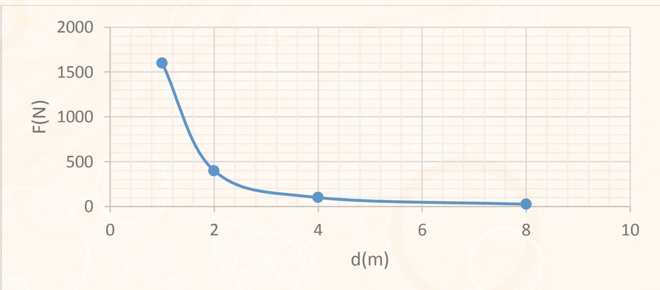
Exercise 1 Solutions

1.1 What is the relationship between the electrostatic force between two charges and the distance between those charges?✓✓

1.2 Electrostatic force✓

1.3 Magnitude of the charges✓

1.4

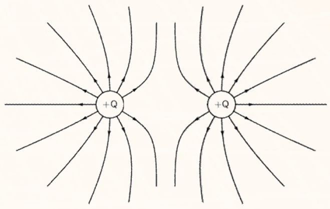


CRITERIA	MARKS/PUNTE
Correct shape	✓
Three or more coordinates plotted correctly	✓

(2)

1.5 The magnitude of the electrostatic force between two charges is inversely proportional to the square of the distance between the charges. ✓✓

1.6.1



CRITERIA	Marks
Shape	✓
Direction of the arrows	✓

(2)

1.6.2

$$F = \frac{kQ^2}{r^2}$$ ✓

✓ $1600 = \frac{(9\times10^9)Q^2}{(1)^2}$ ✓

Q = 4.22×10^{-4} C ✓

(4)

1.6.3

$$E = \frac{kQ}{r^2}$$ ✓

$E = \frac{9\times10^9 \times 4{,}22\times10^{-4}}{(0{,}25)^2}$ ✓

E = $6{,}07 \times 10^{-11}$ N·C^{-1} ✓

[19]

7.4 ELECTRIC CIRCUITS

Exercise 1

1.1

Differences between emf and potential difference:

Electromotive force

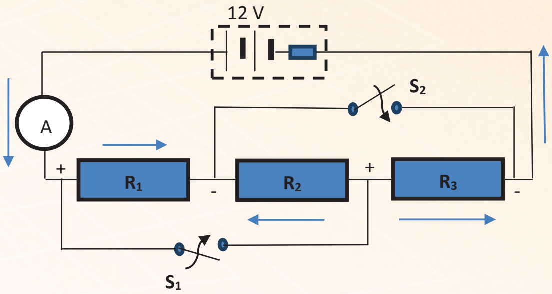
1. Electromotive force transmits current both inside and outside the cell.
2. Electromotive force emf is the cause.
3. Electromotive force is always greater than potential difference.
4. Electromotive force creates potential difference entire the circuit.
5. Electromotive force does not depend on the resistance of the circuit.
6. Electromotive force remains constant.
7. The part of the circuit where electrical energy is created from any other energy then that part contains the source of Electromotive force.

Potential difference:

1. Potential difference current transfers between any two points in the circuit.
2. Potential difference is the result.
3. Potential difference is always less than electromotive force.
4. Potential difference takes place between any two points in the circuit.
5. Potential difference of two points depends on the resistance of those points.
6. It does not remain constant.
7. Potential difference exists in the part of the circuit where electrical potential energy is transformed into another form of energy.

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

1.3 First we must identify the type of connection; for this purpose we must indicate the direction of the current.



To calculate current, we must apply Ohm's law

$I_2 = \frac{V_2}{R_2}$✓

The resistors are connected in parallel:

$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$✓

$R_{eq} = \frac{R}{3}$✓

As the three resistors are in parallel, the potential difference is the same:

$V_1 = V_2 = V_1 = V$

As the resistors have the same resistance, the current through each one is the same.

Solving:

$V_2 = IR_{eq} = I\frac{R}{3}$✓

$I_2 = \frac{I\frac{R}{3}}{R} = \frac{I}{3}$ ✓

$I_2 = \frac{3}{3} = 1\ A$✓

2.4. $V_{ext} = \varepsilon - V_i$✓

$V_{ext} = 12 - 3 \times 0{,}4$✓

$V_{ext} = 10{,}8\ V$ ✓

(6)

2.4.

2.4. $V_{ext} = \varepsilon - V_i$✓

$V_{ext} = 12 - 3 \times 0{,}4$✓

$V_{ext} = 10{,}8\ V$ ✓

(3)

2.5 Increases□

The resistors are now connected in series then total resistance increases□, emf is constant then current decreases□, drop of potential in the battery decreases□ and according to terminal potential increases.

(4)

Exercise 2

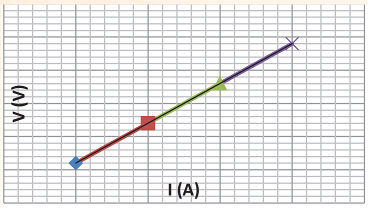
3.1. What is the relationship between potential difference and the strength of the electric current in a circuit with a resistor with constant resistance?

3.2. When current increases, potential difference also increases.

3.3. Independent variable – current

Dependent variable – potential difference

3.4.



2.5 Gradient = $\frac{\Delta Y}{\Delta X} = \frac{\Delta V}{\Delta I}$

Gradient = $\frac{24-6}{0{,}08-0{,}02}$

Gradient = 300

2.6. Resistance of the resistor.

2.7. The hypothesis is correct: the potential difference is directly proportional to the strength of the electric current when the resistance is constant.

7.5 ELECTRODYNAMICS

Exercise 1

1.1 DC generator✓

Mechanical energy to electrical energy✓ (2)

1.2 To make the direction of the (induced) current to be the same in every half cycle/half turn✓✓

OR

To keep the (induced) current unidirectional.✓✓ (2)

1.3 Graph A✓

The DC generator becomes an AC generator.✓

Voltage changes the polarity with every half cycle. ✓ (3)

1.4

$$P_{avg/gem} = \frac{V^2_{rms/wgk}}{R} \checkmark$$

$$P_{avg/gem} = \frac{(\frac{V_{max/maks}}{\sqrt{2}})^2}{R}$$

$$6 = \frac{(\frac{12}{\sqrt{2}})^2}{R} \checkmark$$

R= 12 Ω

$$I_{rms/wgk} = \frac{V_{rms/wgk}}{R} \checkmark$$

$$I_{rms/wgk} = \frac{(\frac{V_{max/maks}}{\sqrt{2}})^2}{R}$$

$$= \frac{(\frac{12}{\sqrt{2}})^2}{12}$$

$I_{rms/wgk}$ = 0,71

$I_{rms\ Total/wgk\ totaal}$ = 2x(0,71) ✓

=1,42 A ✓

Alternative solution:

$$P_{avg/gem} = \frac{V^2_{rms/wgk}}{R} \checkmark$$

$$P_{avg} = \frac{(\frac{V_{max/maks}}{\sqrt{2}})^2}{R}$$

$$6 = \frac{(\frac{12}{\sqrt{2}})^2}{R} \checkmark$$

R= 12 Ω

$V_{rms/wgk} = I_{rmsTot/wgk\ tot} R_T$ ✓

$$\frac{V_{rms/wgk}}{\sqrt{2}} = I_{rms\ Total/wgk\ tot} \cdot (\frac{R}{2})$$

$$\frac{12}{\sqrt{2}} = I_{rms/wgk} \cdot (\frac{12}{2}) \checkmark$$

$I_{rms\ Total/wgk\ tot}$ = 1,42 A ✓

7.6 PHOTOELECTRIC EFFECT

Exercise 1

1.1 Minimum energy needed to eject an electron from a metal surface (substance).

1.2 The extraction (ejection) of electrons from a metal surface by radiation (when light strikes its surface).

1.3.1

$$E = W_o + E_k$$

$$hf = W_o + E_k$$

$$(6{,}63 \times 10^{-34})f = 3{,}52 \times 10^{-19} + 4{,}20 \times 10^{-19}$$

$$f = 1{,}6 \times 10^{15}\ Hz$$

1.3.2

$$c = f\lambda$$

$$3 \times 10^8 = (1{,}16 \times 10^{15})\lambda$$

$$\lambda = 2{,}59 \times 10^{-7}\ m$$

Chemistry

1. How to use this book

This book serves as a guide to understanding the Grade 12 Physical Sciences. However, it does not replace your textbook. The book focuses more on the challenges that have been observed from learners' responses in the Grades 12 National Examinations over the past few years.

The authors have used their experience to focus their attention on the areas that learners seem to struggle with.

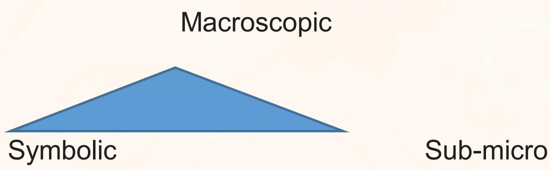
2. Key subject Concepts

The two areas of study in Chemistry are: 1. **Materials** 2. **Chemical Change**. In demonstrating concepts, laws and theories in this book, examples are used; this however does not mean that the laws, concepts and principles applies only to those examples used. It is therefore important to understand **the concept itself and where and when it applies**.

Some theories/laws/concepts apply throughout the content in both organic and inorganic chemistry e.g. atomic theory, The Kinetic Molecular Theory, the mole concept, stoichiometry, rules of oxidation, inter-molecular forces etc. These theories and concepts are applied throughout the chemistry content. There are aslo laws that apply only to a particular group or class of compounds; for example gas laws apply only to gases and not to solids or aqueous substances. It is important to always know where the laws/ rules can be applied.

3. The Representation Model

This model employs a strategy of three stages in understanding Chemistry Education. These stages should be applied almost simultaneously when studying chemistry**:** 1. **The Macro level**: This is what you see as an observer of either a material or chemical change (state, colour, size, etc.) 2. **The Sub-micro level**: This is what happens at the sub-atomic level, e.g. with electrons, protons in atoms or molecules. 3. The **Symbolic level:** This is when you represent what happens at the **sub-atomic level** and macro level using symbols, e.g. instead of saying ice, you write H_2O (s). Learners of Chemistry must be able to move through these three levels with ease when they discuss chemistry. When you deal with a chemistry question, always think about it in terms of these three levels.



Representation Model

4. Tips on specific topics

- **Organic Chemistry: Study how to name organic molecules for all groups. Always remember that the Carbon atom always takes a maximum of 4 bonds in all organic compounds, not more, not less.**

- **Electrochemistry: Pay attention to half reaction and their respective oxidation states. Use the *Table of Reduction Potentials* as discussed in the text. Read about the similarities and differences between the two types of cells: Galvanic and Electrolytic!**

- **Fertilizers: The processes involved in the manufacture of fertilisers is clearly indicated in the text. Study the molecules and their reactions, including their reaction conditions (these would include temperature, pressure, concentrations of reacting species and in some cases catalysts).**

5. Study and examination tips

6. Message to Grade 12 learners from the writers

As you prepare to write your examination, it is important to carefully understand the rules governing certain aspects of your work, and the laws and concepts. Ensure you understand these rules/laws/ concepts properly. Understand **what they mean**, **where they apply** and **when they apply** - and also when and where they do not apply.

Always:

1. Read the question that you are working on carefully.
2. Understand what it says and what is required of you.
3. Write down the information that you have.
4. Write down the information that you do not have.
5. Use the information you have to derive the information you need to answer the question.
6. Check your work by going through these steps again!

7. The Mole Concept

The Mole: The quantity of a substance that contains $6{,}02 \times 10^{23}$ particles. This number is also called Avogadro's number.

A mole is a very, very BIG number and if 12g of Carbon C_{12} contains this number of Carbon atoms, you can imagine how small atoms are. Imagine this many atoms contained in only 12g!

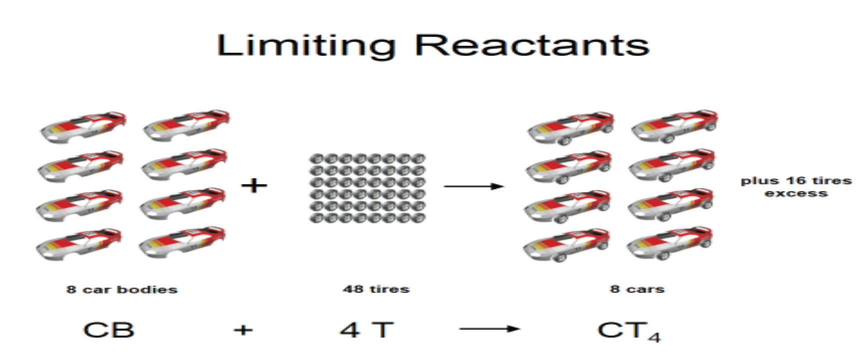
This also demonstrates how small atoms are!

All Chemistry calculations require an understanding of the mole concept. When we do calculations on reactions in chemistry we always use the moles that reacted - NEVER the mass that reacted. If you are given the mass, you must always work out the number of moles contained in the mass!

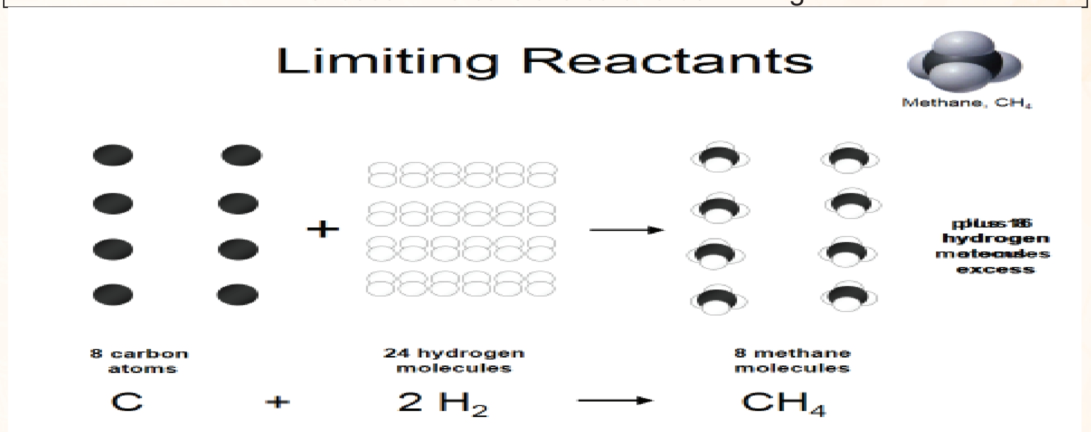
The masses that reacts in a chemical reaction will almost always have one or more of the reactant(s) having a larger than necessary number of moles or fewer that necessary number of moles and the reactions will almost always leave some unreacted reactant(s) that we call an **excess reactant** and the reactant(s) that gets used up while there is still an excess reactant is called a **limiting reactant**(s).

8. Stoichiometry

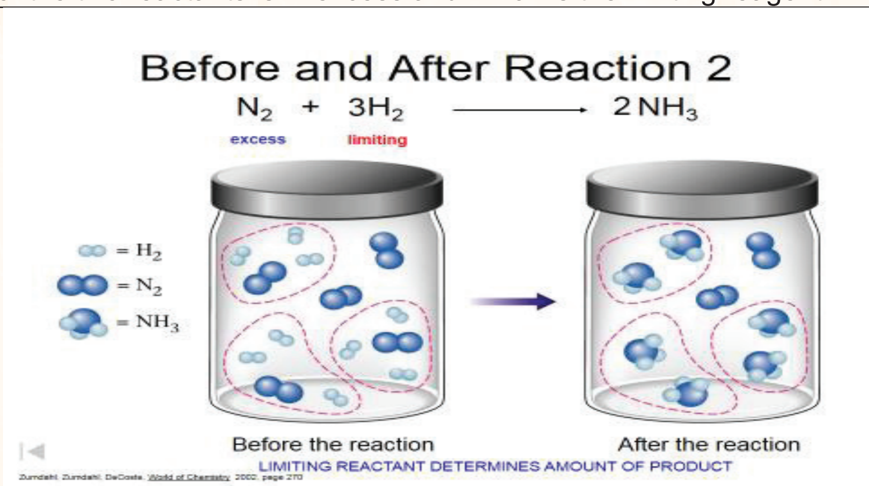
8.1 Excess and Limiting Reagents



See how many tyres you are able to use in this example. The remaining tyres are in excess. The cars are said to be limiting.



Which of the two reactants is in excess and which is the limiting reagent?



Look at the reactants in the jar as they form products in the jar on the right of the arrow. Study this reaction and decide which of the two molecules that are involved in this reaction is limiting H_2 or N_2 is the limiting reagent?

9. Practice activities from Grade 10

Reminder: One MOLE has 6.022×10^{23} items or there are 6.022×10^{23} items/mole.

Show your work!

1. How **many atoms** of potassium make up one MOLE? _____
2. How **many atoms** of potassium make up 2 MOLES? _____
3. How **many formula units** of salt make up 10 MOLES? _____
4. How **many molecules** of water make up 1 MOLE? _____
5. How **many molecules** of water make up 5 MOLES? _____
6. How **many moles** are 6.022×10^{23} atoms of sodium? _____
7. How **many moles** are 12.04×10^{23} atoms of carbon? _____
8. How **many moles** are 18.06×10^{23} atoms of sodium? _____
9. How many moles are 60.22×10^{23} atoms of sodium? _____
10. How many moles are 6.022×10^{23} molecules of water? _____
11. How many moles are 12.04×10^{23} molecules of water? _____
12. How many moles are 30.10×10^{23} molecules of water? _____

10. Dynamic Chemical Equilibrium Graphs

11. CONCENTRATION – TIME GRAPHS

STUDY TIP 1: Concentration, pressure and temperature changes made to a gaseous chemical equilibrium are identified as follows:

- **Concentration Change:** The graph of one of the substances spikes upward or downward
- **Pressure Change:** The graph spikes upward or downward for each substance in the equation.
- **Temperature Change:** The graph does not spike but shows gradual upward and downward changes that are opposite for the forward and reverse reactions

STUDY TIP 2: Upward spiking and gradual upward changes show increase in concentration as well as reaction rate. Downward spiking and gradual downward changes show decrease in concentration as well as reaction rate.

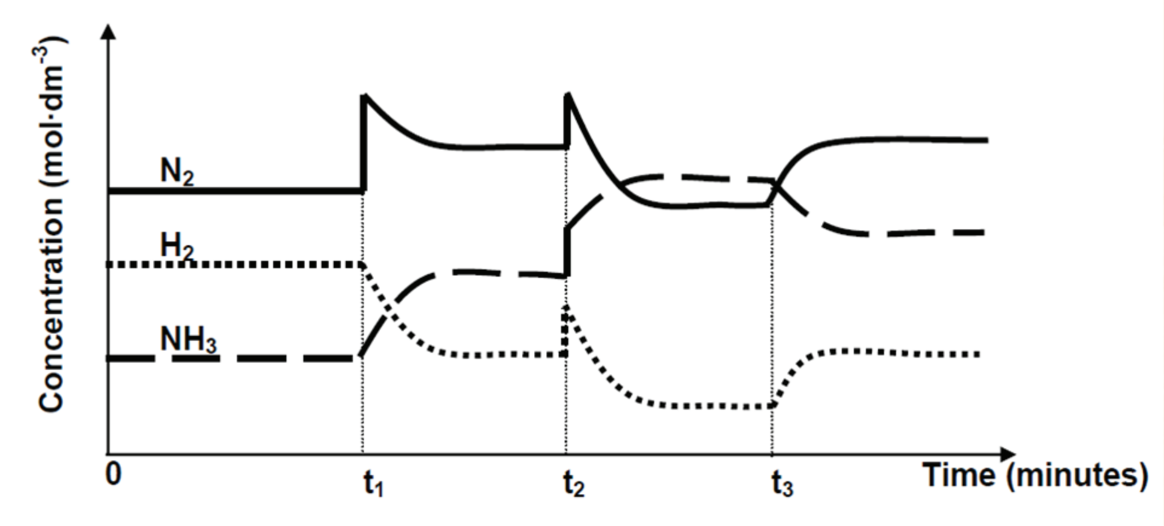
STUDY TIP 3: Pressure is increased by decreasing the volume of the container containing the reaction mixture. Conversely, pressure is decreased by increasing the volume of the closed container. Therefore pressure changes are really concentration changes.

STUDY TIP 4: Once the change is made Le Chatelier's Principle (LCP) can be used to explain the graph shape.

EXAMPLE

In the Haber Process, the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H < 0$ takes place in a closed container.

Changes are made to the reaction at times t_1, t_2 and t_3. The graphs below show the situation.



1. What do the shapes of the graphs between the times 0 and t_1 indicate about the reaction?
2. State the change that was made to the reaction at:
   2.1 t_1 2.2 t_2 2.3 t_3. Give a reason for each answer.
3. Use Le Chatteliers Principle (LCP) to explain the shapes of the graphs between:
   3.1 t_1 and t_2 3.2 t_2 and t_3

ANSWERS

1. The reaction is in equilibrium

2.1 $[N_2]$ was increased Reason: There is an upward spike only for N_2

ANSWERS

1. The reaction is in equilibrium.

2.1 $[N_2]$ was increased. Reason: There is an upward spike only for N_2.

2.2 Pressure was increased. Reason: There is an upward spike for N_2, H_2 and NH_3.

2.3 Temperature was increased. Reason: All changes in the graph line shapes are gradual. The changes are upward for the reverse reaction and downward for the forward reaction.

3.1 STEP 1: Change made: $[N_2]$ increases.

STEP 2: According to LCP, the forward reaction is favoured (i.e. the reaction that reduces the $[N_2]$ is favoured).

STEP 3: Therefore, the $[H_2]$ decreases and the $[NH_3]$ increases until a new equilibrium is established.

3.2 STEP 1: Change made: Pressure was increased.

STEP 2: According to LCP, the forward reaction is favoured (i.e. the reaction that produces less molecules is favoured).

STEP 3: Therefore the $[NH_3]$ increases, but the $[N_2]$ and $[H_2]$ decrease until a new equilibrium is established.

12. **FERTILIZERS**

FERTILISERS

NH_4NO_3 and $(NH_4)_2SO_4$

3 Industrial processes

Fractional distillation of liquid air gives N_2.

Ostwald Process

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

$2NO + O_2 \rightarrow 2NO_2$

$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

Catalyst in step 1: Pt:

Haber Process

$N_2 + 3H_2 \rightarrow 2NH_3$

Catalyst: Iron Oxide

Contact Process

$S + O_2 \rightarrow SO_2$

$2SO_2 + O_2 \rightarrow 2SO_3$

$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ (Oleum)

Catalyst in Step2:V_2O_5

HNO_3 + **NH_3** + **H_2SO_4**

FERTILISERS

(**ONLY 2** Fertilisers to study)

NH_4NO_3 Ammonium Nitrate

$(NH_4)_2SO_4$ Ammonium Sulphate

Primary nutrients (N P K) **Essential Nutrients (C H and O)** **NPK ratio**

TIP 1: Make a CHART showing the OSTWALD, HABER and CONTACT processes and place it in your ROOM where you can always see it. Practice writing out the equations on your own.

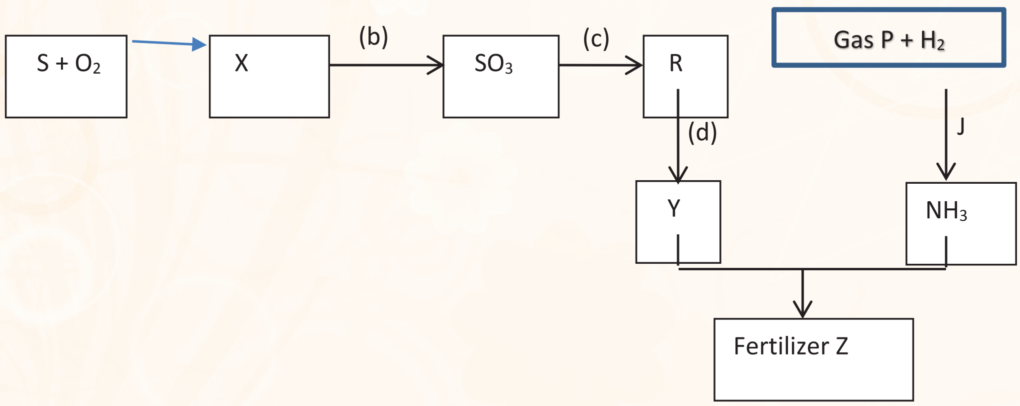
TIP 2: Play this game: Prepare the following cards for your game:
4 cards marked O_2; 2 cards marked NO; 2 cards marked NO_2; 2 cards marked SO_2;
2 cards marked SO_3; 2 cards marked H_2O; 1 card for each of the following - S, H_2SO_4, $H_2S_2O_7$ and HNO_3.

USE THESE CARDS TO DEPICT THE REACTIONS FOR THE TWO PROCESSES ON A WALL. COMPETE WITH YOUR CLASSMATE TO SEE WHO FINISHES FASTER.

Activities

QUESTION 1

The flow diagram below represents two industrial processes that are used to make fertilizer Z. The letters (a) to (d) represent steps in one of the industrial processes. The letter J represents the other industrial process.



1.1 Write down the NAME or FORMULA of:

1.1.1 Product X formed in step (a). (1)

1.1.2 Product Y formed in step (d). (1)

1.1.3 Process J, by which NH_3 is produced.

1.2 Write down a balanced chemical equation for the formation of fertilizer Z. (3)

1.3 A farmer has two labelled bags of fertilizer - **X** and **Y** -as shown below.

X	Y
50 kg	20 kg
6:2:1 (20)	3:5:2 (30)

She mixes the contents of **X** and **Y** together in another bag - **Z.**

Calculate the total mass of phosphorus that **Z** now contains. (7)

1.3 The bag of fertiliser shown below was prepared by mixing 25 kg of pure ammonium sulphate $(NH_4)_2SO_4$ with potassium salts, phosphates and sand.

3:5:1 (30)

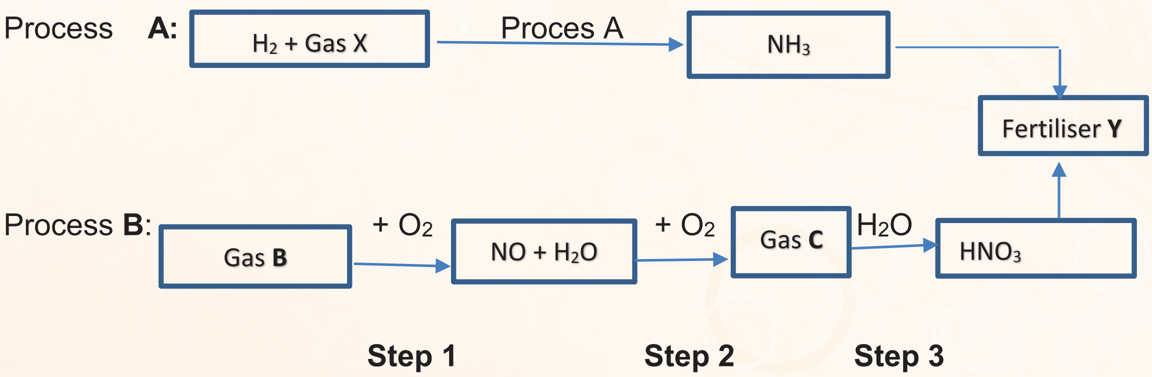
x kg

Calculate the mass of the bag of fertiliser. (4)

(ASSUME THAT AMMONIUM SULPHATE IS THE ONLY SOURCE OF NITROGEN.

QUESTION 2

2.1 The flow diagram below shows the processes involved in industrial preparation of fertiliser **Y**.



2.1.1 Write down the NAME of:

a. The RAW material for gas **X** in process **A**. (1)

b. Process **A.** (1)

c. Process **B,** represented by **Steps 1** to **3.** (1)

2.1.2 Write down the balanced equation for:

a. Process **A** (3)

b. Step 1 (3)

c. Step 2 (3)

d. The reaction that leads to the formation of **fertiliser Y**. (3)

2.2 Two 50 kg bags contain fertiliser P and Q**.**

Fertiliser P: 5:2:3 (25)

Fertiliser Q: 1:3:4 (20)

2.2.1 What do the numbers 25 and 20 represent? (1)

2.2.2 Do a calculation to determine which fertiliser (P or Q) contains the greater mass of potassium. (4)

SOLUTIONS

QUESTION 1

1.1.1 Sulphur dioxide (or SO_2) - give the NAME or FORMULA, **not both.**

1.1.2 Sulphuric acid (or H_2SO_4)

1.1.3 Haber process

1.2 $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

1.3 Approach:

Calculate the mass of phosphorus in each bag and add these figures together.

Bag X; $m_{Phosphorus} = 2/9 \times 30/100 \times 50 = 2.22$ kg

Bag Y: $m_{Phosphorus} = 5/10 \times 30 \times 20 = 3$

$m_{TOTAL} = 3 + 2.22 = 5.22$ kg

1.4 Approach:

First find mass N in $(NH4)_2SO_4$

m $_{Nitrogen}$ = % N in $(NH_4)_2SO_4$ x 25k

= M nitrogen/M $(NH_4)_2 SO_4$ X 25 Kg

= (2 x 14) / (14 x 2) + (2 X 4 X 1)+ 32 + (4 x 16) x 25kg

= 28+3 +32+64+25

= 28/132 x 25 Kg = 5.3 Kg

Mass nitrogen in bag = 5.3 = 3/9 x 30/100 x → 5.3 = 0.1 x → 53 Kg = x

QUESTION 2

2.1.1 a. Air b. Haber c. Ostwald

2.1.2 a. $N_2 + 3H_2 \rightarrow 2 NH_3$

b. $4 NH_3 + 5 O_2 \rightarrow 4 NO + 6 H_2O$

c. $2 NO + O_2 \rightarrow 2NO_2$

d. $NH_3 + HNO_3 \rightarrow NH_4NO_3$

2.2.1 Percentage of fertiliser in the bag.

2.2.2 **P** m_K = 3/10 x 25/100 x 50 = 3.75 kg

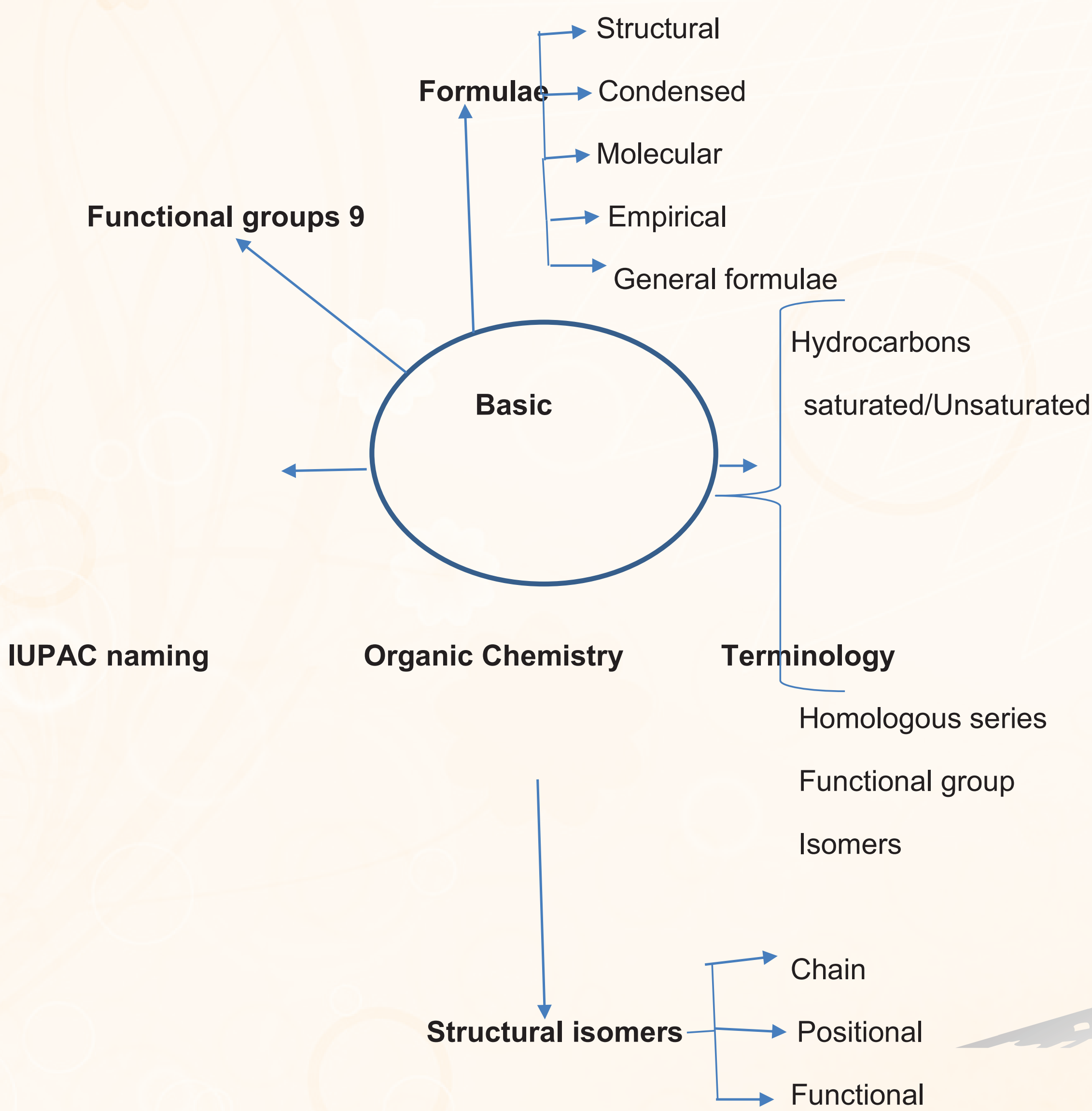
Q m_K = 4/8 x 20 /100 x 50 = 5 **Q** contains more potassium

13. ORGANIC CHEMISTRY

ORGANIC CHEMISTRY

- ✓ **BASIC ORGANIC CHEMISTRY**
- ✓ **PHYSICAL PROPERTIES**
- ✓ **ORGANIC REACTIONS**

13.1 BASIC ORGANIC CHEMISTRY



13.2 NOMENCLATURE OF ORGANIC COMPOUNDS

NOTE: organic compounds in these notes are named according to the 1993 IUPAC RULES.

STRAIGHT CHAIN ALKANES **IUPAC NOMENCLATURE**

The IUPAC names of the first eight are:

Name	**Condensed structural formula**	**Name**	**Condensed structural formula**
Methane	CH_4	Pentane	$CH_3CH_2CH_2CH_2CH_3$
Ethane	CH_3CH_3	Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$
Propane	$CH_3CH_2CH_3$	Heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Butane	$CH_3CH_2CH_2CH_3$	Octane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

IUPAC NOMENCLATURE OF STRAIGHT CHAIN ALKANES CONTAINING AN ALKYL

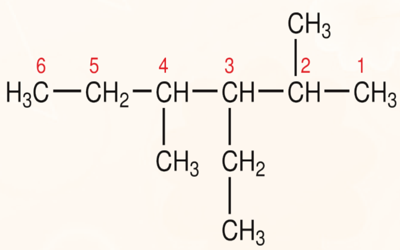
In organic chemistry, an **alkyl substituent** is an alkane missing one hydrogen. The term **alkyl** is intentionally unspecific to include many possible substitutions. ... The smallest **alkyl** group is methyl, with the formula CH_3-

In general, alkyl substituents are named by changing the ending "ane" in an alkane's name to "yl".

EXAMPLE: CH_3 is meth**yl;** it is derived from CH_4 (methane) by changing the "ane" ending in meth**ane** to "yl".

IUPAC RULES should be followed when naming these alkanes:

The following compound will be used to illustrate the IUPAC Rules:



STEP 1: Select the longest continuous chain for the parent name. In this case it has six carbon atoms and is thus *hexane*.

STEP 2: Number the chain from either end, so that the substituents are attached at the lower numbers. In the example, numbering from left to right gives substituents at carbon 2 and 4, whereas numbering from right to left gives substituents at carbon 3 and 5. Thus the lower numbers occur when numbering from left to right.

STEP 3: Substituent groups are assigned the number of the carbon to which they are attached. In the example, the two substituents are called the 2-methyl and 4-ethyl substituent groups. Note that the number is written in front of the substituent group and a hyphen (-) separates the number and the alkyl group's name.

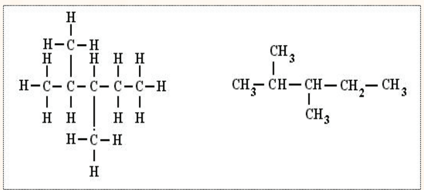
STEP 4: The name of the compound is now composed of the parent name preceded by the names of the substituent groups in alphabetical order. The correct IUPAC name for the example is 4-ethyl-2-methylhexane.

NOTES: In IUPAC nomenclature, a hyphen (-) separates numbers from words, and a comma separates numbers from numbers. Otherwise there is no space between the words that make up the name.

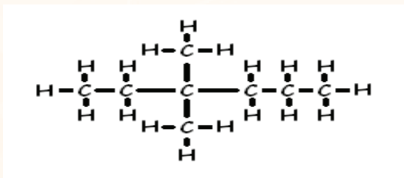
STEP 5: If the same substituent occurs more than once in the molecule, the prefixes "di", "tri", "tetra" and so on, are used to indicate how many times it occurs. If the substituent occurs more than once on the same carbon, the number is repeated. The following examples illustrate this step.

NOTES: In IUPAC nomenclature, the prefixes "di", "tri", "tetra" and so on, are not alphabetised.

EXAMPLES:



2,3 - dimethylpentane



3,3 – dimethylhexane

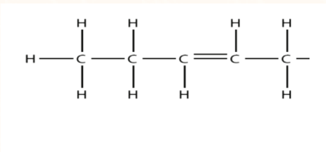
NOTE: The IUPAC nomenclature of the following homologous series is similar to that of alkanes. The only differences in the IUPAC nomenclature of these series is with precedence, position of the functional group and parent name.

HOMOLOGOUS SERIES: ALKENES IUPAC NOMENCLATURE

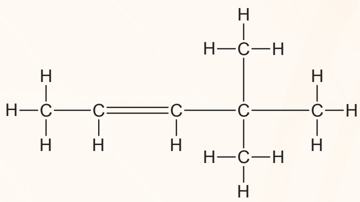
Precedence	Position	Parent name
The longest chain is numbered so that the C=C has the lowest number in the chain.	The first carbon in C=C is used to locate the double bond.	Change the "ane" ending in the alkane to "ene" for the alkene.

EXAMPLES

(a) pent-2-ene



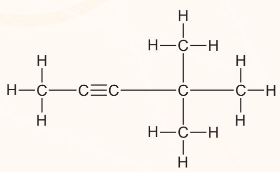
(b) 4, 4-dimethylpent-2-ene



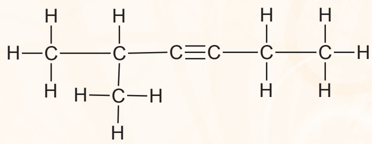
HOMOLOGOUS SERIES: ALKYNES **IUPAC NOMENCLATURE**

Precedence	Position	Parent name
The longest chain is numbered so that the C=C has the lowest number in the chain.	The first carbon in C≡C is used to locate the triple bond.	Change the "ane" ending in the alkane to "yne" for the alkyne.

EXAMPLES (a) 4,4-dimethylpent-2-yne



(b) 2-methylhex-3-yne



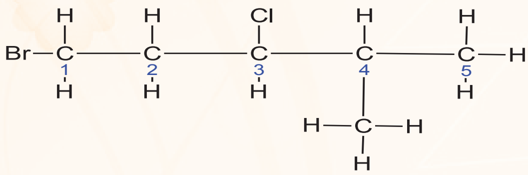
HOMOLOGOUS SERIES: HALOALKANES (ALKYL HALIDES) IUPAC NOMENCLATURE

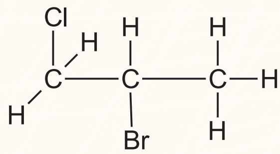
The halogen substituents that occur on the alkane chains are named as follows:

Cl – chloro **Br- bromo** **I – iodo**

Precedence	Position	Parent name
The longest chain is numbered to give the halogen substituents the lowest numbers in the chain.	The carbon atoms to which halogen substituents are bonded are used to locate their positions.	There is no change made to the parent alkane chain. It remains an alkane.

Examples: (a) 1-bromo-4-methylpentane (b) 2-bromo-1-chloropropane



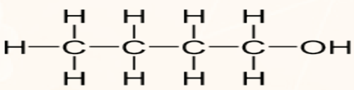


HOMOLOGOUS SERIES: ALCOHOLS IUPAC NOMENCLATURE

NOTES: Just like there are primary, secondary and tertiary alcohols, there are primary, secondary and tertiary alkyl halides.

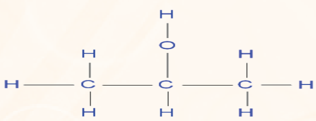
PRIMARY ALCOHOL: The carbon atom attached to the –OH group is attached to one other carbon atom in the molecule.

Example: $CH_3CH_2CH_2CH_2OH$ (butan-1-ol).



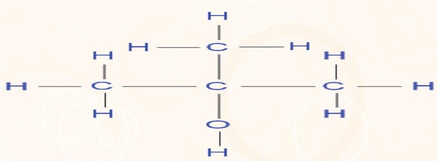
SECONDARY ALCOHOL: The carbon atom attached to the –OH group is attached to two other carbon atoms in the molecule.

Example:



TERTIARY ALCOHOL: The carbon atom attached to the –OH group is attached to three other carbon atoms in the molecule.

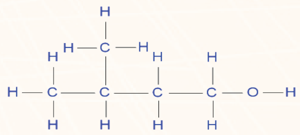
Example:



IUPAC NOMENCLATURE OF ALCOHOLS

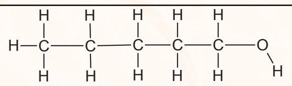
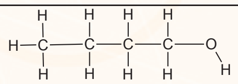
Precedence	Position	Parent name
Longest chain is numbered so that the carbon atom bonded to the OH group has the lowest number in the chain.	The carbon atom to which the OH group is bonded is used to locate it.	Change the “e” ending in the alkane to “ol” for the alcohol.

Examples



2-methylbutan-1-ol

The table below provides information on the structural formula, condensed structural formula, molecular formula, isomer(s) and functional group of some alcohols when their IUPAC name is given.

IUPAC Name	Structural Formula	Condensed Structural Formula	Molecular Formula	Functional / Structural Isomers	Functional Group (structural formula)
Pentan-1-ol		$CH_3CH_2CH_2CH_2CH_2OH$	$C_5H_{12}O$	Pentan-2-ol Pentan-3-ol 3-methylbutan-2-ol	-O-H
Butan-1-ol		$CH_3CH_2CH_2CH_2OH$	$C_4H_{10}O$	Butan-2-ol 2-methylpropan-2-ol	-O-H

HOMOLOGOUS SERIES: CARBOXYLIC ACIDS **IUPAC NOMENCLATURE**

Precedence	Position	Parent name
The longest chain is numbered so that the carbon atom in the COOH group has the lowest number in the chain. It will always be 1, but 1 is omitted in the IUPAC name.	The carbon atom in COOH is used to locate the COOH group.	Change the “e” ending in the alkane name to “oic acid” for the carboxylic acid.

Examples:

(a) HCOOH — methanoic acid

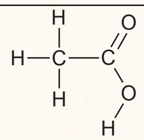
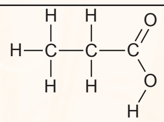
(b) CH_3COOH — ethanoic acid

(c) CH3CH2COOH — propanoic acid

(d) CH3CH2CH3CH2CH2C1OOH (with CH_3 branch) — 4-methylhexanoic acid

Draw all the molecules above (a-d).

The table below provides information on the structural formula, condensed structural formula, molecular formula, isomer and functional group of some carboxylic acids when their IUPAC name is given.

IUPAC Name	Structural Formula	Condensed Structural Formula	Molecular Formula	Functional / Structural Isomers	Functional Group (structural formula)
Ethanoic acid		CH_3COOH	$C_2H_4O_2$	Methyl methanoate	O ‖ - C –O-H
Propanoic acid		CH_3CH_2COOH	$C_3H_6O_2$	Methyl ethanoate Ethyl methanoate	O ‖ - C –O-H

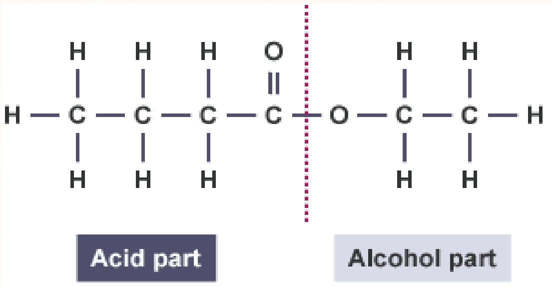
In general, an isomer of a carboxylic acid is usually an ester, and vice versa.

HOMOLOGOUS SERIES: ESTERS

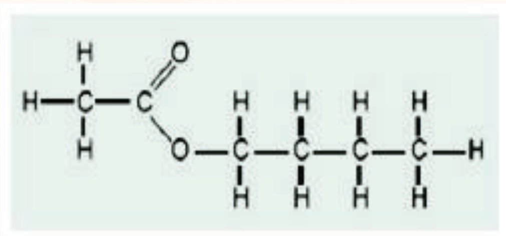
Precedence	Position	Parent name
The alkyl group from the alcohol is named first, followed by the name of the acid, with the "ic" changed to "ate".	Not applicable.	Not applicable.

Examples:

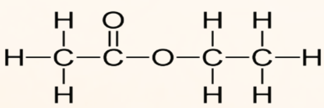
A) butyl ethanoate



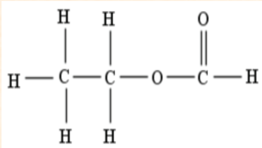
B) ethyl butanoate



C) ethyl ethanoate



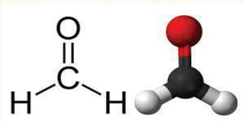
D) ethyl methanoate



HOMOLOGOUS SERIES: ALDEHYDES **IUPAC NOMENCLATURE**

Precedence	Position	Parent name
The longest chain is numbered so that the carbon atom in the CHO group has the lowest number in the chain. It will always be 1, but 1 is omitted in the IUPAC name.	The carbon atom in CHO is used to locate the CHO group.	Change the "e" ending in the alkane to "al" for the aldehyde.

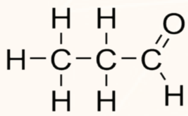
A)



(a) HCHO

methanal

B)



(b) CH_3CH_2CHO

propanal

HOMOLOGOUS SERIES: KETONES **IUPAC NOMENCLATURE**

Precedence	Position	Parent name
The longest chain is numbered so that the carbon atom in the C=O group has the lowest number in the chain.	The carbon atom of the C=O group is used to locate C=O.	Change the "e" ending in the alkane name to "one" for the ketone.

In general, the functional isomer of a ketone is an aldehyde, and vice versa.

Examples:

(a) HCOH

methanone

(b) CH_3COCH_3

Propan-2-one

(c) $CH_3CH_2CH_2CH_2COCH_3$ (with CH_3 branch)

5-methylhexan-2-one

Draw structural formulae for all the molecules above.

PHYSICAL PROPERTIES OF ORGANIC MOLECULES

Definitions (REFER TO YOUR EXAM GUIDELINES)

- Boiling point
- Vapour pressure
- Melting point

Types of inter-molecular forces (NOTE: *ALL inter-molecular forces are*

CALLED as ***Van der Waals forces;*** therefore, Hydrogen bonds are also Van der Waals forces, according to **CAPS)**

REMEMBER THE FOLLOWING:

- The relationship between inter-molecular forces and boiling point: As the strength of inter-molecular forces increases ↑, boiling point increases ↑.
- The relationship between inter-molecular forces and vapour pressure: As the strength of inter-molecular forces increases ↑, vapour pressure decreases ↓.
- What type of inter-molecular forces are present between molecules of

HYDROCARBONS — Alkanes, Alkenes, Alkynes: **Only** *London Forces*

(**Haloalkanes/Aldehydes/Ketones** contain BOTH *London Forces* and **Dipole-dipole forces** (organic molecules where there is a halogen atom or oxygen atom (more electro-negative atoms than C there are **dipole dipole** forces)

✓ **Dipole–dipole** forces are **stronger** than London Forces.

In **Haloalkanes/Aldehydes/Ketones,** the stronger force is the Dipole- dipole force. (Note: London Forces are also present.)

SUMMARY

Hydrocarbons — Alkanes, Alkenes, Alkynes — have **ONLY** London forces between molecules

Haloalkane/Aldehydes and Ketones have:

BOTH London forces and **Dipole-dipole forces (i.e.** a compound with **Br or Cl** or **O** will have **Dipole–dipole forces).**

Dipole–dipole forces are **stronger** than **London** Forces.

Alcohols and Carboxylic acids have**:**

London Forces, Dipole-dipole forces and **Hydrogen bonds (**the strongest of the inter-molecular forces**)** between their molecules.

SUMMARY OF TYPES OF BONDS IN ORGANIC MOLECULES

ONLY London Forces	**BOTH London forces and Dipole –dipole forces**	**ALL THREE** ✓ **London forces** ✓ **Dipole-dipole forces** ✓ **Hydrogen bonding**
Alkane	Haloalkane	Alcohol
Alkene	Aldehyde	Carboxylic acid
Alkyne	Ketone	

Summary of bonds

<table>
<tr><th>Hydrogen Bonds</th><th>Dipole Dipole</th><th>Dispersion Forces/ London Forces</th></tr>
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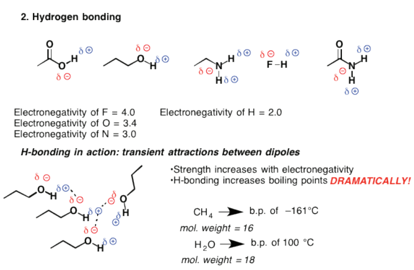
Hydrogen bonding occurs in molecules containing the highly electronegative elements F, O, or N that are directly bound to a hydrogen atom in a molecule. Since H has an electronegativity of 2.2 the bonds are not as polarized as purely ionic bonds and possess some covalent character. However, the bond to hydrogen will still be polarized and possess a dipole.



The dipole of one molecule can align with the dipole from another molecule, leading to an attractive interaction that we call hydrogen bonding. Owing to rapid molecular motion in solution, these bonds are temporary (short-lived) but have significant bond strengths ranging from (9 kJ/mol (2 kcal/mol) (for NH) to about 30 kJ/mol

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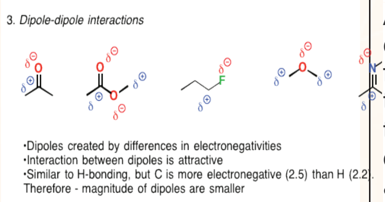
Van Der Waals Dipole-dipole interactions.
Other groups of molecules beside hydrogen can be involved in polar covalent bonding with strongly electronegative atoms due to their electro negativities. The unequal distribution of charge gives the molecule a dipole nature. For instance, each of these molecules contains a dipole:



These dipoles can interact with each other in an attractive fashion, which will also **increase** the boiling point. However since the electronegativity difference between carbon (electronegativity = 2.5) and the

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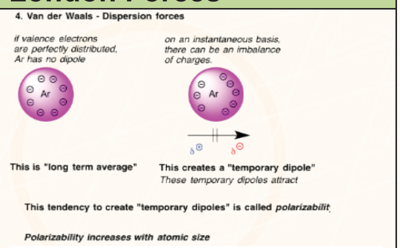

The weakest intermolecular forces of all are called dispersion forces or London forces. These represent the attraction between *instantaneous dipoles* in a molecule. If you cool a gas like Argon to –186 °C, you can actually condense it into liquid argon. The fact that it forms a liquid it means that *something* is holding it together. That "something" is dispersion forces. Think about. *On average* the electrons in the valence shell, are evenly dispersed. But at any given instant, there might be a mismatch between how many electrons are on one side and how many are on the other, which can lead to an *instantaneous* difference in charge.

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</table>

(7 kcal) and higher for HF. As you might expect, the strength of the bond increases as the electronegativity of the group bound to hydrogen is increased. So in a sense, HO, and NH are "sticky" – molecules containing these functional groups will tend to have higher boiling points than you would expect based on their molecular weight.	electronegative atom (such as oxygen or nitrogen) is not as large as it is for hydrogen (electronegativity = 2.2), the polar interaction is not as strong. So on average these forces tend to be weaker than in hydrogen bonding.	For hydrocarbons and other non-polar molecules which lack strong dipoles, these dispersion forces are really the only attractive forces between molecules. The dipoles are weak and transient, they depend on contact between molecules – which means that the forces increase with surface area. A small molecule like methane has very weak intermolecular forces, and has a low boiling point. However, as molecular weight increases, boiling point also goes up. That's because the surface over which these forces can operate has increased. Therefore, d**ispersion forces increase with increasing molecular weight.** Individually, each interaction isn't worth much, but if collectively, these forces can be extremely significant.

COMPARE THE STRENGTH OF INTER-MOLECULAR FORCES

London Forces – WEAKEST

Dipole-dipole - STRONGER than London Forces, but WEAKER than Hydrogen bonds

Hydrogen bonds - STRONGEST

EXAMPLES

1.1 Consider the three compounds: **A:** CH_3OH **B:**CH_3CH_2OH and **C:**$CH_3CH_2CH_2OH$

1.1.1 Which of the three compounds has the HIGHEST boiling point?

1.1.2 Explain your answer to QUESTION 1.1.1 above
Answer:

Approach: Using the summary above, check where the molecules in question belong and check the forces that can be found in that group.

The compounds belong to the same homologous series.

Mention the trend with regard to chain length (surface area).

Mention the trend with regard to London Forces.

More energy is required to break forces.

Generally: *If the compounds belong to the same homologous series, the explanation must mention London Forces, as they are the ONLY forces affected by an increase/decrease in surface area.*

A common **ERROR** is using Hydrogen bonds in the answer, since we are dealing with alcohols - but **hydrogen bonds/Dipole-dipole forces** are **not** affected by chain length.

ANSWER:

1.1.1 **C**

1.1.2 From **A** to **C**
Chain length (or surface area or molecular size) increases.
The strength of London forces increases.
More energy is needed to break inter-molecular forces.
(DO NOT SAY "break bonds". SAY "Break inter-molecular forces".)

1.2 Consider the TWO compounds, **D**: CH_3COCH_3 and **E**:$CH_3CH(CH_3)CH_3$ (with the CH_3 branch drawn above the second carbon)

1.2.1 Which compound has the HIGHEST boiling point?

1.2.2 Explain your answer to QUESTION 1.1 above.

Approach:
The two compounds belong to different homologous series

Step 1: Identify the type of inter-molecular force in each
Step2: Compare the strength of the forces.
Step 3: More energy is needed to break inter-molecular forces.

Answer:
1.2.1 **D**

1.2.2 STEP 1: Between the molecules of **D** there are dipole–dipole forces.
STEP 2: Between the molecules of **E,** there are London forces.
Dipole-dipole forces are stronger than London forces.
STEP 3: More energy is required to break inter-molecular forces in **D.**

EXERCISE : PHYSICAL PROPERTIES

Consider compounds **A** to **C** in the table below:

Compound	IUPAC name
A	ethane
B	propane
C	butane

1.1 To what homologous series do compounds **A** to **C** belong?

1.2 Is compound **A** SATURATED or UNSATURATED? Give a reason.

1.3 Which ONE of the compounds has the HIGHEST vapour pressure?

1.4 Explain your answer to QUESTION 1.3 ABOVE.

1.5 Which compound has the highest boiling point?

EXCERCISE 2: PHYSICAL PROPERTIES

2.1 The table shows five organic compounds represented by the letters A to D.

A	CH_3CH_2OH
B	CH_3CO_2H
C	CH_3CHO
D	$CH_3CH_2CH_3$
E	CH_3CH_3

2.1.1 Which compound in the table is an aldehyde?

Consider the boiling points of compounds **A** to **E,** given in random order below, and use them where applicable to answer the questions that follow.

118 ^{o}C	-89 ^{o}C	78 ^{o}C	-42^{o}C	21 ^{o}C

2.1.2 Write down the boiling point of:

a. Compound **B** b. Compound **C**

2.1.3 Explain the difference in the boiling point of:

a. **A** and **B**

b. **B** and **C**

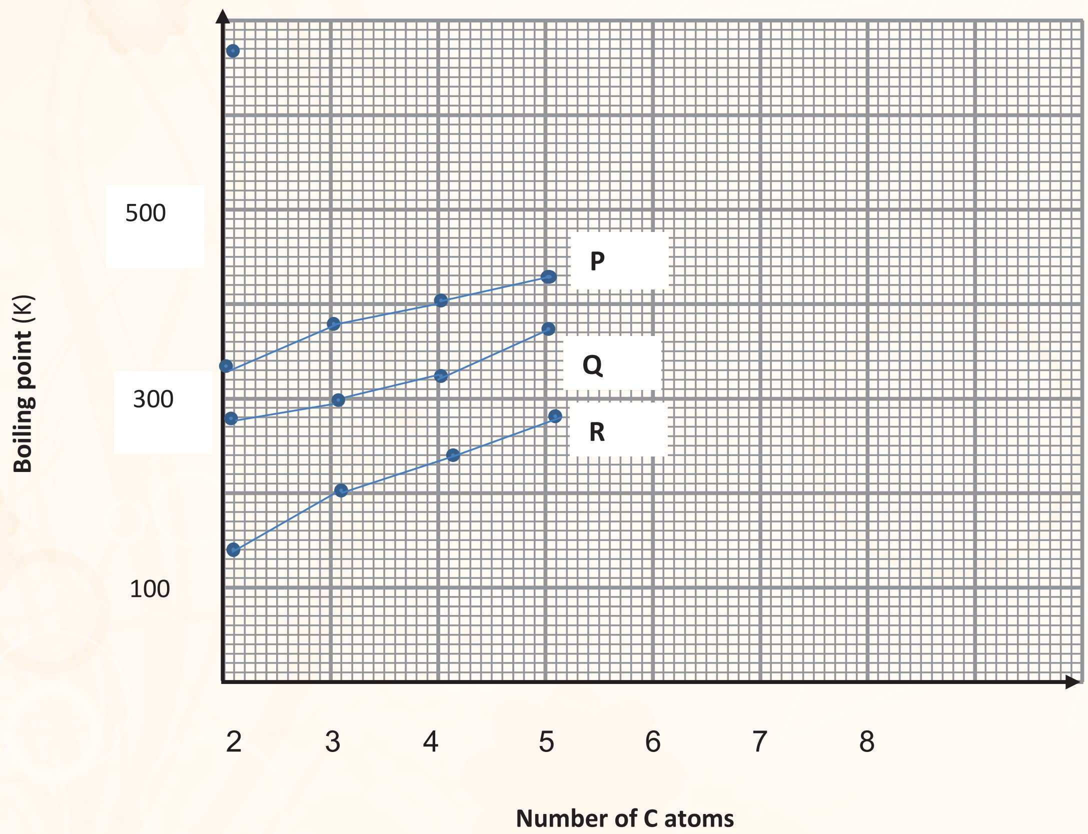
c. **C** and **D**

d. D and **E**

2.1.4 Describe the trend in vapour pressure from **C** to **E**

2.2 The relationship between boiling point and the number of carbon atoms in straight chain molecules of alkanes, carboxylic acids and aldehydes is investigated. Curves **P**, **Q** and **R** are obtained.

GRAPH OF BOILING POINT VERSUS NUMBER OF C ATOMS



2.2.1 Define the following terms:

a. Boiling point (2)
b. Vapour pressure (2)

2.2.2 For curves **A, P, Q, R** write down a conclusion that can be drawn from these results. (2)

2.2.3 Identify the curve that represents each of the following (**A** ,**B** or **C**):

a. Aldehydes (1)

b. Carboxylic acids (1)

2.2.4 Explain your answer to question 2.2.3 above. (5)

SOLUTIONS: PHYSICAL PROPERTIES

EXCERCISE 1: PHYSICAL PROPERTIES

1.1 Alkanes
1.2 Saturated - it contains only single bonds.
1.3 Ethane
1.4 From **A** to **C:**
Surface area (chain length) increases.
Strength of London forces increases.
More energy is needed to break the inter-molecular forces.
1.5 C

EXCERCISE 2: PHYSICAL PROPERTIES

2.1.1. **C**

2.1.2. a.118 ^{o}C

b. 21 ^{o}C

2.1.3 a. Both compound A and B have Hydrogen bonds.

Compound B has more sites for Hydrogen bonds than A (therefore the bonds are stronger in B).

More energy is needed to break inter-molecular forces in B.

b. B has strong Hydrogen bonds.

C has weak dipole–dipole forces.
More energy is needed to break the bonds in B.

c. **C** has dipole dipole forces.
D has weak London forces.
C needs more energy to break forces.

d. From **E** to **D**

Surface area (chain length) increases.

The strength of London forces increases.

More energy is needed to break inter-molecular forces.

GENERALLY, when explaining trends in boiling point and vapour pressure:

- IF the compounds differ in chain length:
  - ✓ Mention the trend in surface area.
  - ✓ Mention the trend in strength of London forces. (Remember ALL compounds have London forces, including alcohols and carboxylic acids.)
  - ✓ Lastly, more energy is needed to break forces in the compound where forces are strongest.
- IF the compounds belong to different homologous series:
  Identify the type of force in each compound.
  Compare the strength of the forces - mention which one is stronger.
  More energy is needed to break inter-molecular forces in the compound where forces are stronger.

(**NOTE:** IT IS **NOT** ACCEPTABLE TO WRITE, "TO BREAK BONDS, AS THESE ARE INTER-MOLECULAR FORCES, NOT INTER-ATOMIC BONDS, LIKE COVALENT BONDS, ETC.")

ORGANIC REACTIONS

- ✓ **ADDITION, SUBSTITUTION, ELIMINATION**
- ✓ **ESTERIFICATION, COMBUSTION, POLYMERISATION**

Draw **contrasts** between **substitution** and **elimination**

addition and **elimination**

SUBSTITUTION

(**NO alkene** in products or reactants)

Reaction Conditions

-mild heat for in all Substitution

For reaction of **Haloalkane** to Produce **Alcohol (hydrolysis)**

- Use H_2O **OR**

–**Dilute strong** base KOH or NaOH

ELIMINATION

Alkene is a **Product**

Reaction conditions

Strong Heat in all Elimination

For Hydrohalogenation

- Use **concentrated** strong base KOH or NaOH

ORGANIC REACTIONS

ADDITION

Alkene is a reactant (On left of arrow)

✓ **Hydrogenation**

Alkene to Alkane: Add H_2 (Catalyst Pt or Pd)

✓ **Hydrohalogenation:** Add HBr or HCl
Alkene to Haloalkane

(Product will have ONE halogen atom)

✓ **Halogenation (Add Br_2 or Cl_2)**

Alkene to haloalkane
Two halogen atoms on Product **(Bromine test)**

✓ **Hydration (Add H_2O)**

Catalyst: H_2SO_4

ELIMINATION

Alkene is a **product**

Reaction Conditions
Strong Heat for all Elimination reactions

✓ **Cracking**

e.g. $C_{15}H_{32}$ $2C_2H_4 + C_3H_6 + C_8H_{18}$
Catalytic cracking Low Temp/Low Pressure
Thermal cracking High Temp/High Pressure

✓ **Dehydrohalogenation**

(Removal of HBr or HCl)
Conditions: Strong heat/**Conc** KOH or NaOH

✓ **Dehydration** (Removal of H_2O)

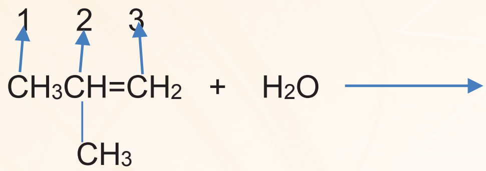
Conditions: Strong heat and excess conc H_2SO_4)

TIPS

In addition, reactions involving compounds **where there is no symmetry across the double bond** remember H "likes many Hs")

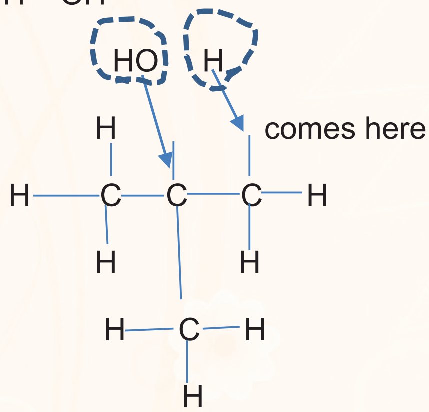
Think of water H—OH in substitution in **addition** reaction and substitution reactions.

E.g. Write down the structural formula of the Major product using structural formulae.



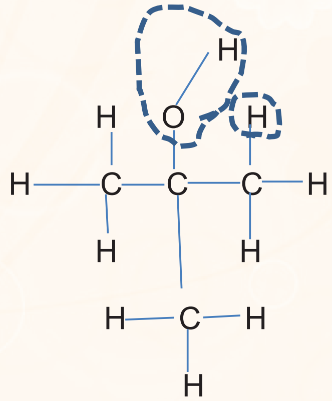
Approach:

Think of H_2O as H —OH

Answer: 

Look at the Carbon atoms at the double bond: Carbon 2 has ONE H; carbon 3 has 2.

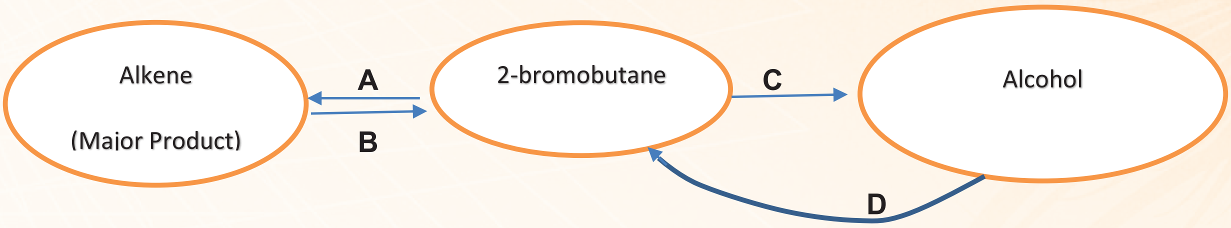
Therefore, there is NO symmetry across double bond H will add where there are many Hs, at Carbon 3 and OH^- adds on Carbon 2 on to form the major product

Answer: 

For substitution the negative part (written second in formula undergoes substitution e.g. when using dilute KOH it is the OH- that substitutes, not the K^+

EXERCISE 1: ORGANIC REACTIONS

The flow diagram below shows how 2-bromopropane can be used to prepare other organic compounds.



1.1 Classify 2-bromobutane as a PRIMARY, SECONDARY or TERTIARY haloalkane. (1)

1.2 Write down the STRUCTURAL FORMULA of a positional isomer of 2-bromobutane. (1)

1.3 Write down the type of reaction represented by:

1.3.1 **A** 1.3.2 **C** 1.3.3 **D** (1x3)

1.4 Write down the:

1.4.1 NAME or FORMULA of the inorganic reagent in

a. reaction **A** b. reaction **C** c. reaction **D** (1x 3)

1.5 Write down the NAME or FORMULA of the inorganic product(s) in

a. reaction **A,** if KOH is used as a reagent (1)

b. reaction **C,** if KOH is used as a reagent (1)

c. reaction **D** (1)

1.6 Write down the FORMULA of the catalyst used in reaction **B**. (1)

EXERCISE 2: ORGANIC REACTIONS

Consider the following compounds: **A:** CH_4 **B:** Ethanol C**:** Propanoic acid

2.1 Compound **A** reacts with unknown compound **X** in the presence of sunlight to produce bromomethane.

Write down a balanced equation for the reaction between:

2.1.1 compound **A** and **X** (3)

2.1.2 compound **A** with excess oxygen (3)

2.2 Compound **B** and **C** react in the presence of an inorganic acid.

Write down the:

2.2.1 name of the inorganic acid (1)

2.2.2 the equation for the reaction between **B** and **C,** using structural formulae for the organic reagents (1)

2.2.3 reaction condition (1)

EXERCISE 3: ORGANIC REACTIONS

3.1 A mixture of 4 grams of ethanol (C_2H_5OH) and 25 dm^3 of air is ignited at 25 ºC and standard pressure. A reaction occurs according to the balanced equation:

$$C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(g)$$

3.1.1Determine, with the aid of a calculation, whether all of Compound **D** will be used up at the end of the reaction, if the molar volume of a gas at 25 ºC and standard pressure is 24,47 dm^3. (5)

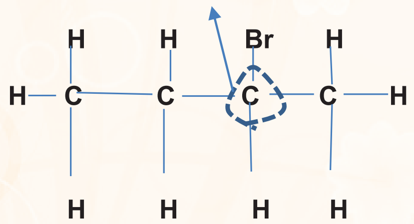
(ASSUME THAT AIR CONTAINS 21% OXYGEN (O_2).)

3.1.2 If the ethanol is not used up, calculate the mass in grams of ethanol that is not used. (3)

SOLUTIONS

EXERCISE 1: ORGANIC REACTIONS

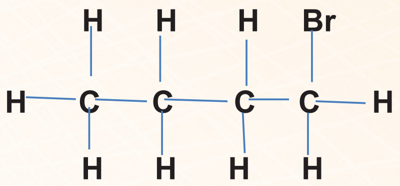
1.1 Secondary ***Carbon 2***



Look at Carbon 2 (middle one) bonded to ONE H; therefore SECONDARY

- ✓ If there were **TWO Hs** on the **Carbon bonded to** Br (carbon 2) then **PRIMARY.**
- ✓ If there were **NO Hs on Carbon 2,** then **TERTIARY.**

1.2 Change position of Br. (Change position of functional group, halogen or side chain to make a positional isomer.)



1.3.1 A Elimination OR Dehydrohalogenation

1.3.2 **C** Substitution or Hydrolysis

1.3.3 **D** Substitution

1.4.1 a. concentrated KOH

b. KOH or H_2O

c. HBr

1.5 a. NaBr + H_2O

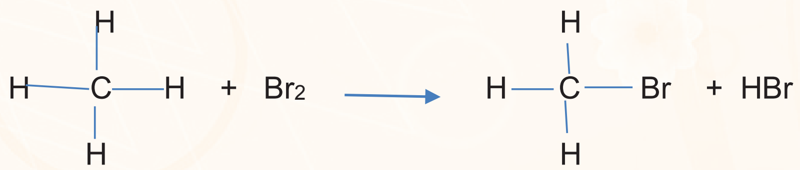
b. KBr

c. H_2O

1.6 **B** H_2SO_4

EXERCISE 2: ORGANIC REACTIONS

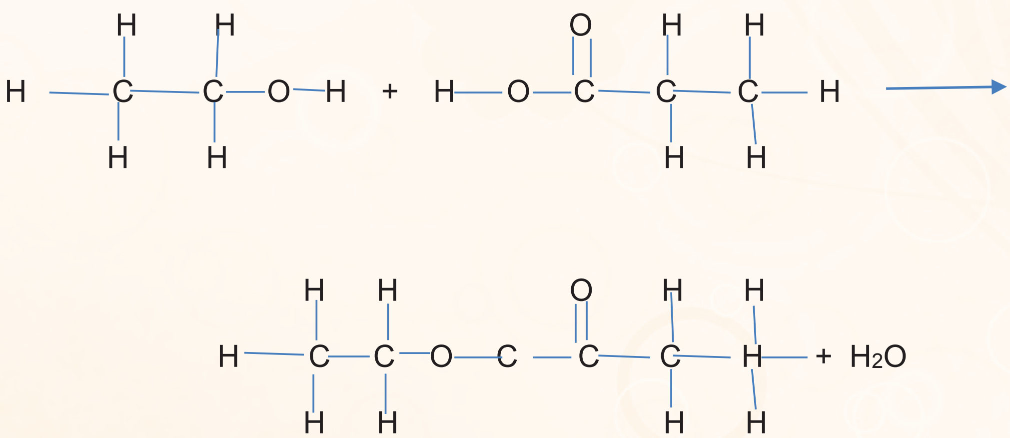
2.1.1



2.1.2 $CH_4 + 2\ O_2 \rightarrow 2CO_2 + H_2O$

2.2.1 Sulphuric acid

2.2.2



2.2.3 Heat mildly over a water bath.

EXERCISE 3: ORGANIC REACTIONS

3.1 $n_{ethanol}$ = m/M = 4/46 = 0.087 mol

V_{O_2} in 25 dm^3 of air = 21/100 x 25 = 5.25 dm^3

n_{O_2} = V/Vm = 5.25/24.47 = 0,215 mol

n ethanol = m/M = 4 /46 = 0.087

Ratio from equation Ethanol: Oxygen 1: 3

0.087 mol ethanol **too much** for 0.215 oxygen (Ratio 0.087:0.215 = 1:2,5 required ratio 1:3)

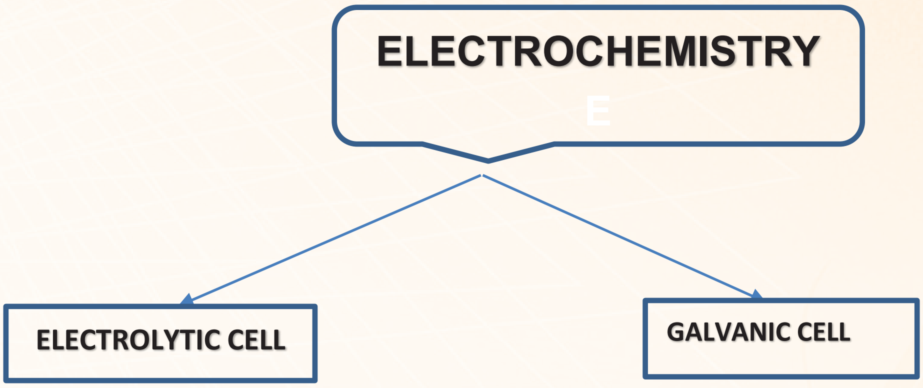
O_2 is the limiting reagent; Ethanol is in excess

3.2 $n_{ethanol}$ reacting = 1/3 x (0.215) = 0.072 mol

$n_{ethanol}$ in Excess = n initial – n final = 0.087 - .072 = 0.015 mol

m ethanol = nM= 0.015 x 46 = 0.69 g

14. ELECTROCHEMISTRY



DIFFERENCE BETWEEN ELECTROLYTIC AND GALVANIC CELLS	
Electrolytic Cell	**Galvanic Cell**
It requires a source of external energy	It is a source of energy.
It converts electrical energy into chemical energy	Converts chemical energy into electrical energy
Has cathode as the negative electrode	Has cathode as positive electrode
Has anode as the positive electrode	Has anode as negative electrode
Involves oxidation at anode and reduction at cathode	It involves oxidation at anode and reduction at cathode

ELECTROLYTIC CELLS (There are 5 electrolytic cells that you must understand.)

- Convert electrical energy to chemical energy.
  (Note there is **NO** mention of **MECHANICAL** energy in chemistry.)
- Reactions at electrodes are **ENDOTHERMIC** (reactions not self – sustaining.)
- In the diagram for electrolytic cell, there will be ONE CONTAINER and a power source or battery.

ELECTROLYSIS OF

concentrated $CuCl_2$(aq)

ELECTROLYSIS OF

saturated NaCl (aq)

ELECTROLYTIC CELL

EXTRACTION OF ALUMINIUM

Need for cryolite

(To lower melting poit saving on operational costs)

Reactions at electrodes

At CATHODE:

$Al^{3+} + 3e \rightarrow Al$

At ANODE: $C + O_2 \rightarrow CO_2$

ELECTROPLATING

The substance that is plated forms the CATHODE.

The electrolyte must have ions of the metal that are plated.

ELECTROREFINING of Copper

(Or Purification)

The substance that is refined forms the ANODE.

The electrolyte must contain ions of the metal that is refined.

ELECTROLYSIS

ELECTROLYSIS OF $CuCl_2$ and NaCl solutions

“Second part of formula” goes to anode for oxidation.

“First part” may go to cathode for reduction if it is a STRONGER OXIDISING agent.

Positive ion “First part of formula” may NOT be reduced at ALL but H_2O will undergo reduction if Positive ion (Metal ion) "First part of formula" is a weaker oxidising agent than H_2O e.g. in NaCl electrolysis **Na^+ DOES NOT** undergo **REDUCTION**

Take $CuCl_2$ (Cu^{2+} $C\ell^- C\ell^-$). The chloride ion Cl^- "Second part" always migrates

towards +ve ANODE (Positive attracted to negative) to undergo OXIDATION ($C\ell^-$ is the reducing agent)

Compare oxidising ability of Cu^{2+} the "first part" of the formula with that of water

H_2O in order to decide which species will undergo reduction (H_2O or Cu^{2+}).

Cu^{2+} is a stronger oxidising agent than H_2O therefore Cu^{2+} will undergo reduction

Consider electrolysis of NaCl (aq)

5.1 Write down the following:

5.1.1 oxidation half reaction

5.1.2 formula of the reducing agent

5.1.3 reduction half reactio5.1.4 formula of the oxidising agent

Approach:

5.1.1 Negative part of formula (second part) Cl^- goes to anode for oxidation

Therefore, Oxidation half reaction $2\ Cl^- \rightarrow Cl_2 + 2\ e$ (From table and reversed)

5.1.2 The reducing agent is found in the oxidation half reaction on left of arrow)

$$2\ Cl^- \rightarrow Cl_2 + 2\ e$$

Therefore Cl^-

5.1.3 Compare the oxidising ability of Na^+ with that of water H_2O.

H_2O is a stronger oxidising agent than Na^+, therefore H_2O undergoes reduction.

Therefore: $H_2O(l) + 2e \rightarrow H_2(g) + OH-$

5.1.4 The oxidising agent is at the left in the reduction half reaction

$$H_2O(l) + 2e \qquad H_2(g) + OH^-$$

Therefore: H_2O is the oxidising agent.

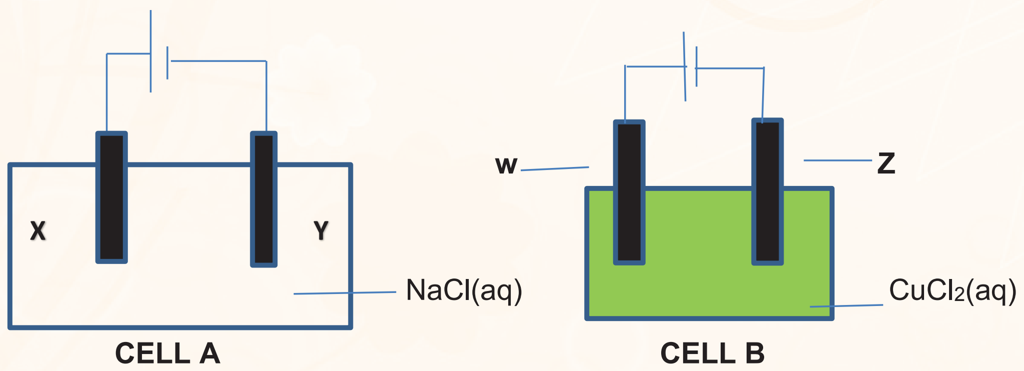
TIPS:

- You are NOT permitted to put double arrows in equations - always use ONE arrow.
- Reducing agent found on the left of arrow in OXIDATION half reaction
- The oxidising agent is ALWAYS on the left of the REDUCTION half reaction.
- There will be NO REACTION involving Na^+ but H_2O in electrolytic cells
- Know the properties of ANODE then know those of CATHODE as the opposite of anode
- Reverse the OXIDATION half reaction when taking it from the table
- Oxidising agents are bbon the FAR LEFT on TABLE of REDUCTION POTENTIALS
- Reducing agents immediately on the right of arrow when reading from left to right
- Smaller E_O value for ANODE
- Write the formula as it is given DATA SHEET e.g. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ (No abbreviations are acceptable, e.g. $E = E^o_{cat} - E^o_{an}$ - NO marks for this.) To get marks for the formula, **you must substitute** values, even if they are INCORRECT.
- In Chemistry, there is no MECHANICAL energy - only CHEMICAL energy

QUESTION 1

Consider the electrolytic cells **A** and **B** given below.

X, Y, W and Z are carbon electrodes.



1.1 Write down the:

a. energy conversion in these cells

b. the reason why a DC power source is used in place of an AC power source

1.2 Write down THREE observable changes in cell **B**.

1.3 Which electrode is the ANODE in:

1.3.1 Cell **A** 1.3.2 Cell **B**

1.4 Write down the half reaction taking place at electrode:

1.4.1 **X** and **W** 1.4.2 **Y** 1.4.3 **Z**

1.5 Write down the FORMULA and NAME of the reducing agent in cell:

1.5.1 **A** 1.5.2 **B**

1.6 Write down the FORMULA and NAME of the oxidising agent in cell:

1.6.1 **A** 1.6.2 **B**

1.7 Write down the name of the gas formed at:

1.7.1 electrode **X**

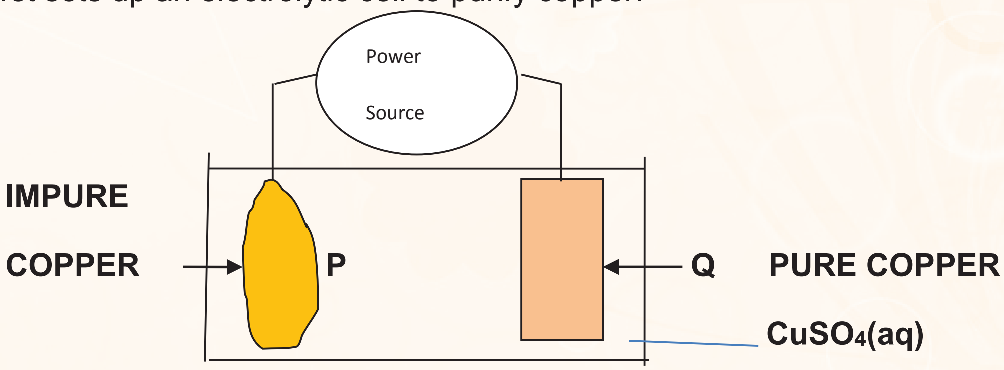
1.7.2 electrode **Y**

1.8 In cell **A,** the Na^{+} ions do not form sodium Na. Explain be referring to the strength of oxidising agents involved.

QUESTION 2

A chemist wants to determine the PERCENTAGE of copper by mass in an IMPURE copper sample containing platinum and silver as the only impurities.

He first sets up an electrolytic cell to purify copper.



2.1 Is electrode **P** the POSITIVE or NEGATIVE electrode? (1)

2.2 Which electrode (**P** or **Q**) will show an increase in mass? (1)

2.3 Write down the following:

2.3.1 The SYMBOL or NAME of the product formed at electrode **P**. (1)

2.3.2 The equation for the half reaction taking place at electrode **Q**. (2)

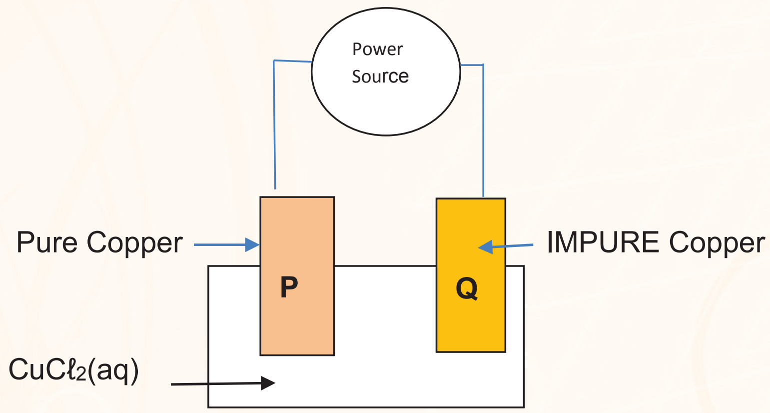
2.4 Use relative strengths of reducing agents involved to explain why the metals platinum and silver do not form ions during this process. (2)

[12]

QUESTION 3

The electrolytic cell below is used for electro refining (purification) an IMPURE copper sample.

Electrode **Q** contains copper, which contains 3% IMPURITIES by mass.



3.1 Write down the observable changes at the:

3.1.1 Anode 3.1.2 Cathode

3.2 Write down the half reaction taking place at the:

3.2.1 Anode 3.2.2 Cathode

3.3 $CuCl_2$ solution is light green.

How will the intensity of the colour of the solution change as the cell is working? Give a reason.

3.4 Calculate the mass of the IMPURE copper sample if 2 moles of electrons are transferred when ALL the copper is extracted from the IMPURE sample.

3.5 The IMPURE copper sample contains metals like silver. Explain why silver does undergo oxidation in this cell.

3.6 What happens to the electrolyte when the cell is in operation? Explain.

GALVANIC CELLS

Questions on galvanic cells may include:

- **DIAGRAM OF A GALVANIC CELL**
- **REACTION EQUATIONS (increase in oxidation number for ANODE)**
- **CELL NOTATION (Anode is on the left)**

KNOW THE PROPERTIES OF AN ANODE.

ANODE

OXIDATION OCCURS (ELECTRONS MOVE AWAY FROM THE ANODE)

SMALLER E^{o}-values

NEGATIVE ELECTRODE (CONNECTED TO NEGATIVE TERMINAL OF VOLTMETER)

DECREASE IN MASS

[POSITIVE IONS] INCREASE

ANIONS MOVE TOWARDS ANODE

OXIDATION NUMBER INCREASES

(Based on the notes above, you can deduce what happens at the CATHODE.

No need to memorise both.)

COMMON MISCONCEPTION

The CATHODE DOES NOT undergo REDUCTION.

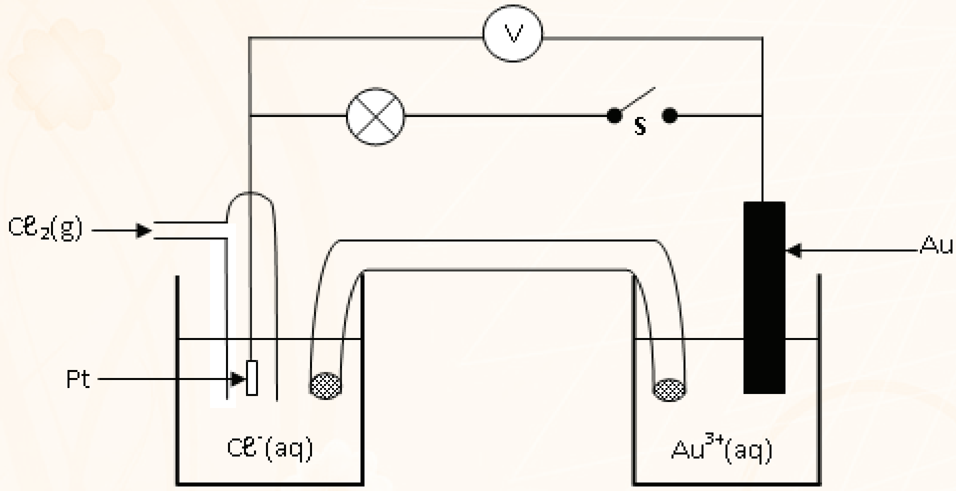
What undergoes reduction (i.e. oxidising agent) is an ION in solution at the CATHODE half cell.

QUESTION 4

STRUCTURED QUESTIONS

The diagram below shows a galvanic cell operating under standard conditions. The cell reaction taking place when the cell is functioning is:

$6C\ell^-(aq) + 2Au^{3+}(aq) \rightarrow 3C\ell_2(g) + 2Au(s)$



With switch **S** OPEN, the initial reading on the voltmeter is 0,14 V.

Write down the following:

4.1 The NAME or FORMULA of the oxidising agent. (1)

4.2 The half-reaction that takes place at the anode. (2)

4.3 The cell notation for this cell. (3)

4.4 Calculate the standard reduction potential of Au. (4)

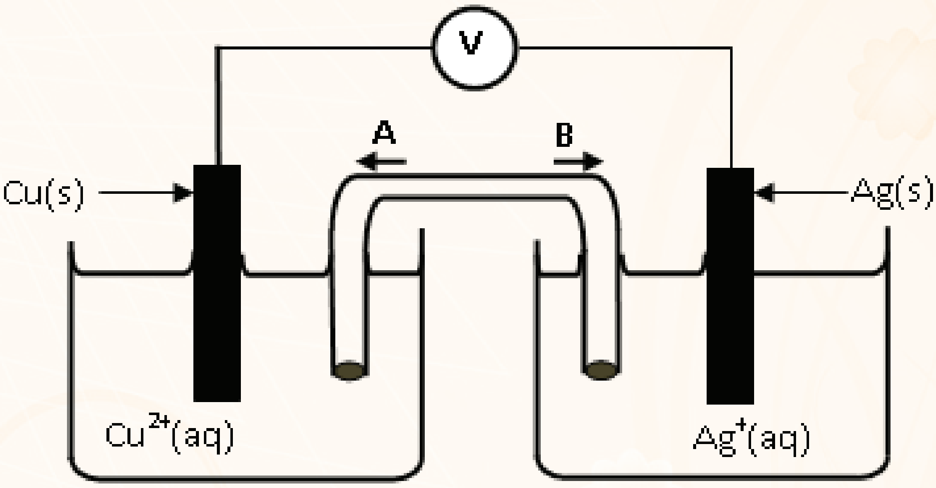
4.5 The concentration of the Au^{3+} is increased. How will this change affect the initial EMF of the cell. Write down INCREASES, DECREASES or REMAINS THE SAME. (1)

Switch **S** is now closed and the bulb lights up.

4.5 How will the reading on the voltmeter now compare to the INITIAL reading of 0,14 V? Write down only LARGER THAN, SMALLER THAN or EQUAL TO. Give a reason for your answer.

QUESTION 5

A learner sets up a galvanic cell as shown below. The cell functions under standard conditions. Nitrates are used as electrolytes.



5.1 Define the following terms:

5.1.1 Electrolyte (2)

5.1.2 Galvanic cell (2)

5.2 Write down the initial concentration of the Copper (II) nitrate ($Cu(NO_3)_2$ Solution. (1)

5.3 Calculate the mass of Copper (II) nitrate needed to prepare the solution if the volume of the solution is 250 cm^3. (4)

5.4 In which direction (**A** or **B**) will ANIONS move in the salt bridge? (1)

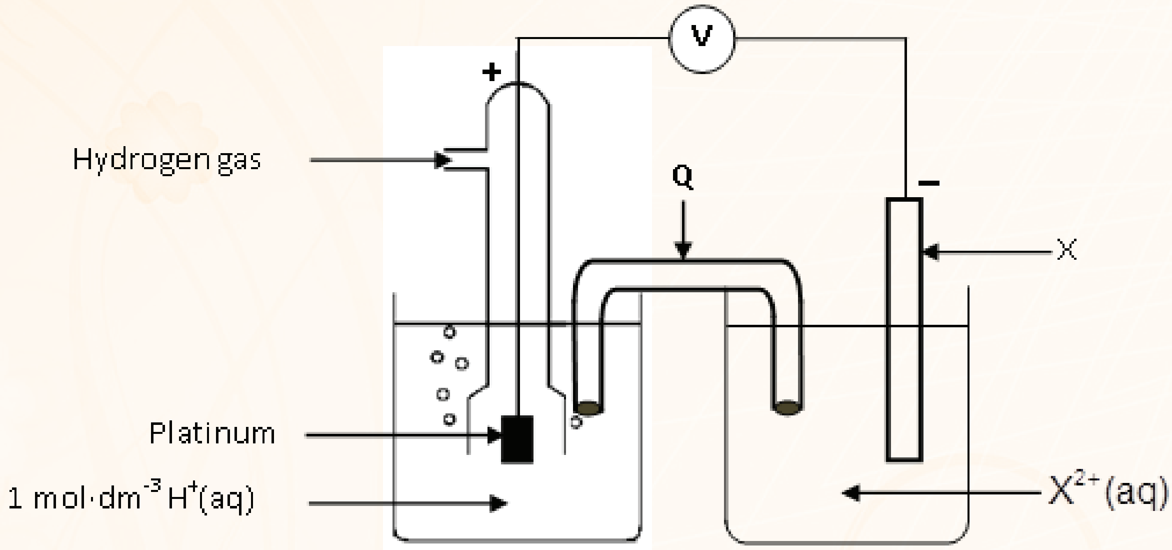
5.5 Calculate the emf of the above cell under standard conditions. (4)

5.6 Write down the balanced equation for the net cell reaction that takes place in this cell. (3)

5.7 Write down the cell notation for this cell. (3)

QUESTION 6

A standard electrochemical cell is set up using a standard hydrogen half-cell and a standard $X|X^{2+}$ half-cell, as shown below. The standard reduction potential of the $X|X^{2+}$ half-cell is - 0.74 V.



6.1 Write down the following:

6.1.1 The function of component **Q.** (1)

6.1.2 The initial reading on the voltmeter. (1)

6.1.3 The half-reaction that takes place at the cathode of this cell. (2)

6. 2 The hydrogen half-cell is now replaced by a **M**|**M**$^{2+}$ half-cell. The cell notation of this cell is: X(s)| X^{2+}(aq) || **M**$^{2+}$(aq) | **M**(s). The initial reading on the voltmeter is now 0.61 V.

6.2.1 Identify metal **M**. Show how you arrived at the answer. (5)

6.2.2 Is the cell reaction EXOTHERMIC or ENDOTHERMIC? (1)

6.3 The reading on the voltmeter becomes zero after using this cell for several hours. Give a reason for this reading by referring to the cell reaction. (1)

QUESTION 7

Consider the following reaction:

$Ce^{3+}(aq) + Ti(s) \longrightarrow Ti^{3+}(aq) + Ce(s)$

Standard electrode potentials are given in the table below.

Redox pair	Standard Electrode Potential
Ti^{3+}/Ti	-1.63 V
Ce^{3+}/Ce	-2.48 V

7.1 Determine by calculation if the reaction is spontaneous.

7.2 According to the data in the given table, which substance is the strongest reducing agent?

SOLUTIONS

ELECTROCHEMISTRY: GALVANIC AND ELECTROLYTIC CELLS

QUESTION 1

1.1 a. Chemical energy to electrical energy.
b. To ensure the polarities of the anode and cathode do not change.

1.2 Bubbles of chlorine gas at Z (Anode)
Brown coating on Y (Copper)
Intensity of blue colour decreases. (The concentration of Cu^{2+} decreases as Cu^{2+} reduced to Cu)

1.3.1 **X** | 1.3.2 **Z**

1.4.1 $2Cl^- \longrightarrow Cl_2 + 2e$ | 1.4.2 $2H_2O(l) + 2e \longrightarrow H_2O + OH^-$

1.5.1 Cl | 1.5.2 Cl-

1.6.1 H_2O | 1.6.2 Cu^{2+}

1.7.1 Chlorine | 1.7.2 hydrogen

1.8 H_2O is a stronger oxidising agent than Na^+. Therefore, H_2O is reduced.

QUESTION 2

2.1 POSITIVE

2.2 Q

2.3.1 Cu^{2+} or Copper (II) ions (From oxidation $Cu \rightarrow Cu^{2+} + 2e$)

2.3.2 $Cu^{2+} + 2e \rightarrow Cu$

2.4 Cu is a stronger reducing agent than both silver and platinum.

QUESTION 3

3.1.1 Mass decreases (ANODE) 3.1.2 Mass increases (CATHODE)

3.2.1 $Cu \rightarrow Cu^{2+} + 2e$ 3.2.2 $Cu^{2+} + 2e \rightarrow Cu$

3.3 n_{Cu} = ½ x 2 = 1 mol (Ratio of mol Cu : mol electrons 1:2)

M pure $_{Cu}$ = n .M = 1 x 63.5 = 63.5 g

Therefore: 97/100 x IMPURE Copper = Pure Copper (3% impurities; therefore

100% - 3% = 97% is pure copper)

3.4 Cu is a stronger reducing agent than Ag.

QUESTION 4

4.1 Au^{3+}

(From oxidation numbers Oxidation number of Au DECREASES from +3 to 0)

4.2 $2\,Cl^- \rightarrow Cl_2 + 2e$

4.3 Pt | Cl^- | Cl_2 || Au^{3+} | Au

4.4 INCREASE

4.5 SMALLER THAN

Lost volts due to internal resistance (when current flows through the cell).

QUESTION 5

5.1.1 Electrolyte – a solution or liquid that conducts electricity because it contains ions.

5.1.2 Galvanic cell: converts chemical energy to electrical energy.

5.2 $c = 1\ mol.dm^{-3}$ (standard conditions)

5.3 $m_{Cu} = ?$

$n_{Cu} = c.V = 1 \times 250/1000 = 0,25$ mol

$m_{Cu} = n.M = 0.25 \times 63.5 = 15.88$ g (15.875 g)

5.4 **A**

5.5 $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ (Formula)

$= 0.80 - 0.34$ (Substitution)

$= 0.46$ V (Answer with UNIT)

5.6 $Cu \rightarrow Cu^{2+} + 2e$

$Ag^+ + e \rightarrow Ag$ (Multiply by 2 to balance the number of electrons.)

$2\ Ag^+ + 2\ e \rightarrow 2\ Ag$

5.7 $Cu/Cu^{2+}//\ Ag^+/Ag$

QUESTION 6

6.1.1 Completes the circuit/ensures electrical neutrality of the solutions.

6.1.2 0,74 V (an use $E^o_{cell} = E^o_{cathode} - E^o_{anode} = 0 - (-0.74) = 0.74$ V

Remember: E^o_{cell} cannot be negative

6.1.3 $2\ H^+ + 2e \rightarrow H_2(g)$

6.2.1 **M** is the cathode (M is on the right-hand side in cell notation.)

$E^o_{cell} = E^o_{cathode} - E^o_{anode}$

$0.61 = E^o_{cathode} - (-0.74)$

$0.61 = E^o_{cathode} + 0.74$

$0.61 - 0.74 = E^o_{cathode}$

-0.31 V $= E^o_{cathode}$ **M** is Pb

QUESTION 7

7.1 According to the equation, Ce is the CATHODE

(Reason: Oxidation number decreases from +3 to 0; **OR**

Ti is the ANODE - Oxidation number increases from 0 to +3.)

Approach:

Calculate EMF. If **EMF is POSITIVE** it means Reaction is **SPONTANEOUS**

$E^o_{cell} = E^o_{cathode} - E^o_{anode}$

$E^o_{cell} = -2.48 - (-1.63)$

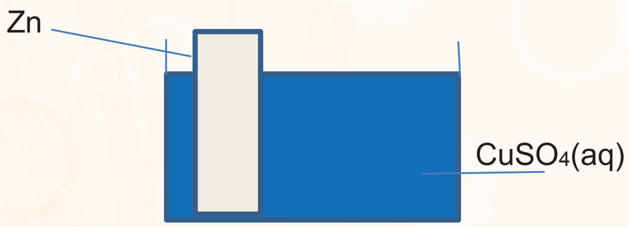
$= -0.85$ V

Reaction NOT SPONTANEOUS, E^o_{cell} is NEGATIVE

7.2 Ce

INDIRECT TRANSFER OF ELECTRONS

e. g. A zinc rod is placed in a copper(II) sulphate solution, as shown below.



EXAMPLE 1

Write down THREE observable changes that will occur.

1.1 Write down the:
- 1.1.1 oxidation half reaction
- 1.1.2 reduction half reaction
- 1.1.3 name of the oxidising agent
- 1.1.4 name of the reducing agent

1.1 Oxidation half: $Zn \rightarrow Zn^{2+} + 2e$

1.2 Reduction half reaction: $Cu^{2+} + 2e \longrightarrow Cu$

1.3 Oxidising agent (on the left of the Reduction half reaction)

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

Oxidising agent: Cu^{2+}

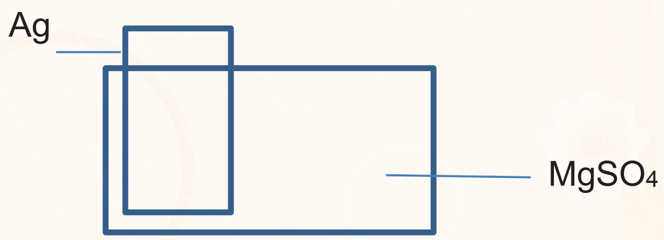
1.4 Reducing agent (on the left of the Oxidation half reaction)

$Zn \longrightarrow Zn^{2+} + 2e$

Zn is the Reducing agent

NOTE: If the reducing ability of the METAL is lower than that of the metal of the positive ion in solution, no reaction will occur.

EXAMPLE 2: A piece of silver is placed in magnesium sulphate, e.g.:



2.1 Will a spontaneous reaction occur?

2.2 Can we store a magnesium sulphate solution in a container made of silver, without the container leaking? Explain.

Approach: Consult the Table of Reduction potentials.

Extract form Table 4B

Li - strongest reducing agent

REDUCING AGENTS

OXIDISING AGENTS

Li^+	+	e	⇌	Li
…………				
…………				
Ba^{2+}	+	2e	⇌	Ba
…………				
…………				
Mg^{2+}	+	2e	⇌	Mg
…………				
…………				
…………				
Cu^{2+}	+	2e	⇌	Cu
…………				
…………				
Ag^+	+	e	⇌	Ag
…………				
Cl_2 (g)	+	2e	⇌	$2Cl^-$
F_2(g)	+	2e	⇌	$2F^-$

F_2 - strongest oxidising agent

RULE: Top right reduces bottom left.

Consider example 1 above:

$Zn + CuSO_4 \longrightarrow$

Find Zn and Cu^{2+} in the table.

Remember Zn is the reducing agent in Example 1.

$Zn^{2+} + 2e \rightleftharpoons Zn$

$Cu^{2+} + 2e \rightleftharpoons Cu$

Zn is a stronger reducing agent than Cu.

Zn reduces Cu^{2+} to Cu.

Example 2:

If a reaction occurs, Ag will be the reducing agent. (It is the METAL.)

Mg^{2+} + 2e ⇌ Mg

THIS CAN NOT TAKE PLACE SPONTANEOUSLY.

Ag^+ + e ⇌ Ag

In Example 2:

2.1 There will be NO reaction.

Reason: Ag is a weaker reducing agent than Mg.

Ag cannot reduce Mg^{2+} to Mg

2.2 To be able to store a solution in a container, the SOLUTION AND THE METAL USED IN THE CONTAINER MUST NOT REACT.

Yes, we can store $MgSO_4$ in Ag container.

Reason:

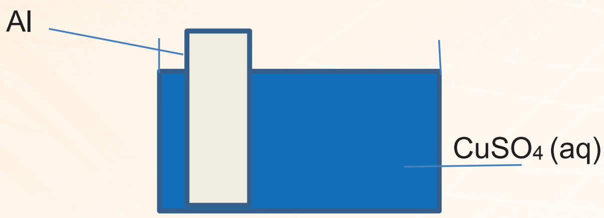
Reaction will not occur spontaneously, as Ag is a weaker reducing agent than Mg. Ag cannot reduce Mg^{2+} to Mg

The table of reduction potentials only gives values of redox reactions under standard conditions. This means that if the experiment is carried out when the conditions are not standard, we cannot rely on the usual equation to give us the. We will need a different type of equation called the Nernst Equation. The Nernst equation however is not prescribed in our current curriculum. Our calculations should therefore confine themselves to Standard Conditions only.

PRACTICE QUESTIONS

QUESTION 1

An aluminium rod is placed in a copper (II) sulphate solution as shown below.



EXAMPLE 1

1.1 Write down THREE observable changes that will occur.

1.2 Write down the following:

1.2.1 oxidation half reaction

1.2.2 reduction half reaction

1.2.3 name of the oxidising agent

1.2.4 name of the reducing agent

EXAMPLE 2

2.1 Can we store:

2.1.1 $CuSO_4$ in a container made of silver metal? Explain.

2.1.2 $MgSO_4$ in a container made of zinc? Explain.

2.1.3 $AgNO_3$ in a container made of copper?

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Published in 2017 by the Department of Basic Education

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