Physical Sciences

CLASS TEXT & STUDY GUIDE

Retha Louw

GRADE

12

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2014 publication | 2022 edition | ISBN: 978-1-920568-74-0

091123 | NOVUS

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THE GRADE 12 NOVEMBER EXAM

Paper	**Content**	**Marks**	**Total marks per paper**	**Duration (hours)**	**Weighting of questions across cognitive levels**			
					Level 1	**Level 2**	**Level 3**	**Level 4**
Paper 1: Physics focus	**Mechanics (Module 1)**	65	150	3	15%	35%	40%	10%
	Waves, Sound and Light (Module 3)	15						
	Electricity and Magnetism (Module 5)	55						
	Matter and Materials (Module 2)	15						
Paper 2: Chemistry focus	**Chemical Change (Module 4)**	92	150	3	15%	40%	35%	10%
	***Chemical Systems (Module 6)**	0						
	Matter and Materials (Module 2)	58						

* ***NOTE:*** *From 2021, '**Chemical Systems**', until further notice, will not be examined.*

SKILLS
REQUIRED FOR PHYSICAL SCIENCES

Science as a field of study evolved from our human need to better understand and explain the world in which we live. Physical Sciences is divided into two disciplines, namely Physics and Chemistry. Physics deals mainly with the study of the laws of the Universe. Chemistry deals with the study of matter and materials.

In both disciplines it is necessary to do scientific investigations, solve problems and present findings.

MATHEMATICS SKILLS REQUIRED FOR PRACTICAL INVESTIGATIONS

Mathematics plays a very important role in this process. Mathematics skills include scientific notation, unit conversions, using formulae, ratios and proportions, and trigonometry.

Scientific notation

- In science we often work with very small and very large numbers; from the mass of an atom to the radius of the earth.
- In scientific notation, a number is expressed as a product of two numbers, i.e.:

coefficient: $1 \leq N < 10$ — $\boxed{N \times 10^n}$ — any integer

base 10

For example: $2,57 \times 10^{-3}$; $-1,09 \times 10^4$

- ***N** is any number from 1 to 9,999... (we refer to it as the coefficient of 10^n).*
- ***n** is any integer, so 10^n represents a power of 10, e.g. 10^{-12}, 10^{-5}, 10^0, 10^9, 10^{29} etc.*
- *Negative numbers get a negative sign (–) before scientific notation.*

Conversion of ordinary numbers to scientific notation

- Move the comma until there is only one place (digit) before the comma.
- If the comma has to move **n** places to the **left**, then the notation is: $N \times 10^{+n}$
- If the comma has to move **n** places to the **right**, then the notation is: $N \times 10^{-n}$

Therefore, a very large number has a positive exponent and a very small number has a negative exponent.

For example:

move comma 4 places to the left
positive exponent

$25789,4 = 2,57894 \times 10^4$

OR $0,000257894... = 2,57894 \times 10^{-4}$

move comma 4 places to the right
negative exponent

Examples

Convert the following numbers to scientific notation:

1) 2 000,40

2) 0,0000000789

Solutions

1) $2,0004 \times 10^3$ *positive exponent*

2) $7,89 \times 10^{-8}$ *negative exponent*

FORCE AND FREE-BODY DIAGRAMS

Both force and free-body diagrams indicate the relative magnitudes and directions of all the forces that act on a single object.

Force diagram

The object/s of interest are drawn and all the forces to and from the object are indicated by arrows. The force arrows point in the direction of the force:

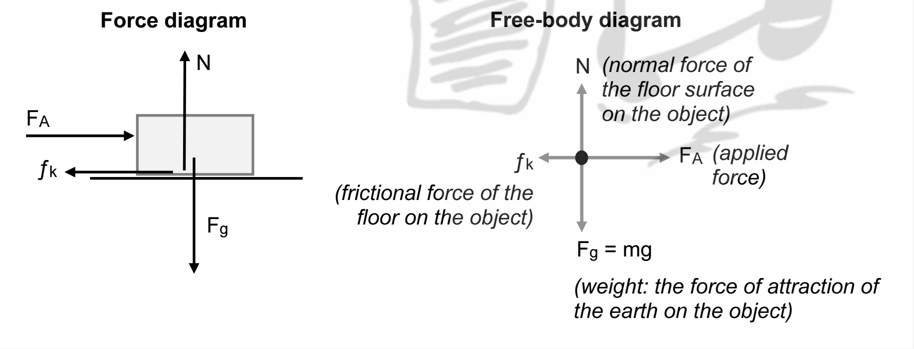
- A pull force or brake force, e.g. frictional force, usually originates on the object and points away from it.
- An external push force usually originates elsewhere and ends on the object.

Free-body diagram

The object is represented by a dot and all the forces that act on the object are indicated by arrows pointing away from the dot.

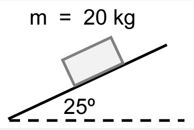
Example 1:

A pushing force F_A is exerted to the right on an object with a mass m. The object experiences a frictional force f_k while it accelerates to the right along the floor.



NB: *The length of the arrows is an indication of the magnitude of the force. Therefore, in this case* $N = F_g$ *and* $f_k < F_A$.

Example 2:



A crate with a mass of 20 kg is at rest on an inclined plane that forms an angle of 25º to the horizontal.

2.1 Draw a free-body diagram and show all the forces exerted on the object.

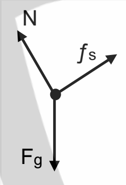
2.2 Calculate the components of the weight of the crate parallel to the plane and perpendicular to the plane.

2.3 Suppose the coefficient of static friction between the surfaces of the crate and the slope is 0,5. Determine the angle of inclination that results in a maximum static frictional force.

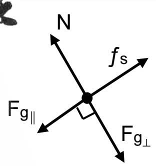
2.4 What is the maximum static frictional force?

Solution:

2.1



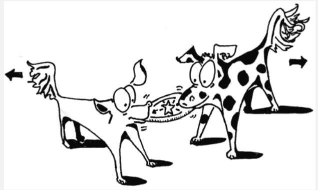
Draw this option when the question asks for forces and components of forces parallel and perpendicular to the plane:



2.2 $F_{g\parallel} = F_g \sin\theta$
$= mg \sin\theta$
$= (20)(9{,}8) \sin 25^\circ$
$= 82{,}83$ N

$F_{g\perp} = F_g \cos\theta$
$= mg \cos\theta$
$= (20)(9{,}8) \cos 25^\circ$
$= 177{,}64$ N

2.3 $\tan\theta = \mu_s$
$= 0{,}5$
$\theta = \tan^{-1}(0{,}5) = 26{,}57^\circ$

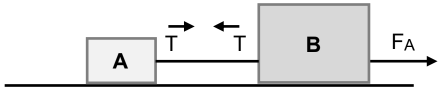


2.4 $f_s^{max} = \mu_s N$
$= \mu_s F_{g\perp}$
$= \mu_s mg \cos\theta$
$= (0{,}5)(20)(9{,}8) \cos 26{,}57^\circ$
$= 87{,}65$ N

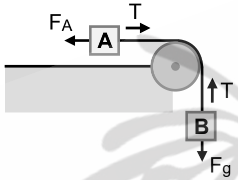
Take note: The terms ***free-body sketch*** *and* ***free-force diagram*** *are sometimes used and refer to a* ***free-body diagram****.*

Problems involving two-body systems (joined by a light, inelastic rope)

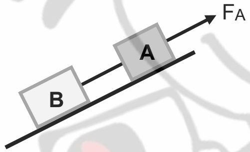
- Consider a system of two bodies that are in contact or connected to each other and move or accelerate together, for example:
  - **Both bodies A and B are on a flat horizontal plane, with or without friction.**



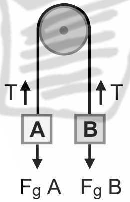
  - **One body A on a horizontal plane, with or without friction, and a second body B, hanging vertically from a string over a frictionless pulley.**



  - **Both bodies A and B are on an inclined plane, with or without friction.**



  - **Both bodies A and B are hanging vertically from a string over a frictionless pulley.**



- Identify the forces on each of the bodies:
  - If a pull force F_A is exerted on B (or A), the string tightens and a tensile force T is present at both ends of the string.
  - A and B experience an equal tensile force (T) in opposite directions.
  - While the length of the string between them is constant, they have the same acceleration.
  - The gravitational force on objects moving vertically forms part of F_{net} and accelerates the system.

Application: Steps in problem-solving

❶ Draw a force or free-body diagram for each of the objects.

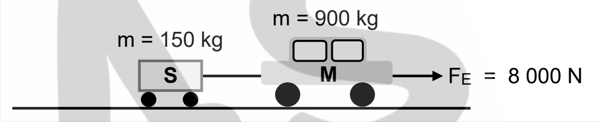
❷ Determine $\mathbf{F_{net}}$ for each object.

❸ State a separate equation, $\mathbf{F_{net} = ma}$, for both objects. (Remember, **a** is the same for both.)

❹ If both the acceleration **a** and one of the forces are unknown, **a** can be calculated by simultaneous solving of the equations.

❺ Substitute **a** back into one of the equations to calculate the contact force between the objects or the tensile force in the string.

Example:

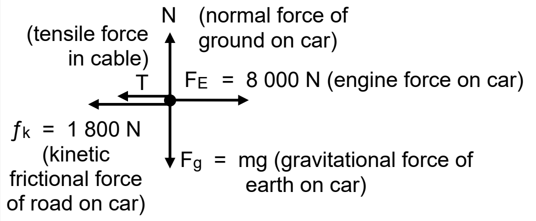


A motor car M, with a mass of 900 kg, pulls a trailer S, with a mass of 150 kg, over a level road in an easterly direction. The engine of the car exerts a force F_E of 8 000 N. The frictional force of the car is 1 800 N and that of the trailer is 300 N.

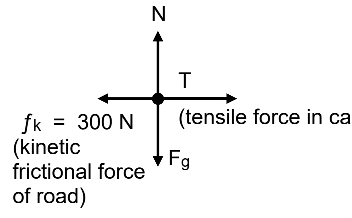
1. Draw separate free-body diagrams for the car and the trailer and clearly label all forces.
2. Determine the acceleration that the system experiences (to 2 decimal places).
3. Determine the tensile force in the cable that connects the car and the trailer.

Solution:

1. **Motor car:**



Trailer:



T = magnitude of tensile force in cable; indicate direction with correct sign.

Law of Conservation of Momentum

If no net external force acts on an object or system, the total linear momentum will not change, i.e. in an isolated system the total momentum before a collision or explosion = the total momentum after the collision or explosion.

Law of Conservation of Momentum:
The total **linear** momentum in an isolated system is constant in magnitude and direction.

In symbols:

$$\textbf{total } p_{\text{initial}} = \textbf{total } p_{\text{final}}$$

❶ **When objects collide and then move away from each other, e.g. snooker balls.**

$$\Sigma p_{\text{initial}} = \Sigma p_{\text{final}}$$

$$\therefore\ p_{i1} + p_{i2} = p_{f1} + p_{f2}$$

$$\therefore\ m_1v_{i1} + m_2v_{i2} = m_1v_{f1} + m_2v_{f2}$$

1 = object 1
2 = object 2

m_1 and m_2 are the masses of objects
v_{i1} and v_{i2} = initial velociy of m_1 and m_2 respectively
v_{f1} and v_{f2} = final velocity of m_1 and m_2 respectively

❷ **When objects collide and remain attached to each other and move as a unit after the collision, e.g. cars that couple or join on collision:**

$$\Sigma p_{\text{initial}} = \Sigma p_{\text{final}}$$

$$\therefore\ p_{i1} + p_{i2} = p_{f(1+2)}$$

$$\therefore\ m_1v_{i1} + m_2v_{i2} = (m_1 + m_2)v_f$$

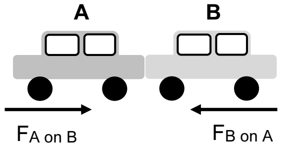
NB: *In collisions from behind, the initial velocities have the same direction. In head-on collisions, the directions and thus the signs of the initial velocities and momentums are opposite.*

Why is momentum conserved in an isolated system?

If two objects collide or an explosion occurs and pushes them apart, equal forces in opposite directions act on each body (Newton III). The time interval (Δt) is the same for both and thus also the change in momentum (Δp) (in opposite directions).

1. **Collision**

Two cars collide:



$$\text{force on A} = -\text{force on B}$$

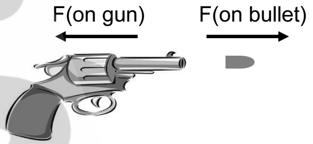
$$\therefore\ \Delta p \text{ for A} = -\Delta p \text{ for B}$$

$$\therefore\ p_{A\,(\text{final})} - p_{A\,(\text{initial})} = -(p_{B\,(\text{final})} - p_{B\,(\text{initial})})$$

$$\therefore\ p_{A\,(\text{initial})} + p_{B\,(\text{initial})} = p_{A\,(\text{final})} + p_{B\,(\text{final})}$$

2. **Explosion**

A gun fires a bullet:



$$\text{force on gun} = -\text{force on bullet}$$

$$\Delta p_{(\text{gun})} = -\Delta p_{(\text{bullet})}$$

$$\therefore\ p_{g\,(\text{final})} - p_{g\,(\text{initial})} = -(p_{b\,(\text{final})} - p_{b\,(\text{initial})})$$

$$\therefore\ p_{g\,(\text{final})} - 0 = -(p_{b\,(\text{final})} - 0) \quad \text{(initially both at rest)}$$

$$\therefore\ p_{g\,(\text{final})} = -p_{b\,(\text{final})}$$

$$\therefore\ p_{b\,(\text{final})} + p_{g\,(\text{final})} = 0$$

Elastic and Inelastic collisions

A collision is considered **elastic** if the total kinetic energy of the objects in the system during the collision is conserved, i.e. $\Sigma E_{k\,\text{initial}} = \Sigma E_{k\,\text{final}}$. Otherwise it is an **inelastic** collision.

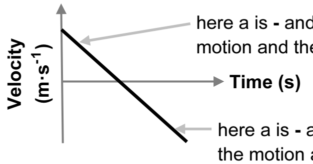
Kinetic energy (E_k) is the energy an object has because it is in motion.

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

[m = mass (kg) ; v = velocity ($m\cdot s^{-1}$)]

✱ A negative gradient does not always mean that the velocity decreases. It actually indicates the direction of the acceleration, namely the direction that was chosen negative.

Velocity-time



here a is - and v + ∴ acceleration is opposite to the direction of motion and the magnitude of the object's velocity decreases

here a is - and v - ∴ acceleration is in the same direction as the motion and the magnitude of the object's velocity increases

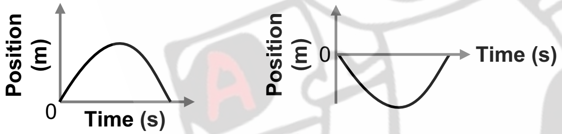
Take note of the following:

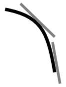
Position-time graph

The position-time graph for an upward and downward projectile motion has a parabolic shape. The position/displacement of the object is a function of time and can be calculated by means of the quadratic equation:

$$f(\Delta t) = \frac{1}{2}g\Delta t^2 + v_i\,\Delta t \qquad \therefore\ \Delta y = v_i\,\Delta t + \frac{1}{2}g\Delta t^2$$

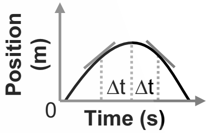
parabolic shape with the equation f(x) = ax^2 + bx + c



- The zero position is the reference point relative to which the object moves, e.g. the ground, the top of a building, etc.
- If the graph moves further away from the reference point (zero position), the displacement increases, and if it moves closer to the reference point, the displacement decreases.
- The gradient of the tangent to the graph at any point gives the instantaneous velocity of the object at that moment:
  -  A decreasing gradient shows that the velocity is busy decreasing, e.g. during upward motion.
  -  An increasing gradient shows that the velocity is busy increasing, e.g. during downward motion.

▶▶

- At the same time interval Δt on either side of the turning point, the instantaneous velocity is the same, but in the opposite direction. (The gradients of the tangents are equal in magnitude, but have opposite signs.)



- At the turning point, the gradient of the tangent is zero and the instantaneous velocity is zero. The object now changes direction. 

❶ Object falls downwards to/from the reference point

Ground as reference point

Starting position as reference point

B - object is at a position above the ground and starts falling (initial velocity = 0 if gradient at B = 0)

C - object moves closer to/away from the reference point with an increasing gradient, i.e. the velocity increases. (For example: ball is moving ever faster down towards the ground.)

❷ Object is projected upwards and returns to the initial position

starting position (ground) as reference point

A - object moves further away from the reference point with a decreasing gradient, i.e. the velocity decreases. (For example: ball is moving slower and slower upwards in the air.)

B - object is at the turning point, gradient and instantaneous velocity = 0; object is the furthest from the reference point.

C - object is moving closer to the reference point with an increasing gradient and velocity.

▶▶

1.3 Determine the value of x.

1.4 Describe the motion of the ball for sections AB and CD of the graph.

1.5 Draw the corresponding position-time graph of the motion of the ball.

PROJECTILE MOTION

❶ Definitions

- **Free fall**
- **Gravitational acceleration** ($g = 9{,}8\ m \cdot s^{-2}$ downward)
- **Projectile**

❷ Downward ↓

❸ Up- and downward; back to starting position

❹ Up- and downward; past starting position

❺ Bouncing ball

- dropped/thrown vertically downward **or** thrown upward; bounces on the ground several times
- each bounce is:
  - an inelastic collision
  - a separate projectile motion

Describe (in words)

- constant acceleration i.e. $g = 9{,}8\ m \cdot s^{-2}$ downward
- **for ↑ motion:** velocity decreases to $0\ m \cdot s^{-1}$ at turning point
- **for ↓ motion:** velocity increases up to a maximum when it hits the ground

Calculate

Choose direction, e.g. ↑+ and ↓-

- Use **equations of motion** and calculate, for example:
  - maximum **height** reached
  - height above ground from which object is projected
  - **time taken** to maximum height **or** until ground is reached

Graphs

- position/displacement-time (Δy-t)
- velocity-time (v-t)
- acceleration-time (a-t)

Calculations: (v-t graph)

- gradient (m) = a = $\frac{\Delta v}{\Delta t}$
- area under graph = displacement

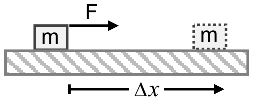
WORK, ENERGY AND POWER

- Our everyday view of the concept 'work performed/done' differs from the scientific view. Normally, we would see any form of physical effort as work. According to the scientific definition of work, work is only performed **when a force acts on an object and the object is displaced in the direction of the force / component of the force** ($F_{net} \neq 0$; $\Delta x \neq 0$).
- When a constant net force acts on an object, the object is accelerated and its velocity will increase or decrease uniformly (Newton II).
- Therefore, the velocity and kinetic energy of such an object changes when work is done on it by an unbalanced net force.
- From this, it is clear that there is a link between the work done on an object and the change in kinetic energy of the object.
- Work done on an object can thus result in an increase or decrease in the energy of the object. The **work-energy theorem** shows the relationship between the net work and change in kinetic energy of an object *(see p. 51).*

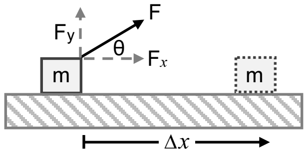
WORK

- Consider the following situations:

❶ A **force** (**F**) acts on the object and the object is **displaced** across a distance (Δx) in the direction of the force.



❷ A force (F) acts on an object and forms an angle to the direction of the displacement Δx:



In case ❶, the full force F is responsible for the displacement of the object. In case ❷, the **horizontal (parallel) component** of the force (**F_x**) causes the displacement (Δx) of the object parallel to the plane. The **vertical (perpendicular) component (F_y)** in this case only tends to slightly lift the object.

Alkenes $>C=C<$ and Alkynes $-C\equiv C-$

Structure

- Alkenes and alkynes are unsaturated hydrocarbons. Alkenes have at least one double bond (═) and alkynes at least one triple bond (≡) in their structure.
- The double or triple bond forms the functional group. These bonds are electron rich, so they are the position in the compound where a reaction with other substances can take place. During the reaction, the bond breaks and more atoms can attach to the molecule to form a more saturated product.

Alkenes

- The general formula of the alkenes is C_nH_{2n}.
- The suffix of the alkenes is **-ene**.
- The first seven alkenes are:

Number of C atoms	Alkene	Molecular formula
2	ethene	C_2H_4
3	propene	C_3H_6
4	butene	C_4H_8
5	pentene	C_5H_{10}
6	hexene	C_6H_{12}
7	heptene	C_7H_{14}
8	octene	C_8H_{16}

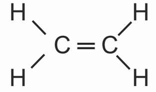
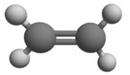
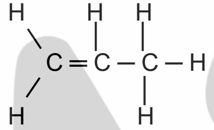
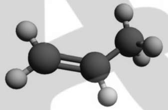
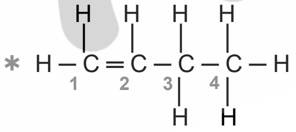
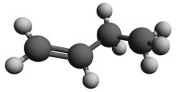
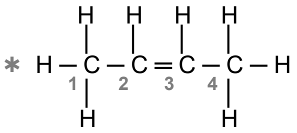
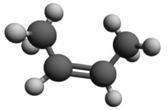
Alkynes

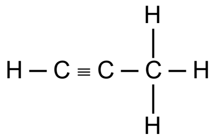
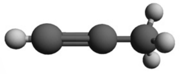
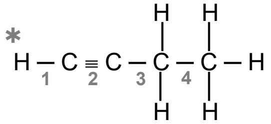
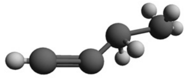
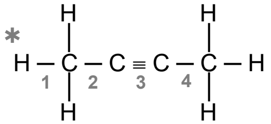
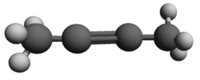
- The general formula of the alkynes is C_nH_{2n-2}.
- The suffix of the alkynes is **-yne**.
- The first seven alkynes are:

Number of C atoms	Alkyne	Molecular formula
2	ethyne	C_2H_2
3	propyne	C_3H_4
4	butyne	C_4H_6
5	pentyne	C_5H_8
6	hexyne	C_6H_{10}
7	heptyne	C_7H_{12}
8	octyne	C_8H_{14}

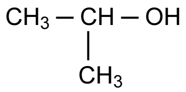
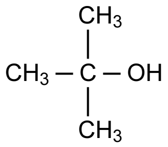
NB: *The simplest alkene and alkyne has a minimum of 2 C atoms.*

- The structural formulae, condensed structural formulae and spatial structures of the first three alkenes and alkynes follow.

Alkenes (general formula C_nH_{2n})	
Name	**Formulae**
ethene **(C_2H_4)**	 **OR** $CH_2=CH_2$ 
propene **(C_3H_6)**	 **OR** $CH_2=CH-CH_3$ 
but-1-ene **(C_4H_8)** **OR**	 * $\mathrm{H-\overset{H}{\underset{1}{C}}=\overset{H}{\underset{2}{C}}-\overset{H}{\underset{3\;H}{C}}-\overset{H}{\underset{4\;H}{C}}-H}$ **OR** $CH_2=CH-CH_2-CH_3$ 
but-2-ene **(C_4H_8)**	 * $\mathrm{H-\overset{H}{\underset{1\;H}{C}}-\overset{H}{\underset{2}{C}}=\overset{H}{\underset{3}{C}}-\overset{H}{\underset{4\;H}{C}}-H}$ **OR** $CH_3-CH=CH-CH_3$ 

Alkynes (general formula C_nH_{2n-2})	
Name	**Formulae**
ethyne **(C_2H_2)**	$H-C\equiv C-H$ **OR** $CH\equiv CH$ 
propyne **(C_3H_4)**	 $\mathrm{H-C\equiv C-\overset{H}{\underset{H}{C}}-H}$ **OR** $CH\equiv C-CH_3$ 
but-1-yne **(C_4H_6)** **OR**	 * $\mathrm{H\underset{1}{-}C\underset{2}{\equiv}C\underset{3}{-}\overset{H}{\underset{H}{C}}\underset{4}{-}\overset{H}{\underset{H}{C}}-H}$ **OR** $CH\equiv C-CH_2-CH_3$ 
but-2-yne **(C_4H_6)**	 * $\mathrm{H-\overset{H}{\underset{H}{C}}\underset{1}{}\underset{2}{-}C\underset{3}{\equiv}C\underset{4}{-}\overset{H}{\underset{H}{C}}-H}$ **OR** $CH_3-C\equiv C-CH_3$ 

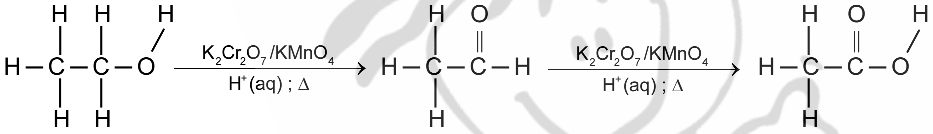
✱ *Butene and butyne both have two different structural isomers as a result of the possible positions of the* ═ *and* ≡ *bonds (see the section on structural isomers p. 80).*

Primary alcohol	Secondary alcohol	Tertiary alcohol
$CH_3-CH_2-CH_2OH$ propan-1-ol	 $CH_3-\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-OH$ propan-2-ol	 $CH_3-\overset{\displaystyle CH_3}{\overset{\vert}{\underset{\displaystyle CH_3}{\underset{\vert}{C}}}}-OH$ 2-methylpropan-2-ol

Additional information (optional)

Oxidation of primary alcohols

Primary alcohols can take part in a redox reaction with a strong oxidising agent such as an acidic aqueous potassium dichromate ($K_2Cr_2O_7$) or potassium permanganate ($KMnO_4$) solution to form an aldehyde. Heating the aldehyde can result in further oxidation to form the corresponding carboxylic acid:



ethanol ⟶ (- 2H) ⟶ ethanal ⟶ (+ O) ⟶ ethanoic acid

The above reaction also shows why wine that has been left standing open becomes sour after a while.

Reaction conditions: Use an acidified oxidising agent, e.g. $K_2Cr_2O_7/KMnO_4$, and heat the reaction mixture.

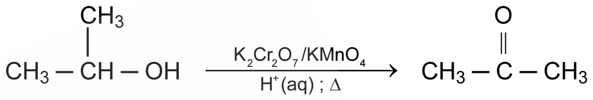
Did you know?

- *The reaction in which orange dichromate ions ($Cr_2O_7^{2-}$) are reduced to green chromium ions (Cr^{3+}) in the presence of alcohol is used in breathalyzers, the devices used to test motorists for drinking and driving.*
- *Ethanol (in alcoholic beverages) is absorbed very quickly into the bloodstream. High levels of alcohol in the bloodstream (harmful to the brain) are reduced by the liver enzyme alcohol dehydrogenase (ADH). ADH oxidises ethanol to ethanal and then to non-toxic ethanoic acid. The liver can only remove a limited quantity of pure alcohol per hour.*

▶▶

Oxidation of secondary alcohols

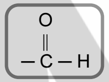
A secondary alcohol is similarly oxidised in reaction with an acidified $Cr_2O_7^{2-}$ or MnO_4^- solution to form a ketone.


$$CH_3-\overset{\displaystyle CH_3}{\overset{\vert}{CH}}-OH \xrightarrow[H^+(aq)\ ;\ \Delta]{K_2Cr_2O_7/KMnO_4} CH_3-\overset{\displaystyle O}{\overset{\Vert}{C}}-CH_3$$

propan-2-ol (- 2H) propan-2-one

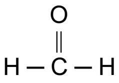
Reaction conditions: Use an acidified oxidising agent, e.g. $K_2Cr_2O_7$ / $KMnO_4$ and heat reaction mixture.

Aldehydes


$-\overset{\displaystyle O}{\overset{\Vert}{C}}-H$

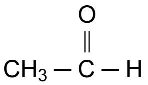
Structure

- Aldehydes are compounds containing a formyl group (carbonyl group with at least 1 H atom on the same C atom).
- The general formula for aldehydes is $C_nH_{2n}O$.
- The suffix of the aldehydes is **-al**.
- Aldehydes are formed during the oxidation of alcohols.
- The first three aldehydes are:

1)  $H-\overset{\displaystyle O}{\overset{\Vert}{C}}-H$ or HCHO

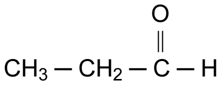
methanal (formaldehyde)

Aqueous solutions of formaldehyde, known as formalin, are used in laboratories as a preservative for biological specimens.

2)  $CH_3-\overset{\displaystyle O}{\overset{\Vert}{C}}-H$ or CH_3-CHO

ethanal (acetaldehyde)

Acetaldehyde is found in abundance in nature e.g. in foodstuffs such as coffee, bread, ripe fruit etc. It forms by the oxidation of alcohol and is responsible for the nausea and headache experienced after an excess intake of alcohol.

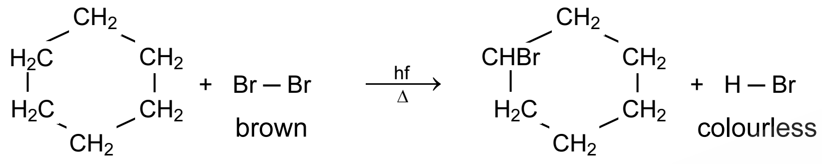
3)  $CH_3-CH_2-\overset{\displaystyle O}{\overset{\Vert}{C}}-H$ **or** CH_3-CH_2-CHO

propanal

Test for saturated/unsaturated hydrocarbons

Reaction of an alkane vs an alkene with bromine water

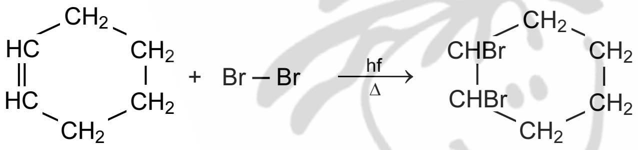
- **Halogenation substitution** of H by Br in an alkane:



cyclohexane 1-bromocyclohexane

Reaction conditions: heat or light

- **Halogenation addition** of the halogen Br_2 to an alkene:



cyclohexene 1,2-dibromocyclohexane

Reaction conditions: spontaneous

The above reactions are a **test** for saturated/unsaturated hydrocarbons:

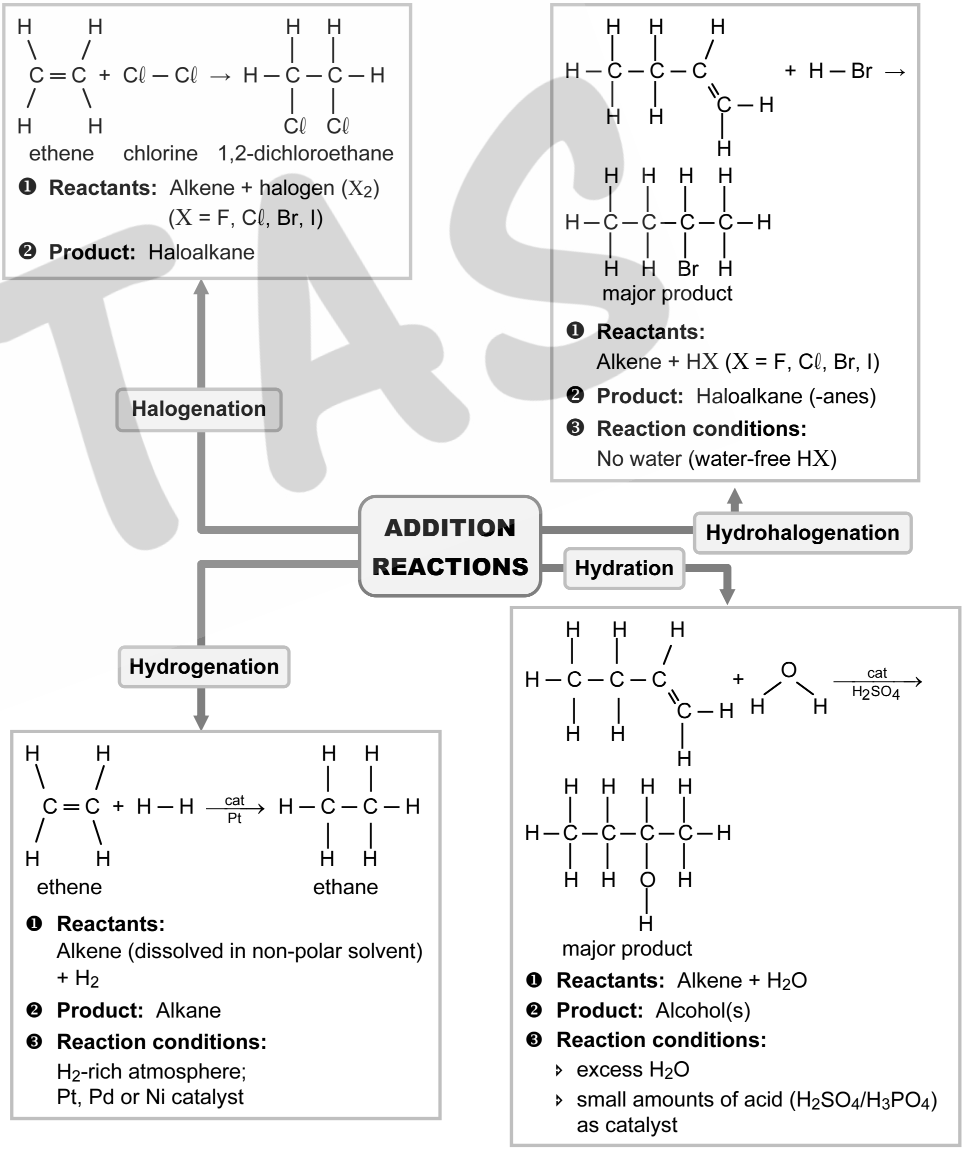
- Add a few drops of orange brown bromine water to the unknown hydrocarbon and shake.
- If the mixture decolorises immediately without application of additional heat or light, the substance was an unsaturated hydrocarbon, i.e. an alkene or an alkyne.
- If the brown colour disappears only with the addition of energy (heat/light) and there is an additional gas product, it was a saturated hydrocarbon, i.e. an alkane.

.

Summary of reactions

Addition reactions

- The **addition** of an atom/group of atoms to a molecule.
- This happens in unsaturated molecules of alkenes and alkynes at the double and triple bonds.



ethene chlorine 1,2-dichloroethane

❶ **Reactants:** Alkene + halogen (X_2) (X = F, Cℓ, Br, I)

❷ **Product:** Haloalkane

major product

❶ **Reactants:**
Alkene + HX (X = F, Cℓ, Br, I)

❷ **Product:** Haloalkane (-anes)

❸ **Reaction conditions:**
No water (water-free HX)

ethene ethane

❶ **Reactants:**
Alkene (dissolved in non-polar solvent) + H_2

❷ **Product:** Alkane

❸ **Reaction conditions:**
H_2-rich atmosphere;
Pt, Pd or Ni catalyst

major product

❶ **Reactants:** Alkene + H_2O

❷ **Product:** Alcohol(s)

❸ **Reaction conditions:**
- excess H_2O
- small amounts of acid (H_2SO_4/H_3PO_4) as catalyst

NB: *Never add water to the acid, as an enormous amount of heat develops, which can be dangerous.*

The **strength** of acids or bases refers to the extent of ionisation. Both strong and weak acids or bases can be concentrated or diluted.

Conjugate acid-base pairs

The conjugate base of an acid

When an **acid** has donated a proton, the remaining ion is called a **conjugate base** because it can accept a proton in the reverse reaction again.

Thus : **acid → proton + conjugate base** (of the acid)

Example: $H_2SO_4 \rightarrow H^+ + HSO_4^-$

$H_3O^+ \rightarrow H^+ + H_2O$

The **conjugate base of an acid** is the ion or molecule that remains when the acid has donated a proton.

The conjugate acid of a base

When a **base** has accepted a proton, the formed product is called a **conjugate acid**, as it can donate a proton in the reverse reaction again.

Thus: **base + proton → conjugate acid** (of the base)

Example: $NH_3 + H^+ \rightarrow NH_4^+$

$OH^- + H^+ \rightarrow H_2O$

The **conjugate acid of a base** is the ion or molecule that forms when the base has accepted a proton.

Net reaction

Therefore, acid-base reactions are a combination of these half-reactions during which ❶ the acid donates a proton and ❷ the base accepts it at the same time. In the net reaction, the conjugate acid-base pairs can be paired off, i.e.

$$\underset{a_1}{\textbf{acid}} + \underset{b_2}{\textbf{base}} \rightarrow \underset{a_2}{\textbf{conjugate acid}} + \underset{b_1}{\textbf{conjugate base}}$$

Example:

Indicate the conjugate acid-base pairs in the following reactions:

1. $\underset{a_1}{HC\ell} + \underset{b_2}{NH_3} \rightarrow \underset{a_2}{NH_4^+} + \underset{b_1}{C\ell^-}$

2. $\underset{a_1}{CH_3COOH} + \underset{b_2}{(Na^+)OH^-} \rightarrow \underset{b_1}{CH_3COO^-\ (Na^+)} + \underset{a_2}{H_2O}$

3. $\underset{b_1}{CO_3^{2-}} + \underset{a_2}{H_2O} \rightarrow \underset{a_1}{HCO_3^-} + \underset{b_2}{OH^-}$

NB: *C—H bonds in organic compounds form free radicals (C• and H•) instead of participating in acid-base reactions.*

Try yourself:

4. $H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$

Solution:

4. $\underset{a_1}{H_3PO_4} + \underset{b_2}{OH^-} \rightarrow \underset{b_1}{H_2PO_4^-} + \underset{a_2}{H_2O}$

Monoprotic and polyprotic acids

- A **monoprotic acid** contains only one ionising proton in its compound that can be donated in an acid-base reaction, e.g. **H**Cℓ, **H**NO₃, CH₃COO**H**.
- A **polyprotic acid** can donate two or three protons, i.e.
  - **Diprotic acids:** can donate two protons per formula unit, e.g. H_2SO_4, H_2CO_3, H_2SO_3
  - **Triprotic acids:** can donate three protons per formula unit, e.g. H_3PO_4.

Ampholytes

An **ampholyte** is a substance that could act as either an acid or a base.

In the previous examples, we saw that water can act as either an acid or a base; therefore, it is an ampholyte, e.g.:

$HC\ell + \underset{\text{base}}{H_2O} \rightarrow H_3O^+ + C\ell^-$ $NH_3 + \underset{\text{acid}}{H_2O} \rightarrow NH_4^+ + OH^-$

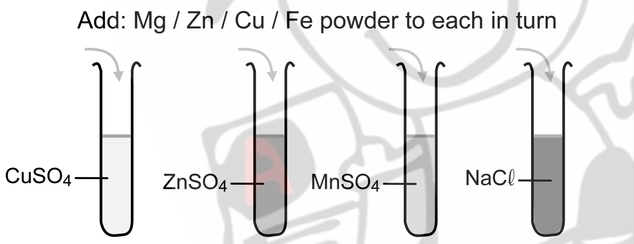
Conclusion:

The voltmeter reading of the Zn | Zn^{2+} and Cu | Cu^{2+} half-cell combination with the Zn half-cell as anode and the Cu half-cell as cathode is the highest. Therefore, it is the strongest galvanic cell of the three cells being investigated. The strongest reducing agent is Zn and the strongest oxidising agent is Cu^{2+}.

Practical Investigation 3: Investigate the reduction of metal ions and halogens

Requirements:

- metals in powder form: Mg, Zn, Cu, Fe
- metal salt solutions, e.g. $MgSO_4$, $ZnSO_4$, $CuSO_4$, $NaC\ell$ solutions
- bromine water, chlorine water (domestic bleach, e.g. Jik)
- halide salt solutions, e.g. $KC\ell$, KBr and KI
- non-polar solvent, e.g. carbon tetrachloride ($CC\ell_4$)
- test tubes
- thermometer
- spatula



Method:

Investigation A:

- Half-fill four test tubes with $CuSO_4$, $ZnSO_4$, $MgSO_4$ and $NaC\ell$ respectively.
- Note the temperature reading of each.
- Add a spatula of Mg powder to each and stir with a glass rod.
- Take the temperature again. Also note and record any colour changes.
- Rinse the test tubes.
- Repeat three times but now add Zn powder, then Cu powder and then Fe powder to each in turn.
- Arrange the metals above in order of reactivity (from the strongest to the weakest reducing agent).

(Remember that a more reactive metal is a stronger reducing agent and so can displace another metal from the solution of its salt.)

▶▶▶

Investigation B:

- Fill three test tubes up to one third with $KC\ell$, KBr and KI solutions respectively.
- Note the temperature reading of each.
- Add approximately one third of non-polar solvent to each and shake well.
- Add 1 cm^3 of chlorine water to each and shake well.
- Let them stand for a while until the two layers separate. Determine whether a reaction has taken place. Note the colours of the layers.
- Rinse the test tubes.
- Repeat, but now add bromine water to each and complete the investigation.
- Arrange the halogens Cℓ, Br and I in order of reactivity.

(Remember that a more reactive halogen is a stronger oxidising agent and can displace another halogen from the solution of its salt.)

Bromine water is poisonous. Wear gloves and do not inhale fumes.

Results:

An increase in temperature in some of the test tubes indicates that a reaction has taken place. In some cases, a change in colour also shows that a reaction has occurred.

Investigation A:

	$CuSO_2$	$FeSO_4$	$ZnSO_4$	$MgSO_4$	$NaC\ell$
Mg	✓	✓	✓		×
Zn	✓	✓		×	×
Fe	✓		×	×	×
Cu		×	×	×	×

Investigation B:

	KI		KBr		$KC\ell$
$C\ell_2$	✓	purple	✓	brown	
Br_2	✓	purple			×

Conclusion:

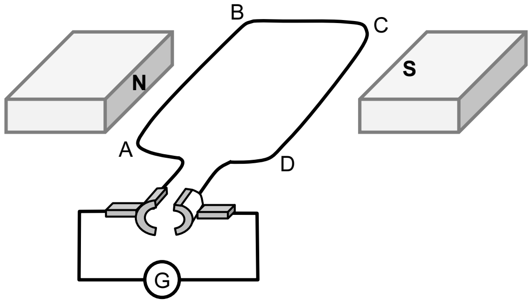
Investigation A:

Order of decreasing reactivity (decreasing strength as reducing agent): Na, Mg, Zn, Fe, Cu.

Investigation B:

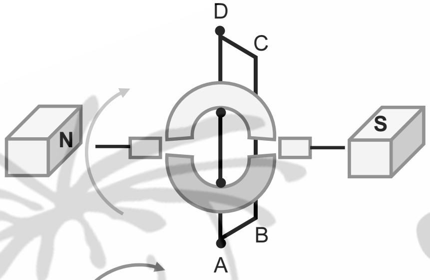
Order of decreasing reactivity (decreasing strength as oxidising agent): $C\ell_2$, Br_2, I_2.

The direct current generator (DC generator)

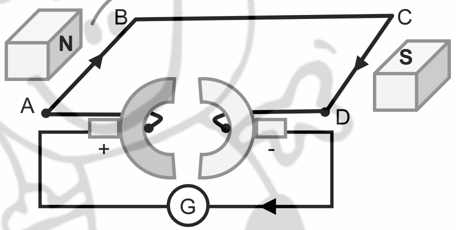


When the **slip rings** are replaced by a **split-ring commutator**, DC can be generated instead of AC to create a DC generator.

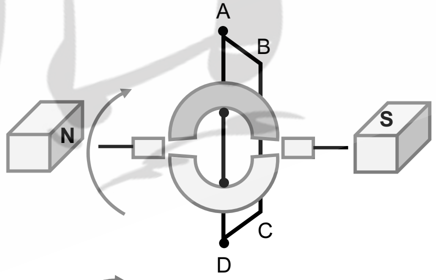
❶ The coil is turned clockwise to a vertical position. The brushes lose contact with the commutator segments and no current flows.



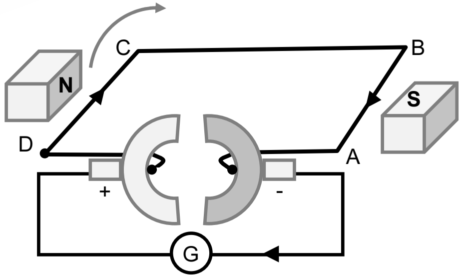
❷ The coil is rotated **clockwise**: AB moves upwards while CD moves downwards to a horizontal position. A current is induced in the armature, which flows from A → B → C → D. The current in the external circuit moves clockwise.



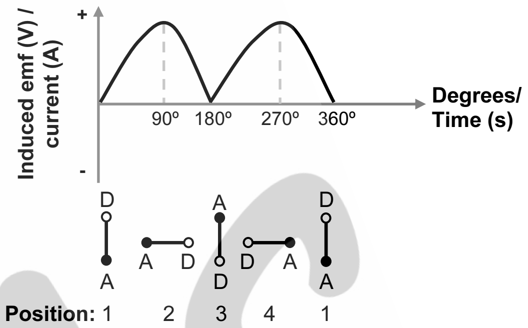
❸ The coil is turned further clockwise to a vertical position. The brushes lose contact with the commutator segments and no current flows.



❹ The coil is rotated further clockwise (AB moves downwards while CD moves upwards) to a horizontal position. A current is induced which moves from D → C → B → A in the armature, but still clockwise in the external circuit.



Each carbon brush makes contact with another segment of the split-ring commutator every half a revolution. Although the current in the coil/armature changes direction every 180º, the current in the external circuit always flows in the same direction, and DC is supplied.



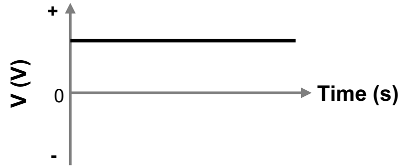
The magnitude of the emf/current induced still changes from zero to a maximum, to zero again, etc., the same as in the AC generator.

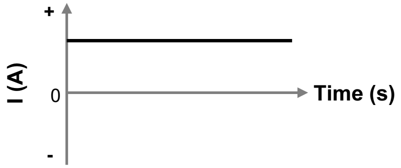
ALTERNATING CURRENT: SYMBOL ~

In South Africa, generators supply alternating current at 50 cycles per second (50 Hz or 50 s^{-1}).

Average current and potential difference in an AC circuit

- A **source of direct current** such as a cell or battery can supply a constant maximum voltage and current to a circuit for a long time. (Later, it will decrease as the battery runs down.)





Therefore, the **average** value of the voltage and current coincides with the **maximum**. The current/charge constantly flows in the same direction.

NB: *The DC supplied by a DC generator varies.*

RMS VOLTAGE AND CURRENT

Question 25

The municipality of Dinaledi implements a power cutback in the town. As a result of the cutback, the V_{RMS} drops from 220 V_{RMS} to 200 V_{RMS}.

25.1 Calculate the peak voltage during cutback.

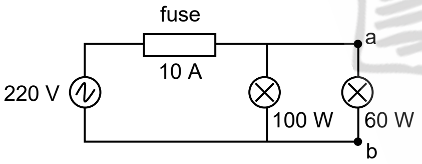
25.2 A certain electric appliance dissipates 1 200 W when it operates at 220 V_{RMS}. Calculate the power at which it will operate during the cutback.

25.3 It is common practice to connect many appliances to a multi-plug. Modern types of multi-plugs have a cut-off switch built in.

Using physics principles, explain clearly why this cut-off switch is important.

Question 26

Lights in most households are connected in parallel, as shown in the simplified circuit below. Two light bulbs rated at 100 W; 220 V and 60 W; 220 V respectively are connected to an AC source with an RMS value of 220 V. The fuse in the circuit allows a maximum current strength of 10 A.



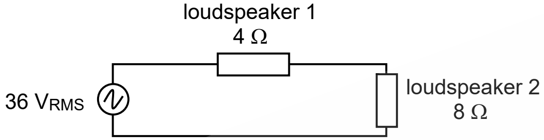
26.1 Calculate the peak voltage of the source.

26.2 Calculate the resistance of the 100 W light bulb, when operating at optimal conditions.

26.3 An electric iron, with a power rating of 2 200 W, is connected across points a and b in place of the 60 W light bulb. Explain, using a calculation, why this is not advisable.

Question 27

A source provides an RMS potential difference of 36 V to a 4 Ω and an 8 Ω speaker connected in series, as shown in the diagram below.



27.1 Calculate the following:

27.1.1 RMS current strength through the 4 Ω speaker

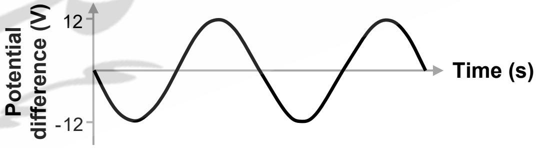
27.1.2 peak current strength through each speaker

27.1.3 average power dissipated by the 4 Ω speaker.

27.2 Without using a calculation, state how the average power dissipated by the 4 Ω speaker compares to the power dissipated by the 8 Ω speaker. Give a reason for your answer.

Question 28

The average power of a lamp is 15 W. The lamp can be used with either an AC supply or a DC supply. The graph below shows the AC potential difference.



28.1 Calculate the potential difference of a DC supply that will produce the same brightness of the lamp.

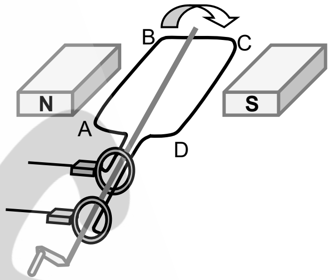
28.2 Calculate the peak current through the lamp when connected to a 12 V AC supply.

28.3 Draw a sketch graph of current strength through the lamp versus time when connected to the AC supply. Indicate the value of the peak current on the graph.

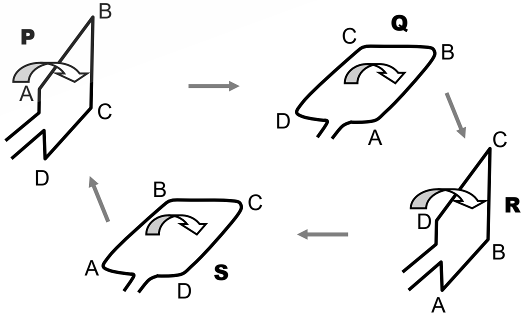
ELECTRODYNAMICS

Question 29

The simplified sketch below shows how an alternating current (AC) generator, also called an alternator, works. The coil (ABCD) is rotated clockwise as indicated by the arrow.



The following diagrams show various positions (P, Q, R, S) of the coil while it is rotated inside the magnetic field. The positions are shown in order. Positions P and R are vertical and positions Q and S are horizontal.



29.1 What is the direction of the current in length AB of the coil in position Q? Is it from A to B or from B to A?

29.2 At which two positions is the induced emf in the coil at a maximum? Give a reason for your answer.

29.3 Draw a sketch graph of induced emf versus time for the above AC generator. Indicate clearly the positions P, Q, R and S on the graph.