JENN
Training and Consultancy
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Province of the
EASTERN CAPE
EDUCATION

PHYSICAL SCIENCES

WINTER CLASSES

GRADE 12

TERM 2

TEACHER AND LEARNER CONTENT MANUAL

PHYSICAL SCIENCES PROGRAMME FOR 2025 WINTER CLASSES

PAPER	TOPICS	TOTAL MARKS	WEIGHTING
WEEK 1 AND WEEK 2			
PHYSICS (PAPER 1)	Work, Energy and Power (5 hours)	20	± 9 %
CHEMISTRY (PAPER 2)	Acids and Bases (8 hours)	13	± 13%
	Chemical Equilibrium (5 hours)	20	± 12 %
TOTAL		53	
Pre-test and Post-test to be administered since it's a revision of Term 1 & 2.			

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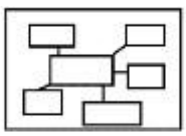
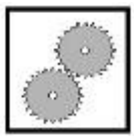
ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

Work, Energy and Power

(This section must be read in conjunction with the CAPS, p. 117–120.)

Work

- Define the work done on an object by a constant force F as $F\Delta x cos\theta$, where F is the magnitude of the force, Δx the magnitude of the displacement and θ the angle between the force and the displacement. (Work is done by a force – the use of the term 'work is done against a force', e.g. work done against friction, must be avoided.)
- Draw a force diagram and free-body diagrams.
- Calculate the net work done on an object.
- Distinguish between positive net work done and negative net work done on the system.

Work-energy theorem

- State the work-energy theorem: The work done on an object by a net force is equal to the change in the object's kinetic energy OR the work done on an object by a net force is equal to the change in the object's kinetic energy. In symbols: $Wnet = \Delta K = Kf - Ki$
- Apply the work-energy theorem to objects on horizontal, vertical, and inclined planes (for both frictionless and rough surfaces).

Conservation of energy with non-conservative forces present.

- Define a conservative force as a force for which the work done in moving an object between two points is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulombic forces).
- Define a non-conservative force as a force for which the work done in moving an object between two points depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc.
- State the principle of conservation of mechanical energy: The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant. NOTE: A system is isolated when the net external force (excluding the gravitational force) acting on the system is zero.
- Solve conservation of energy problems using the equation: $W_{nc} = \Delta E_k + \Delta E_p$
- Use the relationship above to show that in the absence of non-conservative forces, mechanical energy is conserved.

Power

- Define power as the rate at which work is done or energy is expended. In symbols: $P = \frac{W}{\Delta t}$
- Calculate the power involved when work is done.
- Perform calculations using $P_{ave} = Fv_{ave}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

IMPORTANT TERMS AND DEFINITIONS	
Work	Work done on an object by a constant force is the product of the magnitude of the force, the magnitude of the displacement and the angle between the force and the displacement. In symbols: $W = F\Delta x cos\theta$
Positive work	The kinetic energy of the object increases.
Negative work	The kinetic energy of the object decreases.
Work-energy theorem	The net/total work done on an object is equal to the change in the object's kinetic energy OR the work done on an object by a resultant/net force is equal to the change in the object's kinetic energy. In symbols: $W_{net} = \Delta K = K_f - K_i$.
Principle of conservation of mechanical energy	The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant. (A system is isolated when the resultant/net external force acting on the system is zero.) In symbols: $E_{M(intial)} = E_{M(final)}$ OR $(E_p + E_k)_{initial} = (E_p + E_k)_{final}$
Conservative force	A force for which the work done (in moving an object between two points) is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulomb forces).
Non-conservative force	A force for which the work done (in moving an object between two points) depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc
Power	The rate at which work is done or energy is expended. In symbols: $P = \frac{W}{\Delta t}$ Unit: watt (W)

TABLE 1: WORK, ENERGY AND POWER

$W = F\Delta x \cos\theta$	$U = mgh$ or/*of* $E_P = mgh$
$K = \frac{1}{2}mv^2$ or/*of* $E_k = \frac{1}{2}mv^2$	$W_{net} = \Delta K$ or/*of* $W_{net} = \Delta E_k$ $\Delta K = K_f - K_i$ or/*of* $\Delta E_k = E_{kf} - E_{ki}$
$W_{nc} = \Delta K + \Delta U$ or/*of* $W_{nc} = \Delta E_k + \Delta E_p$	$P = \frac{W}{\Delta t}$
$P_{ave} = Fv_{ave}$ / $P_{gemid} = Fv_{gemid}$	

MIND MAP

WORK DONE

- **Work** is the transfer of energy.

- **Work done (W)** on an object by a constant force is the product of the displacement and the component of the force parallel to the displacement.

$$W = F\Delta x cos\theta$$

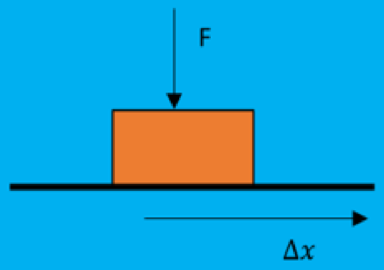
WHERE:

$$\boldsymbol{W \rightarrow Work\ done\ in\ Joules(J)}$$
$$\boldsymbol{F \rightarrow magnitude\ of\ force\ in\ Newtons(N)}$$
$$\boldsymbol{\Delta x/\Delta y \rightarrow magnitude\ of\ displacement\ in\ metres(m)}$$
$$\boldsymbol{\theta \rightarrow magnitude\ of\ the\ angle\ between\ force\ and\ displacement}$$

- Work is a scalar quantity, i.e. no direction.
- The joule is the amount of work done when a force of one newton moves its point of application one metre in the direction of the force.

Work always involves two things:

- A constant force which acts on a certain object.
- The displacement of that object.

<table>
<tr><th>Zero Work done</th><th colspan="2">Positive Work done</th><th>Negative Work done</th></tr>
<tr>
<td>
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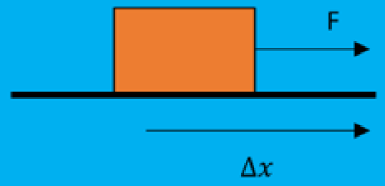
<td>
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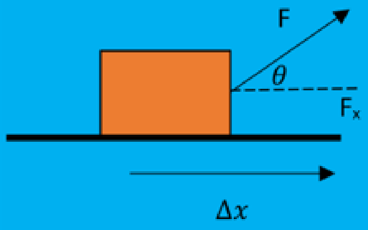
<td>
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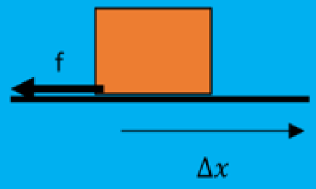
<td>
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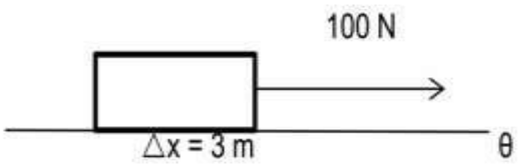
</tr>
<tr>
<td>$W = F\Delta x\cos\theta$
$F \text{ and } \Delta x$
$\boldsymbol{perpendicular\ to\ each\ other}$
$\theta = 90^\circ$
$\boldsymbol{\cos\theta = \cos 90^\circ = 0}$</td>
<td>$W = F\Delta x\cos\theta$
$F \text{ and } \Delta x \text{ parallel to each other}$
$\boldsymbol{same\ diraction}$
$\theta = 0^\circ$
$\boldsymbol{\cos\theta = \cos 0^\circ = 1}$</td>
<td>$W = F_x\Delta x\cos\theta$
$F \text{ and } \Delta x$
$\boldsymbol{angle\ \theta\ to\ each\ other}$
$F_x = F\cos\theta$
$W = F\cos\theta\Delta x\cos\theta$
$\theta = 0^\circ$
$\boldsymbol{\cos\theta = \cos 0^\circ = 1}$</td>
<td>$W = f\Delta x\cos\theta$
$F \text{ and } \Delta x \text{ parallel to each other}$
$\boldsymbol{opposite\ diraction}$
$\theta = 180^\circ$
$\boldsymbol{\cos\theta = \cos 180^\circ = -1}$</td>
</tr>
<tr>
<td>• No Work done on an object if the force and displacement are perpendicular to each other.</td>
<td>• A force in the direction of the displacement does positive work on the object. The force increases the energy of the object.</td>
<td>• A force component in the direction of the displacement does positive work on the object. The force increases the energy of the object.</td>
<td>• A frictional force in the opposite direction of the displacement does negative work on the object. The force decreases the energy of the object.</td>
</tr>
<tr>
<td></td>
<td colspan="2">• Positive work means that energy is added to the system.</td>
<td>Negative work means that energy is removed to the system.</td>
</tr>
</table>

EXAMPLE 1

A box lying on a horizontal frictionless surface is pulled by a horizontal force of 100 N. The box is displaced 3m to the right, as shown in the sketch below. Calculate the work done by the force on the box.



There is one force acting on the object. .

$W = F\Delta x cos\theta$

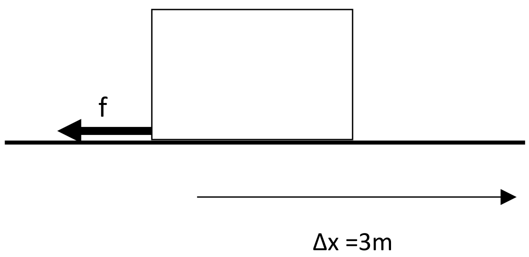
$W = (100)(3)cos0^{\circ}$

$W = 300\ J$

EXAMPLE 2

A box on a horizontal rough surface slide to the right and experiences a frictional force of 100 N. The box is displaced 3 m to as shown in the sketch below.

Calculate the work done by the frictional force on the box.



. **There is one force acting on the object.**

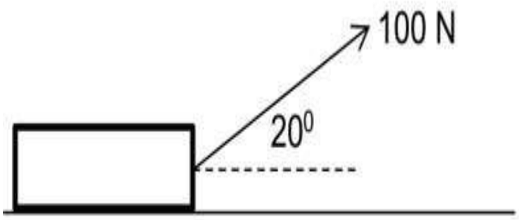
$W = f\Delta x cos\theta$

$W = (100)(3)cos180^{\circ}$

$W = -300\ J$

EXAMPLE 3

Calculate the work done on a box lying on a horizontal frictionless surface, by a 100 N force, which acts at an angle of 20º to the horizontal. The force displaces the box 3 m, as shown in the diagram below.



Again, there is one force (100 N) acting on the object.

$F_x = F cos\theta$

$F_x = 100 cos 20^\circ$

$F_x = 93.9692620786 N$

$W = F_x \Delta x cos\theta$

$W = (93.9692620786)(3) cos 0^\circ$

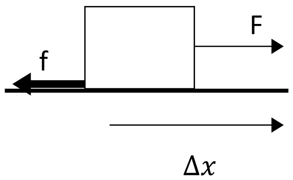
$W = 281.91\ J$

NET WORK ON AN OBJECT

- Several forces can act on an object at the same time.
- Each force can do work on the object to change the energy of the object.
- The net work done on the object is the sum of the work done by each force acting on the object.

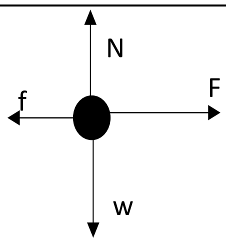
  If W_{net} is **positive**, **energy is added** to the system.
  If W_{net} is **negative**, **energy is removed** from the system.

EXAMPLE 4



Calculate the net work done on a crate if a force of 60 N is applied on a crate. The crate moves 6 m to the right and experiences a frictional force of 10 N to the left.

N.B Draw a free-body diagram showing all the forces acting on the crate and label the forces.



Work done by weight and Normal force equal 0J BOTH are perpendicular to the displacement ($\theta = 90^\circ$)

OPTION 1

$W_{net} = W_F + W_f$
$W_{net} = F\Delta x cos\theta + f\Delta x cos\theta$
$W_{net} = (60)(6)cos 0^\circ + (10)(6)cos 180^\circ$
$W_{net} = 300 J$

OPTION 3

OPTION 2

$F_{net} = F - f$
$F_{net} = 60 - 10$
$F_{net} = 50 N$

$W_{net} = F_{net}\Delta x cos\theta$
$W_{net} = (50)(6)cos 0^\circ$
$W_{net} = 300 J$

EXAMPLE 5

An electric motor is used to lift a load of bricks through a vertical height of 20m. The tension in the cable attached to the lift is 2000 N. Calculate the work done by the electric motor on the bricks.

- Draw a free-body diagram showing all the forces acting on the bricks and label the forces. There is one acting on the bricks, which is the tension (T) in the cable. Note that there is no normal force in this example

The angle between w and Δx is 180^0.

There are two forces, and we use W_{net} and $F_{net.}$ $W_{net} = F_{net}\Delta x\cos\theta$

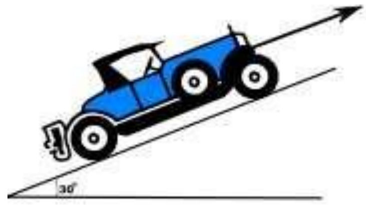
$$W_T = T\Delta x\cos\theta$$
$$W_T = 2000(20)\cos 0°$$
$$= 40000\ J$$

$$W_w = w\Delta x\cos\theta$$
$$W_w = (50\ x\ 9,8)\ (20)\cos 180$$
$$= -9800\ J$$

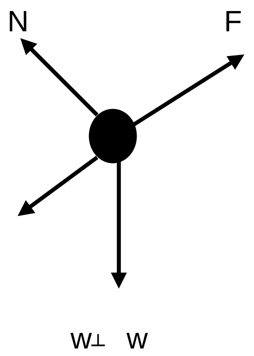
$$W_{net} = W_T + W_w$$
$$= 40000 + (-9800)$$
$$= 30200\ J$$

EXAMPLE 4

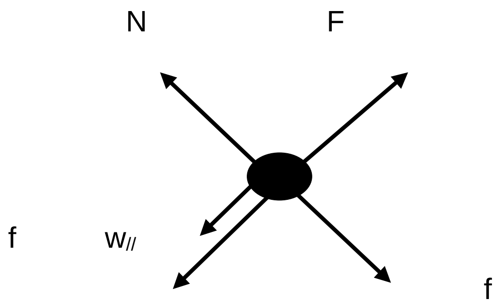
A 1200kg car is pulled 3m up an incline (30^0 with the ground) by a rope exerting a force of 8000N on the car. The car experiences a 20N frictional force.



4.1. Draw a labelled free body diagram of all the forces acting on the car.



or



4.2. Calculate the net work done on the car.

<u>**Work done by force applied (F)**</u>	<u>**Work done by friction (f)**</u>	<u>**Work done by weight.**</u>
$W_F = F\Delta x cos\theta$ $W_F = 8000(3)cos0°$ $W_F = 24000J$	$W_f = f\Delta x cos\theta$ $W_f = 20(3)cos180°$ $W_f = -60J$	$W_{w//} = w_{//}\,\Delta x cos\theta$ $W_{w//} = [mgsin\theta]\,\Delta x cos\theta$ $W_{w//} = [(1200)(9,8)sin30°](3)cos\,180°$ $W_{w//} = -17640J$

<u>**Work Net**</u>

$W_{net} = W_F + W_f + W_{w//}$

$W_{net} = 24000 - 60 - 17640$

$W_{net} = 6300\,J$

WORK - ENERGY THEOREM:

- The net work done on an object is equal to the change in the object's kinetic energy.
- The work done on an object by a resultant/net force is equal to the change in the object's kinetic energy.

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

$$W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

- The work - energy theorem can be applied to the objects on horizontal, vertical, and inclined planes for both frictionless and rough surfaces.

CONSERVATIVE AND NON-CONSERVATIVE FORCES CONSERVATIVE FORCE

- Conservative force is a force for which the work done in moving an object between two points is independent of the path taken. *A force is a conservative force if:*

  The work done by the force in moving an object from point A to point B is independent of the path taken.

  The net work done in moving an object in a closed path which starts and ends at the same point is zero.

NON-CONSERVATIVE FORCE

- Non-conservative force is a force for which the work done in moving an object between two points depends on the path taken. *A force is a non-conservative force if:*

  The work done by the force in moving an object from point A to point B depends on the path taken.

  The net work done in moving an object in a closed path which starts and ends at the same point is not zero.

CONSEVATIVE FORCES	NON-CONSEVATIVE FORCES
Gravitational force	Frictional force
Electrostatic force	Tension
Elastic force	Applied force
	Air resistance

ENERGY

PRINCIPLE OF CONSERVATION OF MECHANICAL ENERGY

The total mechanical energy in an isolated system remains constant.

- Mechanical energy is **sum of gravitational potential energy** and **kinetic energy**.
- A system is isolated when the resultant/net external force acting on the system is zero.
- Be in the position to use the principles of energy to show that in the absence of nonconservative forces, mechanical energy is conserved.
- The **mechanical energy of a system is conserved** when **only conservative forces are present** in the system.
- The **mechanical energy of a system is not conserved when non-conservative forces are present** in the system (e.g. friction, air resistance, applied forces and tension).
- The **work done by these non-conservative forces** is **equal to the change in the total mechanical energy** of the system.

POWER

the rate at which work is done or energy is expended.

$$P = \frac{W}{\Delta t}$$

P → Power in Watts(W)

W → work done in Joules (J).

Δt → change in time in seconds (s).

- Be in the position to calculate the power involved when work is done.
- Perform calculations using when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.

AVERAGE POWER (CONSTANT VELOCITY)

- We can calculate the average power needed to keep an object moving at constant speed.
- If the car is driven at a constant speed, the magnitude of the forward force is equal to the magnitude of the frictional force.
- If the car is driven at constant speed, then the force of the engine up the slope must be equal in magnitude to the force down the slope.
- Be able to calculate the power output for a pump lifting a mass (e.g. lifting water through a height at constant speed).

Velocity is given by displacement over time:

$$v_{ave} = \frac{\Delta x}{\Delta t}$$

$$P_{ave} = F v_{ave}$$

NOTE:

P → Average Power
F → Force
V → Constant Velocity

<u>ACTIVITY 1 [MULTIPLE CHOICE QUESTIONS]</u> **<u>10 MARKS 10 MINUTES</u>**

Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Write only the letter (A–D) next to the question number (1.1–1.10) in the ANSWER BOOK

1.1 A 20,4 kg box remains at rest on a horizontal surface while the box is pushed horizontally with a force of 60 N. The coefficient of static friction between the box and the surface is 0,60.
What is the force of friction acting on the box during the push? (Rounded off to the closest whole number)

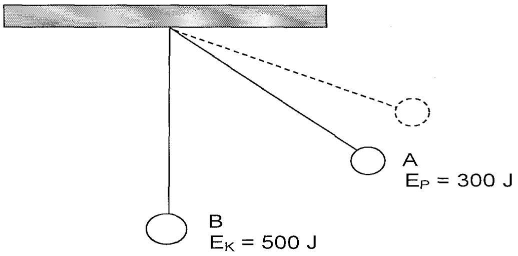
A 200 N

B 140 N

C 120 N

D 60 N (2)

1.2 Consider the pendulum in the sketch. At a certain point A of its swing the ball has a gravitational potential energy of 300 J with respect to its **lowest point at B**. At point B the ball has a kinetic energy of 500 J.



The total mechanical energy of the system is ...

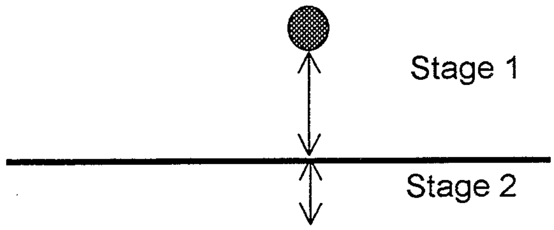
A. 800 J

B. 500 J

C. 300 J

D. 200 J (2)

1.3 A solid rubber ball dropped from a certain height above a swimming pool, takes 0,3 seconds to reach the surface of the water (**stage 1**). The ball enters the water and reaches its maximum depth after 0,2 seconds (**stage 2**). (Air resistance is negligible.



Which one of the following statements is **TRUE**?

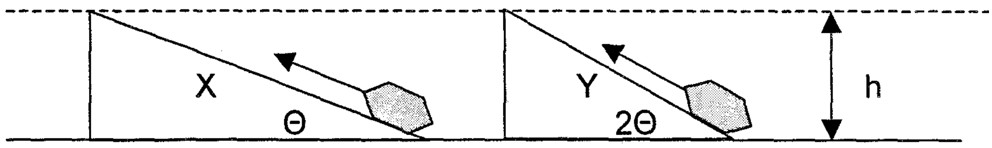
A. Both the mechanical energy and momentum of the ball are constant during **both stages** (0,5 seconds).

B. Both the mechanical energy and momentum of the ball are constant during **stage 1** (first 0,3 seconds).

C. Only the mechanical energy of the ball remains constant during **both stages** (0,5 seconds).

D. Only the mechanical energy of the ball remains constant during **stage 1** (0,3 seconds), but changes during **stage 2** (0,2 seconds) (2)

1.4 Two boys are pulling two identical objects at the same uniform speed up two different inclines, X and Y, of different gradients, but equal height. Friction can be ignored.

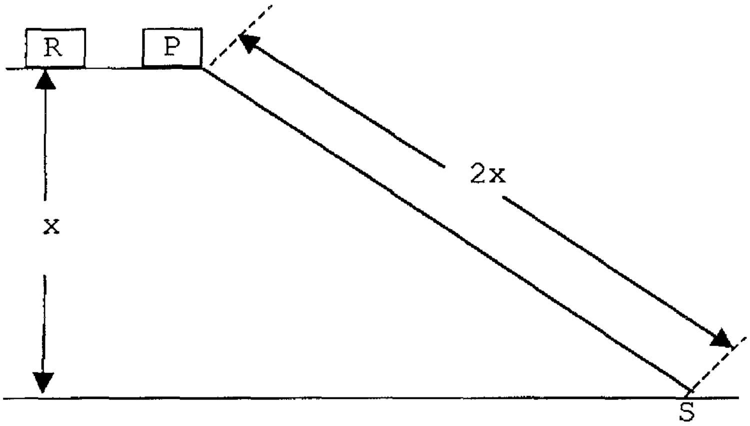


The **magnitude of the force** exerted by each of the boys and the **work done** can be compared as follows:

	Magnitude of the force	Work done
A	$F_X < F_Y$	$W_X > W_Y$
B	$F_X > F_Y$	$W_X > W_Y$
C	$F_X < F_Y$	$W_X = W_Y$
D	$F_X > F_Y$	$W_X = W_Y$

(2)

1.5 Two objects, **R** and **P**, of equal mass are at rest on top of a wall that has a vertical height **x**. **R** falls straight down and hits the ground with a speed ***v***. **P** slides down the frictionless incline, length **2x**, as shown in the sketch:



The speed of **P** at the bottom of the incline (point **S**) is …

A. ½ ***v***

B.***v***

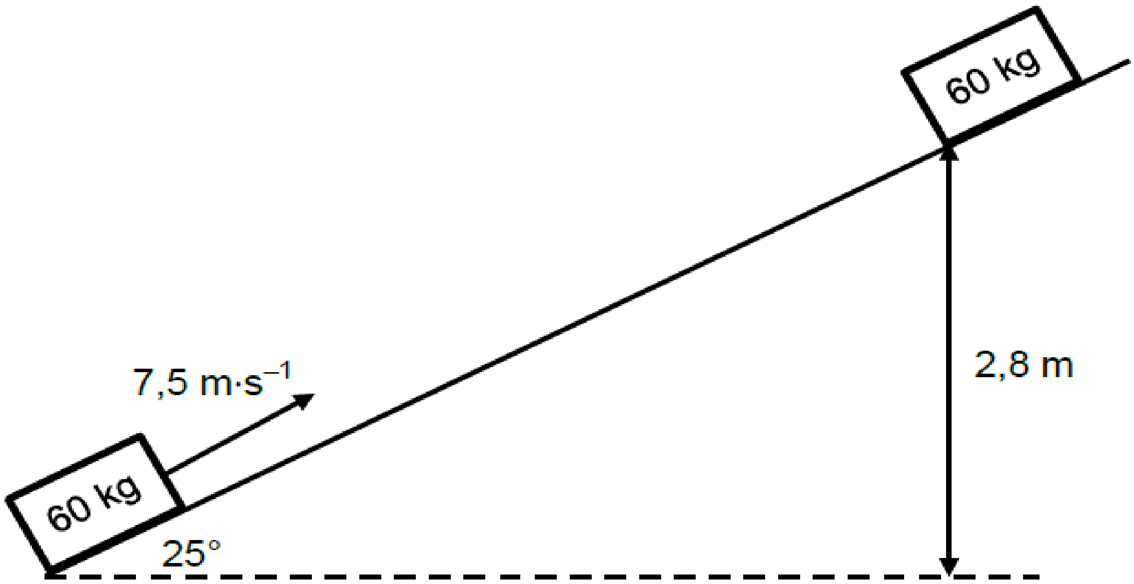
C. $\sqrt{2}$ ***v***

D.2 ***v*** (2)

[10]

ACTIVITY 2 **14 marks 14 minutes**

A cart with a mass of 60 kg is travelling at a speed of 7,5 $m \cdot s^{-1}$ at the bottom of a rough slope inclined at 25° to the horizontal. The cart comes to rest after travelling up the slope to a vertical height of 2,8m.



2.1 Define *kinetic energy* (2)

2.2 Calculate the kinetic energy of the cart at the bottom of the slope. (3)

2.3 Calculate the gain in gravitational potential energy of the cart at the highest point. (3)

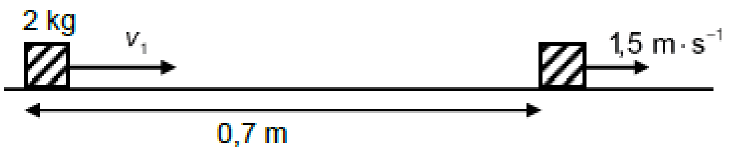
2.4 Calculate the work done against the frictional force as the cartmoves up the slope. (2)

2.5 Hence, calculate the magnitude of the frictional force acting onthe cart as it moves up the slope. (4)

[14]

ACTIVITY 3 **23 MARKS 23 MINUTES**

3.1 A box of mass 2 kg has an initial speed of v_i. The box travels across a rough surface and has a speed of 1,5 m·s^{-1} after it has travelled 0,7 m. The frictional force acting on the box is 26 N.



3.1.1 Define *frictional force*. (2)

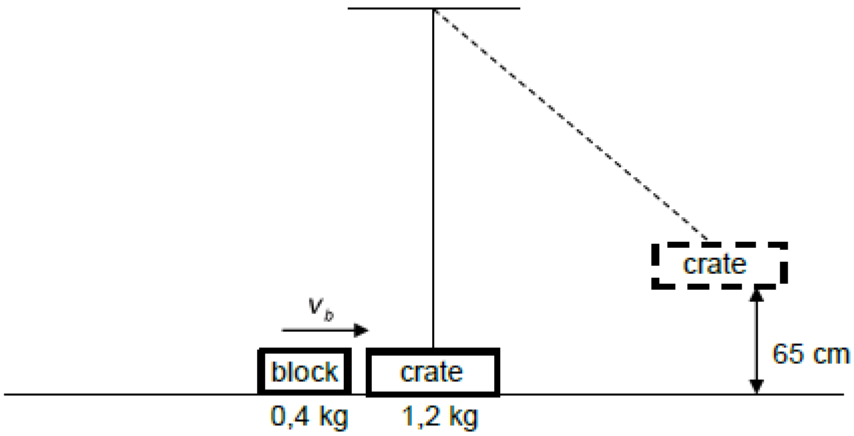
3.1.2 Calculate the kinetic energy of the box while it is travelling at 1,5 m·s^{-1} . (3)

3.1.3 Calculate the work done on the box by the frictional force. (3)

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

3.1.5 Calculate the initial speed v_i of the box. (3)

3.2 A 1,2 kg crate is attached to a long string as shown in the diagram. A block of mass 0,4 kg collides with the stationary crate with a velocity v_b and rebounds with a velocityof 0,36m·s^{-1} causing the crate to swing up through a vertical height of 65 cm. (Frictional forces are negligible)



3.2.1 State *the principle of conservation of mechanical energy.* (2)

3.2.2 Calculate the magnitude of the velocity of the crate immediately after the block collided with the crate. (3)

3.2.3 State *the law of conservation of linear momentum*. (2)

3.2.4 Calculate the magnitude of the velocity of the block, just before it collides with the crate. (3)

[23]

ACTIVITY 4 **13 MARKS 13 MINUTES**

A rescue helicopter is stationary (hovering) above the water to rescue a man in difficulties off the Clifton beachfront (**FIGURE 1**). It lowers a a lifebuoy with a mass 2 kg onto the
water for the man to cling to it while the crew prepare to bring him aboard the helicopter
(**FIGURE 2**). When the buoy is at a height of 10 m above the ground it has a velocity of
1,5 $m.s^{-1}$. A buoy is then lowered at a constant acceleration onto the water with a cable, where it eventually comes to rest. Assume there is no sideways motion during the descent. *Air friction is NOT to be ignored*.

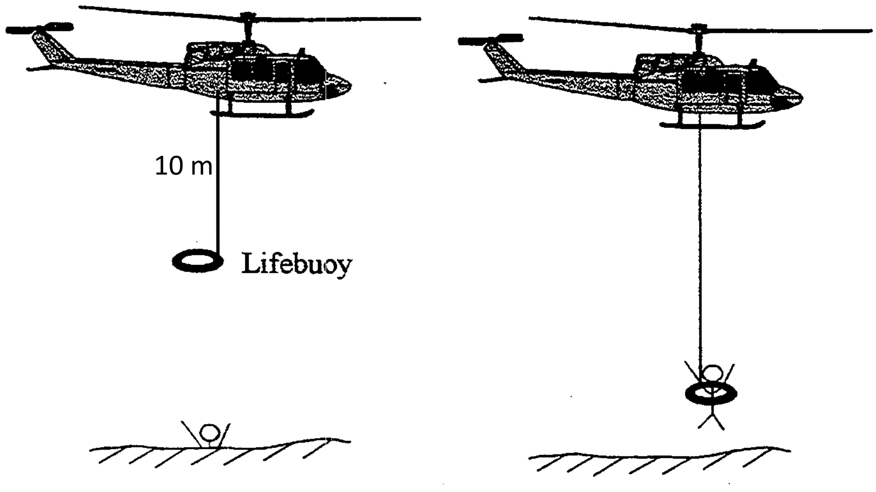


FIGURE 1 FIGURE 2

4.1 Define a *non-conservative force*. (2)

4.2 Identify TWO *non-conservative forces* acting on the buoy during its downward descent (motion). (2)

4.3 Write down the name of a *non-contact force* that acts on the man while he is out of the water and being hoisted upwards. (1)

4.4 Draw a free-body diagram showing ALL the forces acting on the buoy while it is being lowered to the water. (3)

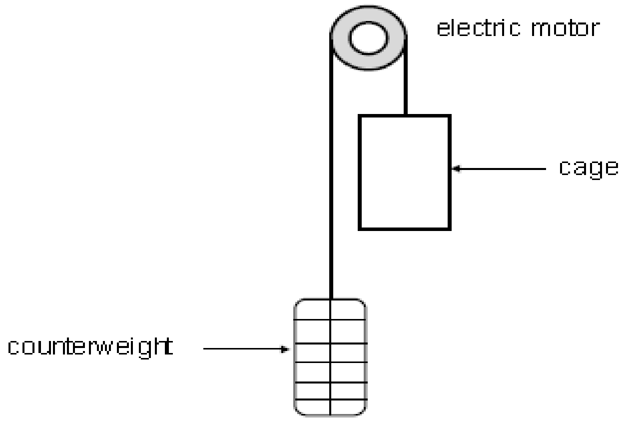
4.5 Write down the equation/formula of the WORK-ENERGY THEOREM (1)

4.6 Use the work-energy theorem to calculate the acceleration of the buoy as it is lowered to the water. (4)

[13]

QUESTION 5 **10 MARKS 10 MINUTES**

A lift arrangement comprises an electric motor, a cage, and its counterweight. The counterweight moves vertically downwards as the cage moves upwards. The cage and counterweight move at the same constant speed. Refer to the diagram below.



The cage, carrying passengers, moves vertically upwards at a constant speed, covering
60 m in 3 minutes. The counterweight has a mass of 870 kg. The total mass of the cage and passengers is 1 100 kg. The electric motor provides the power needed to operate the lift system. Ignore the effects of friction.

5.1 Calculate the work done by the:

5.1.1 Gravitational force on the cage (3)

5.1.2 Counterweight on the cage (2)

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

[10]

JENN

Training and Consultancy

The path to enlightened education

SUBJECT: SUBJECT NAME

GRADE 12

2025 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

ACID AND BASES

EXAMINATION GUIDELINES:

Acids and Bases

(This section must be read in conjunction with the CAPS, p. 127–128.)

Acid-base reactions

- Define acids and bases according to Arrhenius and Lowry-Brønsted theories: Arrhenius theory: Acids produce hydrogen ions (H^+/H_3O^+/hydronium ions) in aqueous solution. Bases produce hydroxide ions (OH^-) in aqueous solution. Lowry-Brønsted theory: An acid is a proton (H^+ ion) donor. A base is a proton (H^+ ion) acceptor.

Relative strengths of acids and bases

- Distinguish between strong acids/bases and weak acids/bases with examples. Strong acids ionise completely in water to form a high concentration of H_3O^+ ions. Examples of strong acids are hydrochloric acid, sulphuric acid, and nitric acid. Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions. Examples of weak acids are ethanoic acid and oxalic acid. Strong bases dissociate completely in water to form a high concentration of OH^- ions.

  Examples of strong bases are sodium hydroxide and potassium hydroxide. Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^-ions. Examples of weak bases are ammonia, calcium carbonate, potassium carbonate, calcium carbonate and sodium hydrogen carbonate.
- Distinguish between concentrated acids/bases and dilute acids/bases. Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to the volume of water. Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to the volume of water.

Acid-base reactions

- Write down the reaction equations of aqueous solutions of acids and bases.

  Examples: HCℓ(g) + H2O(ℓ) → $H3O^+$(aq) + $Cℓ^-$(aq) (HCℓ is a monoprotic acid.)

  NH_3(g) + H_2O(ℓ) → NH_4^- (aq) + OH^-(aq)

  H_2SO_4(aq) + $2H_2O$(ℓ) → $2H_3O^+$(aq) + SO_4^{2-} (aq) (H_2SO_4 is a diprotic acid.)

• Identify conjugate acid-base pairs for given compounds.

- Describe a substance that can act as either acid or base as ampholyte. Water is a good example of an ampholyte substance. Write equations to show how an ampholyte substance can act as acid or base.
- Write down neutralisation reactions of common laboratory acids and bases.

Examples: HCℓ(aq) + NaOH(aq)/KOH (aq) → NaCℓ(aq)/KCℓ(aq) + H2O(ℓ)

HCℓ(aq) + Na2CO3(aq) → NaCℓ(aq) + H2O(ℓ) + CO2(g)

HNO3(aq) + NaOH(aq) → NaNO3(aq) + H2O(ℓ)

H2SO4(aq) + 2NaOH(aq) → Na2SO4(aq) + 2H2O(ℓ)

(COOH)2(aq) + NaOH(aq) → (COO)2Na2(aq) + H2O(ℓ)

CH3COOH (aq) + NaOH(aq) → CH3COONa(aq) + H2O(ℓ)

NOTE: The above are examples of equations that learners will be expected to write from given information. However, any other neutralisation reaction can be given in the question paper to assess, e.g. stoichiometry.

Hydrolysis

- Define hydrolysis as the reaction of a salt with water.
- Determine the approximate pH (equal to, smaller than or larger than 7) of salts in salt hydrolysis. o Hydrolysis of the salt of a weak acid and a strong base results in an alkaline solution, i.e. the pH > 7. Examples of such salts are sodium ethanoate, sodium oxalate and sodium carbonate.
  - Hydrolysis of the salt of a strong acid and a weak base results in an acidic solution, i.e. the pH < 7. An example of such a salt is ammonium chloride.
  - The salt of a strong acid and a strong base does not undergo hydrolysis and the solution of the salt will be neutral, i.e. pH = 7.

Acid-base titrations

- Motivate the choice of a specific indicator in a titration. Choose from methyl orange, phenolphthalein, and bromothymol blue.
- Define the equivalence point of a titration as the point at which the acid/base has completely reacted with the base/acid.
- Define the endpoint of a titration as the point where the indicator changes colour.
- Perform stoichiometric calculations based on titrations of a strong acid with a strong base, a strong acid with a weak base and a weak acid with a strong base. Calculations may include percentage purity.
- For a titration, e.g. the titration of oxalic acid with sodium hydroxide: o List the apparatus needed or identify the apparatus from a diagram. o Describe the procedure to prepare a standard oxalic acid solution.
    - Describe the procedure to conduct the titration. o Describe safety precautions.
    - Describe measures that need to be in place to ensure reliable results.
    - Interpret given results to determine the unknown concentration.

pH and the pH scale

- Explain the pH scale as a scale of numbers from 0 to 14 used to express the acidity or alkalinity of a solution.
- Calculate pH values of strong acids and strong bases using pH = -log[H_3O^+].
- Define K_w as the equilibrium constant for the ionisation of water or the ion product of water or the ionisation constant of water, i.e. K_w = [H_3O^+][OH^-] = 1 x 10^{14} by 298 K.
- Explain the auto-ionisation of water, i.e. the reaction of water with itself to form H3O+ ions and OH^- ions.
- Interpret K_a values of acids to determine the relative strength of given acids. Interpret K_b values of bases to determine the relative strength of given bases.
- Compare strong and weak acids by looking at:
- pH (monoprotic and diprotic acids)
- Conductivity o Reaction rate

IMPORTANT TERMS AND DEFINITIONS

CHEMICAL CHANGE: ACIDS AND BASES	
Acid-base indicator	A dye used to distinguish between acidic and basic solutions by means of the colour changes it undergoes in these solutions.
Amphiprotic substance/ampholyte	A substance that can act as either an acid or a base.
Arrhenius theory	An acid is a substance that produces hydrogen ions (H^+)/ hydronium ions (H3O$^+$) when it dissolves in water. A base is a substance that produces hydroxide ions (OH^-) when it dissolves in water.
Auto-ionisation of water	A reaction in which water reacts with itself to form ions (hydronium ions and hydroxide ions).
Concentrated acids/bases	Contain a large amount (number of moles) of acid/base in proportion to the volume of water.
Conjugate acid-base pair	A pair of compounds or ions that differ by the presence of one H^+ ion. Example: CO_3^{2-} □ and HCO_3^- □ OR HCℓ and Cℓ$^-$
Conjugate acid and base	A conjugate acid has one H^+ ion more than its conjugate base. Example: HCO_3^- is the conjugate acid of base CO_3^{2-} □ CO_3^{2-} □ is the conjugate base of acid HCO_3^- □.
Dilute acids/bases	Contain a small amount (number of moles) of acid/base in proportion to the volume of water.
Diprotic acid	An acid that can donate two protons. Example: H_2SO4
Dissociation	The process in which ionic compounds split into ions.
Endpoint	The point in a titration where the indicator changes colour.
Equivalence point	The point in a reaction where equivalent amounts of acid and base have reacted completely.

Exam Question:

Define an **acid/base** in terms of the **Arrhenius theory**. (2 MARKS)

Arrhenius Theory

An acid is a substance that produces **hydrogen ions (H^+)/hydronium ions** (H_3O^+) when it dissolves in water.

$$HC\ell \rightarrow H^+ + C\ell^-$$

(Hydrogen ions)

$$HC\ell + H_2O \rightarrow H_3O^+ + C\ell^-$$

(Hydronium ions)

A base is a substance that produces **hydroxide ions (OH^-)** when it dissolves in water.

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

(Hydroxide ions)

Exam Question:

Define an **acid/base** in terms of the **Lowry-Brønsted theory**. (2 MARKS)

Lowry-Bronsted theory

An acid is a proton (H^+ ion) donor.

$$HC\ell(aq) + H_2O(\ell) \xrightarrow{} C\ell^-(aq) + H_3O^+(aq)$$

(H^+ transferred from $HC\ell$ to H_2O; $HC\ell$: Proton donor)

A base is a proton (H+ ion) acceptor.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

(H^+ transferred from H_2O to NH_3; NH_3: Proton acceptor)

Exam Question:

Give a reason why Nitric acid/ Sulphuric acid/ Hydrocloric acid is classified as a strong acid. (2 MARKS)

Strong acids → ionise completely in water to form **a high concentration of H_3O^+ ions** → Hydrochloric acid **HCl**, Sulphuric acid **H_2SO_4**, Nitric acid **HNO_3**

$HC\ell(aq) + H_2O(\ell) \rightarrow C\ell^-(aq) + H_3O^+(aq)$

Hydrochloric acid | Water | Chloride ion | Hydronium ion

$H_2SO_4(aq) + H_2O(\ell) \rightarrow SO_4^{2-}(aq) + 2H_3O^+(aq)$

Sulphuric acid | Water | Sulphate ion | Hydronium ion

$HNO_3(aq) + H_2O(\ell) \rightarrow NO_3^-(aq) + H_3O^+(aq)$

Nitric acid | Water | Nitrate ion | Hydronium ion

All strong acids ionizes completely with K_a greater than 1 (K_a> 1). K_a values of strong acids are very large and no values are given for K_a

Weak acids → ionise incompletely in water to form **a low concentration of H_3O^+ ions** → Ethanoic acid **CH_3COOH**, Oxalic acid **$H_2C_2O_4$**

$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$

Ethanoic acid (Acetic acid) | Water | Hydronium ion | Ethanoate ion (Acetate ion)

$$K_a = \frac{[products]}{[reactants]} = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$$

$(COOH)_2(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + H(COO)_2^-(aq)$

oxalic acid | Water | Hydronium ion | Oxalate ion

OR

$H_2C_2O_4(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HC_2O_4^-(aq)$

oxalic acid | Water | Hydronium ion | Oxalate ion

All weak acids that ionise incompletely or only partially, with K_a smaller than one (K_a < 1).

$$K_a = \frac{[products]}{[reactants]} = \frac{[HC_2O_4^-][H_3O^+]}{[H_2C_2O_4]}$$

Strong bases → dissociates completely in water to form a high concentration of OH^- ions. → Sodium hydroxide **NaOH**, Potassium hydroxide **KOH**

$$NaOH(s) \xrightarrow{H_2O(\ell)} Na^+(aq) + OH^-(aq)$$

Sodium Hydroxide — Sodium ion — Hydroxide ion

$$KOH(s) \xrightarrow{H_2O(\ell)} K^+(aq) + OH^-(aq)$$

Potassium Hydroxide — Potassium ion — Hydroxide ion

All strong bases that dissociates completely with K_b greater than one ($K_b > 1$),

Weak bases → dissociate/ionise incompletely in water to form a low concentration of OH^- ions. →

- Ammonia **NH_3**
- Sodium Carbonate **Na_2CO_3**
- Potassium carbonate **K_2CO_3**
- Calcium carbonate **$CaCO_3$**
- Sodium hydrogen carbonate **$NaHCO_3$**

$$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$$

Ammonia — Water — Ammonium ions — Hydroxide ions

$$K_a = \frac{[products]}{[reactants]} = \frac{[NH_4^+][H_3O^+]}{[NH_3]}$$

All weak bases that ionizes/dissociates incompletely or only partially, with K_b smaller than one ($K_b < 1$).

Distinguish between concentrated acids/bases and dilute acids/bases.

Even when a strong acid/base is very dilute, it is still a strong acid/base

Concentrated acids/bases

Contain a large amount (number of moles) of acid/base in proportion to the volume of water.

Dilute acids/bases

contain a small amount (number of moles) of acid/base in proportion to the volume of water.

For example, sodium hydroxide will always be a strong base, regardless of how much water is present in a sodium hydroxide solution.

Mono- and polyprotic acids

Acids can be classified according to the number of protons (H^+) that they can donate.

Monoprotic acid -An acid that can donate one proton.

$$HC\ell + H_2O \rightarrow C\ell^- + H_3O^+$$

$$HNO_3 + H_2O \rightarrow NO_3^- + H_3O^+$$

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$$

Conjugate acid-base pairs

Conjugate acid-base pair

$$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

Acid 1 — Base 2 — Acid 2 — Base 1

Conjugate acid-base pair

- ❖ When a **BASE** accepts a proton, its **CONJUGATE ACID** is produced.
  - When the base $\mathbf{H_2O}$ gains a proton, the acid $\mathbf{H_3O^+}$ is formed.
  - Add $\mathbf{H^+}$ to a given compound or ion. E.g. $H_2O + H^+ \rightarrow H_3O^+$
- ❖ When an ACID donates a proton, its **CONJUGATE BASE** is produced.
  - When the acid $\mathbf{CH_3COOH}$ donates a proton, the base $\mathbf{CH_3COO^-}$ is formed.
  - Remove $\mathbf{H^+}$ to a given compound or ion. E.g. $CH_3COOH - H^+ \rightarrow CH_3COO^-$
- ❖ Each of these acid-base pairs **differ by the presence of one hydrogen ion (H^+)** and is a called a **conjugate acid-base pair.**
- ❖ CH_3COO^- is the **conjugate base** of CH_3COOH and H_3O^+ is the **conjugate acid** of H_2O.

Conjugate acid-base pairs

$$HNO_3(aq) + H_2O(\ell) \rightarrow NO_3^-(aq) + H_3O^+(aq)$$

Stronger acid — Stronger base — Weaker base — Weaker acid

$\mathbf{HNO_3}$ is completely ionised because it is a **strong acid**.

The **forward reaction is favoured**.

Its conjugate base ($\mathbf{NO_3^-}$) is weaker base than $\mathbf{H_2O}$ because it has a poor tendency to accept a proton to form $\mathbf{HNO_3}$

$$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

Weaker acid — Weaker base — Stronger acid — Stronger base

$\mathbf{CH_3COOH}$ is a weak acid and is thus incompletely ionised

The **reverse reaction is favoured.**

$\mathbf{CH_3COO^-}$ is a stronger base than $\mathbf{H_2O}$ because it readily accepts a proton from $\mathbf{H_3O^+}$ to form $\mathbf{CH_3COOH}$.

$\mathbf{H_3O^+}$ is a stronger acid than $\mathbf{CH_3COOH}$ as it readily donates a proton to $\mathbf{CH_3COO^-}$ to form $\mathbf{CH_3COOH}$.

AMPHIPROTIC SUBSTANCE/AMPHOLYTE

A substance that can act as either an acid or a base.

$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$

Base Acid

Water can thus act as acid and base and is an amphiprotic substance

$HC\ell(aq) + H_2O(\ell) \rightarrow C\ell^-(aq) + H_3O^+(aq)$

Acid Base

AMPHIPROTIC SUBSTANCE/AMPHOLYTE

A substance that can act as either an acid or a base.

Reaction 1: $H_2SO_4(aq) + H_2O(\ell) \rightarrow H_3O^+ + HSO_4^-(aq)$

Acid 1 Base 2 Acid 2 Base 1

In reaction 1: HSO_4^- acts as a base.

In reaction 2: HSO_4^- acts as an acid.

HSO_4^- can either donate or accept a proton and is an amphiprotic substance.

Reaction 2: $HSO_4^-(aq) + H_2O(\ell) \rightarrow H_3O^+ + SO_4^{2-}(aq)$

Base 1 Acid 2 Base 2 Acid 1

ACTIVITY 1 **20 MARKS: 20 MINUTES**

Various options are provided as possible answers to the following questions. Choose the answer and write down only the letter (A–D) next to the question numbers (1.1 to 1.10) in the ANSWER BOOK, e.g. 1.5 D.

1.1 According to the Arrhenius theory, an acid ...

A forms hydroxide ions in water

B forms hydronium ions in water.

C is a proton donor.

D is a proton acceptor. (2)

1.2 The following reaction is a Lowry-Bronsted acid base reaction.

$$NH_3(g) + HC\ell(g) \leftrightharpoons NH_4C\ell(g)$$

The reason the reaction is classified as an acid base reaction is that …

A NH_3 accepts a proton.

B $HC\ell$ accepts a proton.

C NH_3 donates a proton.

D $HC\ell$ donates an electron. (2)

1.3 Consider the following reaction:

$$CH_3NH_2(aq) + H_2O(\ell) : CH_3NH_3^+(aq) + OH^-(aq)$$

The CH_3NH_2 acts as a/an …

A.proton donor.

B.proton acceptor

C.oxidising agent.

D. reducing agent. (2)

1.4 In the reaction **X** + $H_2O \leftrightharpoons H_3O^+ + HSO_4^-$, **X** represents the following:

A acid SO_4^{2-}

B base SO42–

C acid H_2SO_4

D base H_2SO_4 (2)

1.5 Consider the four different solutions. Which of these solutions is a dilute weak acid solution?

A 0,1 mol·dm^{-3} $HC\ell$ solution

B 5 mol·dm^{-3} CH_3COOH solution

C 0,5 mol·dm^{-3} oxalic acid solution

D 5 mol·dm^{-3} NaOH solution (2)

1.6 Which ONE of the following is a CORRECT description for a 0,1 mol·dm^{-3} hydrochloric acid solution?

A Dilute strong acid
B Dilute weak acid
C Concentrated weak acid
D Concentrated strong acid (2)

1.7 Consider the reactant **Y** in the following reaction:

$$\boldsymbol{Y} + H_2O \rightleftharpoons H_3O^+ + H_2PO_4^-$$

A PO_{43-}

B $H_2PO_4^-$

C HPO_4^{2-}

D H_3PO_4 (2)

1.8 An aqueous solution that contains more hydronium ions than hydroxide ions is a(n)

A basic solution
B acidic solution
C neutral solution
D standardised solution (2)

1.9 Consider the reaction represented by the equation below:

$$H_3PO_4(aq) + HCO^{-3}(aq) \rightleftharpoons H_2PO^{-4}(aq) + H_2CO_3(aq) \qquad K_a > 1$$

The strongest base in the above reaction is:

A $H_2PO_4^-$

B HCO_3^-

C H_3PO_4

D H_2CO_3 (2)

1.10 The conjugate base of HPO_4^{2-} is …

A OH^-

B PO_4^{3-}

C $H_2PO_4^-$

D H_3PO_4 (2)

[20]

Neutralisation

Acid + Base → Salt + Water

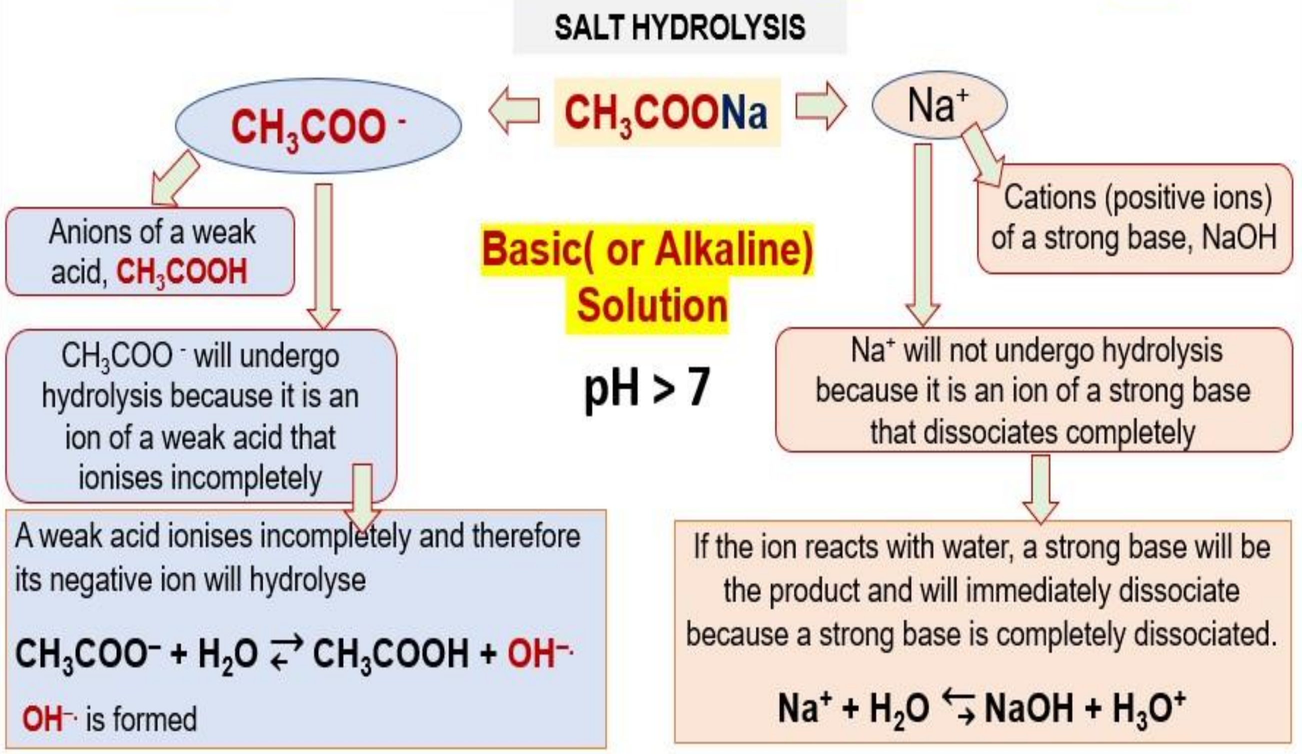
Strong Acid	+	Strong Base	→	Salt	+	Water
$HC\ell(aq)$	+	$NaOH(aq)$	→	$NaC\ell(aq)$	+	$H_2O(\ell)$

Weak Acid	+	Strong Base	→	Salt	+	Water
$CH_3COOH(aq)$	+	$NaOH(aq)$	→	$CH_3COONa(aq)$	+	$H_2O(\ell)$

Weak Acid	+	Strong Base	→	Salt	+	Water
$HC\ell(aq)$	+	$NH_4OH(aq)$	→	$NH_4C\ell(aq)$	+	$H_2O(\ell)$

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$$

Weak Acid — Strong Base — Salt — Water



$$HC\ell(aq) + NH_4OH(aq) \rightarrow NH_4C\ell(aq) + H_2O(\ell)$$

Strong Acid — Weak Base — Salt — Water

SALT HYDROLYSIS

$NH_4C\ell$ → NH_4^+ and $C\ell^-$

NH_4^+: Cations of a weak base, NH_4OH

NH_4^+ will undergo hydrolysis because it is an ion of a weak base that dissociates incompletely

A weak bases dissociates incompletely and therefore its positive ion will hydrolyse.

$$NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$$

H_3O^+ is formed.

$C\ell^-$: Anions of a strong acid, $HC\ell$

$C\ell^-$ will not undergo hydrolysis because it is an ion of a strong acid that ionises completely

If the ion reacts with water, a strong acid will be the product and will immediately ionise because a strong acid is completely ionised.

$$Cl^- + H_2O \leftrightarrows HCl + OH^-$$

Acidic Solution

pH < 7

$$HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

Strong Acid — Strong Base — Salt — Water

SALT HYDROLYSIS

$NaC\ell$ → Na^+ and $C\ell^-$

Na^+: Cations (positive ions) of a strong base, NaOH

Na^+ will not undergo hydrolysis because it is an ion of a strong base that dissociates completely

If the ion reacts with water, a strong base will be the product and will immediately dissociate because a strong base is completely dissociated.

$$Na^+ + H_2O \leftrightarrows NaOH + H_3O^+$$

$C\ell^-$: Anions of a strong acid, $HC\ell$

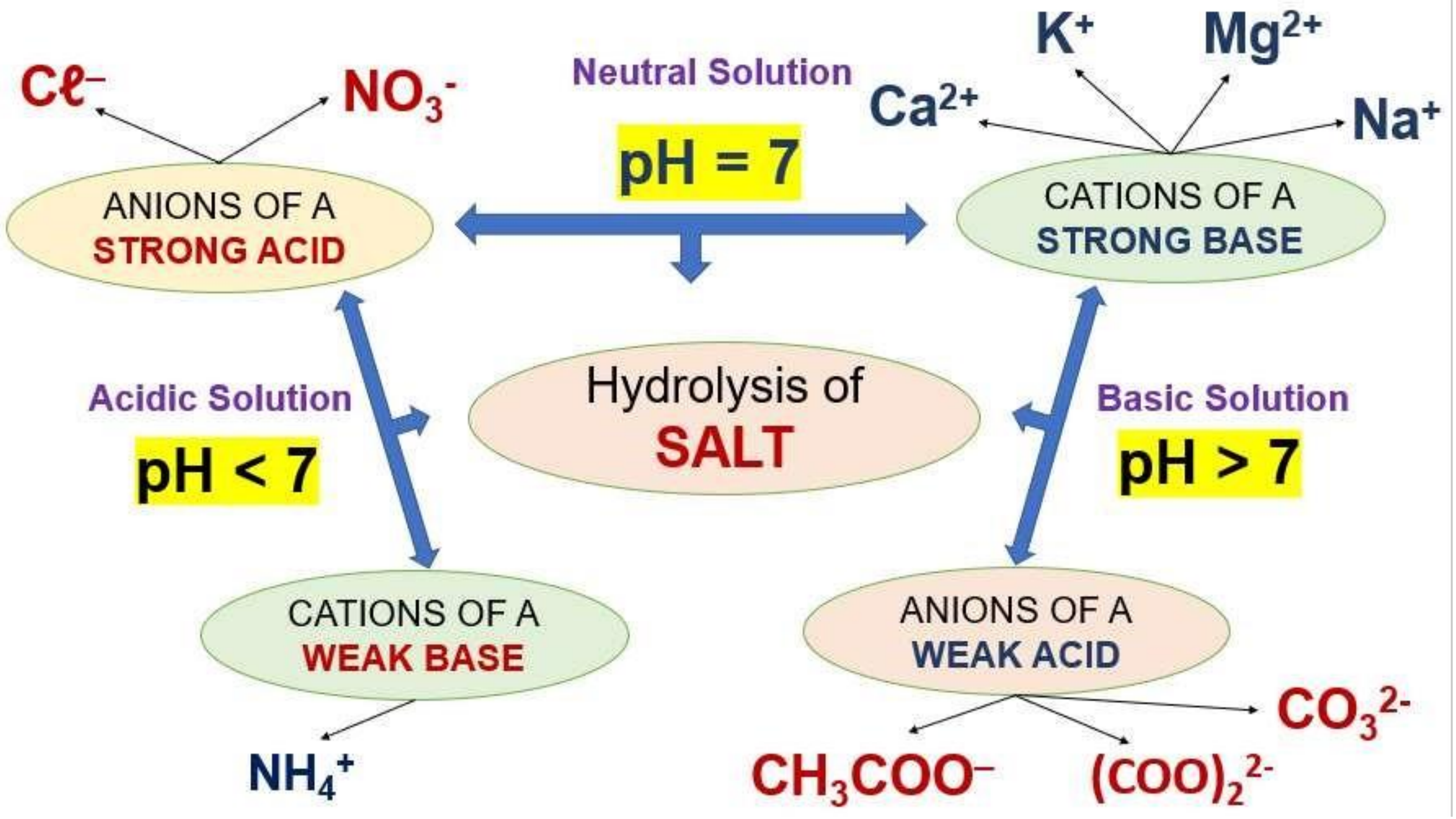
$C\ell^-$ will not undergo hydrolysis because it is an ion of a strong acid that ionises completely

If the ion reacts with water, a strong acid will be the product and will immediately ionise because a strong acid is completely ionised.

$$Cl^- + H_2O \leftrightarrows HCl + OH^-$$

Neutral Solution

pH = 7


Cℓ⁻
NO_3^-
ANIONS OF A STRONG ACID
Neutral Solution
pH = 7
Ca^{2+}
K^+
Mg^{2+}
Na^+
CATIONS OF A STRONG BASE
Hydrolysis of SALT
Acidic Solution
pH < 7
Basic Solution
pH > 7
CATIONS OF A WEAK BASE
NH_4^+
ANIONS OF A WEAK ACID
CH_3COO^-
$(COO)_2^{2-}$
CO_3^{2-}

Example 1

A hydrochloric acid solution has a concentration of 0,2 mol·dm^{-3} at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. pH of the solution.
3. OH^- concentration in the solution

Solution 1

Strong Acid
ionise completely in water to form **a high concentration of H_3O^+ ions**

HCl

Monoprotic Acid
An acid that can donate one proton.

Steps to follow when calculating the pH of monoprotic acid.					
Write down a balanced equation	**HCℓ**	**+ H_2O**	→	**H_3O^+**	**+ $Cℓ^-$**
1. Use ratios to calculate the concentration of $[H_3O^+]$.	1 mol			1mol	
	1:1 ratio (Monoprotic acid) $\therefore [H_3O^+] = [HCℓ]$ $= 0,2$ mol·dm^{-3}				
2. Substitute the concentration of $[H_3O^+]$ in the formula, **pH = -log $[H_3O^+]$,** to calculate the pH.	$pH = -\log [H_3O^+]$ $\therefore pH = -\log (0,2)$ $\therefore pH = 0,70$				
3. Substitute the concentration of $[H_3O^+]$ in the formula, **$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$** ,to calculate the OH^- concentration in the solution	$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$ $\therefore (0,2)[OH^-] = 1,0 \times 10^{-14}$ $\therefore \therefore [OH^-] = \frac{1,0 \times 10^{-14}}{0,2}$ $\therefore [OH^-] = 5 \times 10^{-14}$ mol·dm^{-3}				

Example 2

A sulphuric acid solution has a concentration of 0,2 mol·dm^{-3} at 25 °C. Calculate

1. H_3O^+ concentration in the solution.
2. pH of the solution.
3. OH^- concentration in the solution.

Solution 2:

Strong Acid
ionise completely in water to form **a high concentration of H_3O^+ ions**

H_2SO_4

Diprotic Acid
An acid that can donate two protons.

Steps to follow when calculating the pH of diprotic acid.					
Write down a balanced equation	**H_2SO_4**	**+ H_2O**	→	**$2H_3O^+$**	**+ SO_4^{2-}**
1. Use ratios to calculate the concentration of $[H_3O^+]$.	1 mol			2mol	
	1:2 ratio (Diprotic acid) $\therefore [H_3O^+] = 2[H_2SO_4]$ $= 2(0,2)$ $= 0,4$ mol·dm^{-3}				
2. Substitute the concentration of $[H_3O^+]$ in the formula, **$pH = -\log [H_3O^+]$,** to calculate the pH.	$pH = -\log [H_3O^+]$ $\therefore pH = -\log (0,4)$ $\therefore pH = 0,4$				
3. Substitute the concentration of $[H_3O^+]$ in the formula, **$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$** to calculate the OH^- concentration in the solution	$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$ $\therefore (0,4)[OH^-] = 1,0 \times 10^{-14}$ $\therefore [OH^-] = \frac{1,0 \times 10^{-14}}{0,4}$ $\therefore [OH^-] = 2,5 \times 10^{-14}$ mol·dm^{-3}				

Example 3

Sodium hydroxide solution has a concentration of 0,4 mol·dm^{-3} at 25 °C. Calculate

1. OH^- concentration in the solution.
2. H_3O^+ concentration in the solution.
3. pH of the solution.

Solution 2

NaOH

Strong Base
dissociates completely in water to form a high concentration of **OH^- ions**.

Steps to follow when calculating the pH of a base.				
Write down a balanced equation	**NaOH**	→	**Na^+**	**+ OH^-**
1. Use ratios to calculate the concentration of $[OH^-]$.	1 mol			1mol
	1:1 ratio $\therefore [OH^-] = [NaOH]$ $= 0,4$ mol·dm^{-3}			
2. Substitute the concentration of $[OH^-]$ in the formula, **$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$**, to calculate the OH^- concentration in the solution	$K_w = [H_3O^+][OH^-] = 1,0 \times 10^{-14}$ $\therefore [H_3O^+](0,4) = 1,0 \times 10^{-14}$ $\therefore [H_3O^+] = \frac{1,0 \times 10^{-14}}{0,4}$ $\therefore [H_3O^+] = 2,5 \times 10^{-14}$ mol·dm^{-3}			
3. Substitute the concentration of $[H_3O^+]$ in the formula, **pH = -log $[H_3O^+]$**, to calculate the pH.	pH = -log $[H_3O^+]$ $\therefore$ pH = -log ($2,5 \times 10^{-14}$) $\therefore$ pH = 13,60			

Example 4

The pH of a hydrochloric acid solution is 4,5 at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. Concentration of HCl.

Solution 1

Strong Acid		Monoprotic Acid
Strong Acid ionise completely in water to form **a high concentration of H_3O^+ ions**	⟵ **HCl** ⟶	**Monoprotic Acid** An acid that can donate one proton.

Steps to calculating the concentration of monoprotic acid if given the pH	
Write down a balanced equation.	**HCℓ + H_2O → H_3O^+ + $Cℓ^-$**
1. Substitute the pH value in the formula, **pH = -log [H_3O^+],** and calculate the concentration of [H_3O^+].	pH = -log [H_3O^+] ∴ 4,5 = -log [H_3O^+] ∴ [H_3O^+] = $10^{-4,5}$ ∴[H_3O^+] = 3,16× 10^{-5} mol·dm^{-3}
2. Use ratios to calculate the concentration of the HCl.	**HCℓ + H_2O → H_3O^+ + $Cℓ^-$** 1 mol : 1mol **1:1 ratio (Monoprotic acid)** ∴ [HCℓ] = [H_3O^+] =3,16× 10^{-5} mol·dm^{-3}

Example 5

The pH of a sulphuric acid solution is 4,5 at 25 °C. Calculate

1. H_3O^+concentration in the solution.
2. Concentration of HCl.

Solution 2:

Strong Acid		**Diprotic Acid**
ionise completely in water to form **a high concentration of H_3O^+ ions**	← **H_2SO_4** →	An acid that can donate two protons.

Steps to calculating the concentration of diprotic acid if given the pH					
Write down a balanced equation.	**H_2SO_4**	**+ H_2O**	→	**$2H_3O^+$**	**+ SO_4^{2-}**
3. Substitute the pH value in the formula, **pH = -log [H_3O^+],** and calculate the concentration of [H_3O^+].	pH = -log [H_3O^+] ∴ 4,5 = -log [H_3O^+] ∴ [H_3O^+] = $10^{-4,5}$ ∴ [H_3O^+] = $3,16 \times 10^{-5}$ mol·dm^{-3}				
4. Use ratios to calculate the concentration of the **H_2SO_4**.	**H_2SO_4**	**+ H_2O**	→	**$2H_3O^+$**	**+ SO_4^{2-}**
	1 mol			2mol	
	1:2 ratio (Diprotic acid) ∴ [H_2SO_4] = $\frac{1}{2}$[H_3O^+] = $\frac{1}{2}$ ($3,16 \times 10^{-5}$) = $1,58 \times 10^{-5}$ mol·dm^{-3}				

BASIC CALCULATIONS

MASS	SOLUTIONS
$n = \frac{m}{M}$	$c = \frac{n}{V}$ **OR** $c = \frac{m}{MV}$
n - is number of moles (mol) m - is mass (g) M - is molar mass ($g.mol^{-1}$)	c - is concentration ($mol.dm^{-3}$) v - is volume (dm^3)

EXAMPLE 1

A laboratory technician dissolves a 4,5 g sample of the magnesium oxide in 100 cm^3 hydrochloric acid of concentration 1,5 $mol{\cdot}dm^{-3}$ Calculate the number of moles of hydrochloric acid added to the magnesium oxide.

SOLUTION 1

SOLUTION 1

Choose the correct formula and copy formulae correctly from the data sheet.

Given Data:	n (HCl) =?
m (MgO) = 4,5 g Convert cm^3 to dm^3 by dividing the volume by 1000. V (HCl) = 100 cm^3 $\therefore$ V (HCl) = $\frac{100}{1000}$ = 0,1 dm^3 c (HCl) = 1,5 $mol{\cdot}dm^{-3}$	$c = \frac{n}{V}$ $1,5 = \frac{n}{0,1}$ $\therefore n\ (HCl) = 0,15\ mol$

EXAMPLE 2

A sulphuric acid solution is prepared by dissolving 7,35 g of $H_2SO_4(\ell)$ in 500 cm^3 of water. Calculate the number of moles of H_2SO_4 present in this solution.

Acid-base titrations

An acid-base titration is a procedure for determining the **amount of acid (or base) in a solution** by measuring the **volume of the base (or acid) of known concentration** that will completely react with it.

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

The solution of known concentration is called a **standard solution**.

The **equivalence point** of a titration is the point at which the acid/base has

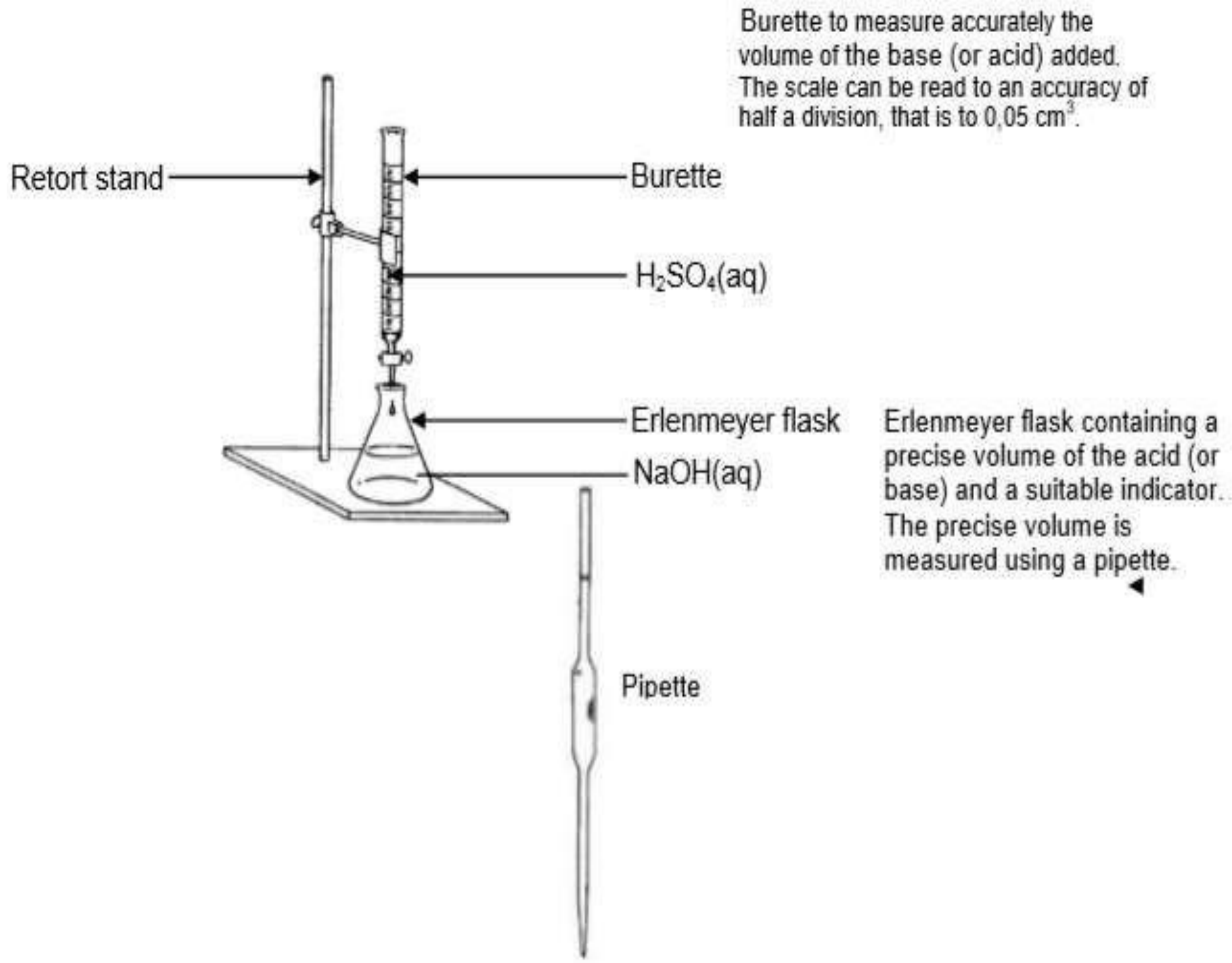
SOLUTION 2

Given Data: m (H_2SO_4) = 7,35 g Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 500 cm^3	n (H_2SO_4) =? M(H_2SO_4) = 2(1) + 32 + 4(16) = 98 $g.mol^{-1}$ $n = \frac{m}{M}$ **OR**	$c = \frac{m}{MV}$ $c = \frac{7,35}{(98)(0,5)}$ $c = 0,15\ mol{\cdot}dm^{-3}$

$\therefore$ V (H_2SO_4) = $\frac{500}{1000}$ = 0,5 dm^3 n (H_2SO_4) =?	$n = \frac{7,35}{98}$ $\therefore n\ (H_2SO_4) = 0,08\ mol$	$c = \frac{n}{V}$ $0,15 = \frac{n}{0,5}$ $\therefore n\ (H_2SO_4) = 0,08\ mol$

completely reacted with the base/acid.

The **endpoint** of a titration is the point where the indicator changes colour.



Motivate the **choice of a specific indicator in a titration**. Choose from methyl orange, phenolphthalein, and bromothymol blue.

Titration of a strong acid and a strong base.

Acid	Base	pH of the Salt formed	Indicator used	pH range of the indicator
Strong Acid **Yellow**	strong base **Blue**	Neutral (pH =7)	bromothymol blue	6,0 – 7,8

- When a strong acid reacts with a stoichiometrically equivalent amount of a strong base, the resulting salt solution is neutral.
- Th e endpoint of the titration of a strong acid (e.g., HCℓ) with a strong base (e.g., NaOH) is at pH = 7.

• The best choice of indicator will be bromothymol blue because the pH at the endpoint of the titration falls within the range in which the indicator will change colour (yellow to blue) i.e., pH 6,0 - 7,8.

Titration of a strong acid with a weak base

Acid	Base	pH of the Salt formed	Indicator used	pH range of the indicator
Strong Acid **Red**	weak base **Yellow**	Acidic pH < 7	Methyl orange	3,1 - 4,4

- When a strong acid reacts with a stoichiometrically equivalent amount of a weak base, the resulting salt solution is acidic.
- The endpoint of the titration of a strong acid (e.g., HCℓ) with a weak base (e.g., Na_2CO_3) is at pH < 7.
- The best choice of indicator will be methyl orange because the pH at the endpoint of the titration falls within the range in which the indicator will change colour (red to orange to yellow) i.e., pH 3,1 – 4,4.

Titration of a weak acid and a strong base

Acid	Base	pH of the Salt formed	Indicator used	pH range of the indicator
Weak Acid **Clear**	strong base **Red**	Basic pH > 7	Phenolphthalein	8,3 – 10,0

- When a weak acid reacts with a stoichiometrically equivalent amount of a strong base, the resulting salt solution is basic.
- The endpoint of the titration of a weak acid (e.g., CH3COOH) with a strong acid (e.g., NaOH) is at pH > 7.
- The best choice of indicator will be phenolphthalein because the pH at the endpoint of the titration falls within the range in which the indicator will change colour i.e., pH 8,3 – 10,0.

EXAMPLE 3

Learners use the reaction of a 0,15 $mol \cdot dm^{-3}$ sulphuric acid solution with a sodium hydroxide solution in two different experiments. The balanced equation for the reaction is:

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell)$$

They use 24 cm^3 of H_2SO_4(aq) in a titration to neutralise 26 cm^3 of NaOH(aq). Calculate the concentration of the NaOH(aq).

SOLUTION 3

Given Data:	**Titration formula**
c_a = c(H_2SO_4) =0,15 mol·dm^{-3} Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 24 cm^3 ∴V (H_2SO_4) = $\frac{24}{1000}$ = 0,024 dm^3 V (NaOH) = 26 cm^3 ∴V (NaOH) = $\frac{26}{1000}$ = 0,026 dm^3 c (NaOH) = c_b =?	**H_2SO_4(aq) + 2NaOH(aq) → Na_2SO_4(aq) + H_2O(ℓ)** 1 mol 2 mol $\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$ $\frac{(0{,}15)(0{,}024)}{c_b(0{,}026)} = \frac{1}{2}$ $c_b = 0{,}28\ mol.dm^{-3}$ $\therefore c\ (NaOH) = 0{,}28\ mol.dm^{-3}$ This formula should only be used for neutralisation reactions.

Given Data:	**Stoichiometric calculations**
c (H_2SO_4) =0,15 mol·dm^{-3} Convert cm^3 to dm^3 by dividing the volume by 1000. V (H_2SO_4) = 24 cm^3 ∴V (H_2SO_4) = $\frac{24}{1000}$ = 0,024 dm^3 V (NaOH) = 26 cm^3 ∴V (NaOH) = $\frac{26}{1000}$ = 0,026 dm^3 c (NaOH) =? Label formulae when doing multistep calculations	**Step 1:** Calculate the number of moles of H_2SO_4 $c = \frac{n}{V}$ $0{,}15 = \frac{n}{0{,}024}$ $\therefore n\ (H_2SO_4) = 3{,}6 \times 10^{-3}\ mol$ **Step 2:** Use the mole ratio from the balanced equation to calculate the number of moles of the other substance required: **H_2SO_4(aq) + 2NaOH(aq) → Na_2SO_4(aq) + H_2O(ℓ)** 1 mol 2 mol ∴n(NaOH) = 2 n(H_2SO_4) = 2(3,6 x 10^{-3}) = 7,2 x 10^{-3} mol **Step 3:** Simply calculate the concentration of NaOH. $c = \frac{n}{V}$ $c = \frac{7{,}2 \times 10^{-3}}{0.026}$ $\therefore c\ (NaOH) = 0{,}28\ mol.dm^{-3}$

ACTIVITY 2 **26 MARKS 30 MINUTES**

2.1 Consider the reaction below:

$$H_2O(\ell) + NH_3(g) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

In the reaction, ammonia is a weak base.

2.1.1 Define the term *weak base* (2)

2.1.2 Use the information in the equation to explain why ammonia is a *Lowry-Bronsted Base.* (2)

2.1.3 Identify the *conjugate acid* of NH_3 in the reaction (1)

2.1.4 Write down a balanced chemical equation to show the hydrolysis of ammonium ions in the solution (3)

2.2 An environmental disaster threatens the O.R Tambo ProMaths Centre in QwaQwa. There is a spillage of concentrated hydrochloric acid ($HC\ell$) into the only water storage tank at the centre.

The acidity of a sample of water is tested and the pH is found to be 3, 5.

2.2.1 State which ions (OH^- or H_3O^+) were in excess in the sample (1)

2.2.2 Calculate the concentration of H_3O^+ ions in the sample (3)

The science teacher, Mr Mohapi, at the centre decided to add sodium carbonate (Na_2CO_3) to the sampled water in the school tank in order to restore the pH to a value close to 7.

The balanced equation for the reaction is

$$Na_2CO_3(s) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + H_2O(\ell) + CO_2(g)$$

2.2.3 Define the term *neutralization* (2)

2.2.4 Calculate the mass of sodium carbonate (Na_2CO_3) required to neutralize each 1 dm^3 of the sample water. (6)

2.2.5 After the neutralization, the water tasted salty. Give a reason for the salty taste of the water. Refer to the equation above. (2)

2.3 An aqueous solution of sodium carbonate (Na_2CO_3) is prepared by adding distilled water according to the following equation:

$CO_3^{2-}(aq) + H_2O(\ell) \rightarrow HCO_3^-(aq) + OH^-(aq)$

2.3.1 Identify the reactant which acts as a Lowry-Brønsted base. (1)

2.3.2 Is the solution ACIDIC, BASIC or NEUTRAL? (1)

2.3.3 Use information from the equation to explain the answer to QUESTION 4.3.2 (2)

[26]

ACTIVITY 3 **20 MARKS 25 MINUTES**

A learner determined the pH of a number of solutions. The following results were obtained:

Solution	pH
Hydrochloric acid	1
Grape juice	3,1
Sodium hydroxide	13

3.1 Which solution contains the highest concentration of hydrogen ions? (1)

3.2 How will the pH of grape juice change when …

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

3.2.1 distilled water is added to it? (1)

3.2.2 some of the sodium hydroxide solution is added to it? (1)

3.2.3 some of the hydrochloric acid solution is added to it? (1)

3.3 The learner now analyses sea water, and finds the concentration of the hydroxide ions $[OH^-]$ in sea water to be 10^{-6} $mol.dm^{-3}$. Calculate the pH of sea water. (5)

3.4 At Kutlwanong Promaths Centre in Philippi, Grade 12 learners were asked to determine the amount of inert (unreactive) impurities in a contaminated sample of anhydrous oxalic acid ($H_2C_2O_4$).One group of learners prepared a standard solution of sodium hydroxide (NaOH) by diluting 50 cm^3 of a 1,63 $mol.dm^{-3}$ solution in a 1 dm^3 volumetric flask.

They then prepared a solution of the contaminated oxalic acid by dissolving 0,25 g of the oxalic acid in 75 cm^3 of water. The acid was then titrated against the NaOH solution. The titration required 40 cm^3 of the NaOH solution to reach the end point.

The equation for this reaction is:

$$2NaOH + H_2C_2O_4 \rightarrow Na_2C_2O_4 + H_2O$$

3.4.1 What is meant by *end point*? (2)

3.4.2 Use the information that the learners obtained and calculate the *Percentage purity* of the oxalic acid sample. (9)

[20]

ACTIVITY 4 **18 MARKS 20 MINUTES**

The Arrhenius and Lowry Brønsted theories can be used to define an acid or a base.

4.1 Define the term *acid* according to the Arrhenius theory (2)

4.2 Consider the following chemical reactions:

P: $SO_2 + H_20 \rightleftharpoons 2H^+ + SO_3^{2-}$

Q: $HC\ell(aq) + NH_3(g) \rightleftharpoons NH_4^+(aq) + C\ell^-(aq)$

4.2.1 From reactions **P** and **Q**, identify the reaction that illustrates the Arrhenius theory (1)

4.2.2 The ammonium ions NH_4^+ in chemical reaction **Q** undergoes hydrolysis

(a) Write down a balanced equation for the hydrolysis of the ammonium ions (3)

(b) Will the resultant solution be ACIDIC, BASIC or NEUTRAL? Explain your answer by referring to QUESTION 8.2.2(a) above. (2)

4.3 A sodium hydroxide solution (NaOH) is prepared by dissolving 4g of sodium hydroxide in water to make a 500 cm^3 solution.

4.3.1 Calculate the concentration of the sodium hydroxide solution (3)

During a titration, 12,5 cm^3 of a sodium hydroxide (NaOH) solution neutralises 25 cm^3 of sulphuric acid (H_2SO_4) solution, according to the following balanced chemical equation:

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$$

4.3.2 Calculate the pH of the H_2SO_4 solution (7)

[18]

ACTIVITY 5 **32 MARKS 40 MINUTES**

5.1 Define an *acid* in terms of the Lowry-Brønsted theory. (2)

5.2 Consider the reaction the reaction below:

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$

5.2.1 Identify the reactant which acts as a Lowry-Brønsted base (1)

5.2.2 Write down the FORMULA of the conjugate acid of the base identified in 8.2.1. (1)

5.3 Consider the balanced chemical equations (i) and (ii) and equilibrium constants (K_a) for the ionisation of acid HF and HI in water respectively, at 25 °C, as given below.

(i) $\mathbf{HF(g) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + F^-(aq)}$ $\mathbf{K_a = 6{,}6 \times 10^{-4}}$

(ii) $\mathbf{HI(g) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + I^-(aq)}$ $\mathbf{K_a = 3{,}2 \times 10^{9}}$

5.3.1 Define a *strong acid.* (2)

5.3.2 Which acid is stronger, HF or HI? Justify your choice. (2)

5.3.3 Which acid would be a better electrical conductor, HF or HI? Explain your answer. Assume the concentration of both acids is the same. (2)

5.3.4 The concentration of hydronium ions (H_3O^+) in a solution of **hydrofluoric acid (HF)** at equilibrium at 25 °C is 0,02 $mol \cdot dm^{-3}$.

(a) Calculate the concentration of hydroxide ions (OH^-) in the solution of hydrofluoric acid (HF) at 25 °C. (3)

(b) Write down the expression for the equilibrium constant (K_a) for reaction (i). (2)

(c) Calculate the concentration of un-ionised hydrofluoric acid (HF) in the solution at 25 °C. (3)

5.4 Consider the hydrolysis of NH_4NO_3 in water as represented by the balanced chemical equations below:

$$NH_4NO_3(s) \rightleftharpoons NH_4^+(aq) + NO_3^-(aq)$$

$$H_2O(\ell) \rightleftharpoons OH^-(aq) + H^+(aq)$$

With reference to the above equations, explain why an aqueous solution of the salt NH_4NO_3 would be weakly acidic. (4)

5.5 Katlego is given the task of determining the percentage of magnesium oxide in a health tablet. She dissolves the tablet in 0,05 dm^3 of 0,8 $mol{\cdot}dm^{-3}$ hydrochloric acid.

5.5.1 Calculate the number of moles of acid present in 0,05 dm3 of 0,8 $mol{\cdot}dm^{-3}$ hydrochloric acid solution. (3)

All of the magnesium oxide in the tablet reacts with the hydrochloric acid as shown in the balanced chemical equation below.

$$MgO(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2O(\ell)$$

Not all of the hydrochloric acid reacts. Katlego titrates the excess hydrochloric acid with a solution of sodium hydroxide. It takes 0,02 dm^3 of 0,5 $mol{\cdot}dm^{-3}$ sodium hydroxide to neutralise the excess hydrochloric acid. The hydrochloric acid and sodium hydroxide react as shown in the balanced chemical equation below.

$$NaOH(aq) + HC\ell(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

5.5.2 The original mass of the tablet is 0,96 g. Calculate the percentage of magnesium oxide in the tablet. (7)

[32]

Training and Consultancy
The path to enlightened education

SUBJECT: SUBJECT NAME

GRADE 12

2025 WINTER CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

CHEMICAL EQUILIBRIUM

Chemical Equilibrium
(This section must be read in conjunction with the CAPS, p. 125–126.)

Chemical equilibrium and factors affecting equilibrium

- Explain what is meant by:
  - Open and closed systems: An open system continuously interacts with its environment, while a closed system is isolated from its surroundings.
  - A reversible reaction: A reaction is reversible when products can be converted back to reactants and vice versa. ○ Chemical equilibrium: It is a dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction.
- List the factors that influence the position of an equilibrium, i.e. pressure (gases only), concentration and temperature.

Equilibrium constant

- List the factors that influence the value of the equilibrium constant, K_c.
  - Write down an expression for the equilibrium constant, having been given the equation for the reaction.
- Perform calculations based on K_c values.
- Explain the significance of high and low values of the equilibrium constant.

Application of equilibrium principles

- State Le Chatelier's principle: When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.
- Use Le Chatelier's principle to explain changes in equilibria qualitatively.
- Interpret graphs of equilibrium, e.g. concentration/rate/number of moles/mass/ volume versus time.

IMPORTANT TERMS AND DEFINITIONS

TERMS AND DEFINITIONS	
Open system	A system which continuously interacts with the environment – it exchanges matter and energy with its environment.
Closed system	A system that only exchanges energy with its surroundings, but it does not exchange matter with its surroundings.
Reversible reaction	A reaction is reversible when products can be converted back to reactants.
Chemical equilibrium	Dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction.
Factors that influence the equilibrium position	Pressure (gases only), concentration and temperature.
Le Chatelier's principle	When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.

CHEMICAL EQUILIBRIUM

Equilibrium and list the factors that influence the position of equilibrium (i.e. **Pressure (gases only), Concentration** and **Temperature)**.

NB: Most industrial processes in the manufacture of fertilizers are equilibrium reactions. So ask learners to write down K_c expression for the various stages of industrial processes discussed.

- Explain the significance of high and low values of the equilibrium constant.
- Perform calculations based on Kc values.
- Explain the use of rate and equilibrium principles in the Haber process and the contact process.

NB: Explain why the a high yield of NH_3 in the Haber process will be achieved at **Higher Pressure** and **Lower Temperature** in terms of Le Chatelaine's Principle. **Application of Le Chatelier's Principle**

When Le Chatelier's Principle is used to predict the influence of a disturbance on an existing equilibrium, the following steps must be followed:

- Identify the disturbance
- Indicate the action of the system on the disturbance.
- Indicate how the system will oppose the disturbance.
- Indicate what the result of the action will be on the system.

USEFUL GUIDELINES WHEN APPLYING LE CHATELIER'S PRINCIPLE

EQULILIBRIUM SYSTEMS tend to compensate for the effects of perturbing influences.

- If the ***concentration of a solute reactant is increased,*** the equilibrium position shifts to use up the added reactants by producing more product. Thus favouring the forward reaction in the direction of products.

- If the ***concentration of a solute reactant is decreased***, the equilibrium position shifts to replace the removed reactants by producing more reactants. Thus, favoring the reverse reaction in the direction of reactants.

- If the ***concentration of a solute product is increased***, the equilibrium position shifts to use up the added products by producing more reactants. Thus, favoring the reverse reaction in the direction of reactants.

- If the ***concentration of a solute product is decreased***, the equilibrium position shifts to replace the removed products by producing more products. Thus, favouring the forward reaction in the direction of products.

- If the ***pressure on an equilibrium system is*** i***ncreased***, then the equilibrium position shifts to reduce the pressure. This can be done by favouring the reaction that produces the ***least*** number of gas molecules.

- If the ***pressure on an equilibrium system is decreased***, then the equilibrium position shifts to increase the pressure. This can be done by favouring the reaction that produces the ***greatest*** number of gas molecules.

- ***If the volume of a gaseous equilibrium system is reduced (equivalent to an increase in pressure)*** then the equilibrium position shifts to increase the volume (equivalent to a decrease in pressure).

- ***If the volume of a gaseous equilibrium system is increased (equivalent to an decrease in pressure)*** then the equilibrium position shifts to decrease the volume (equivalent to an increase in pressure).

- If the ***temperature*** of a forward **ENDOTHERMIC** equilibrium system ***is increased***, the equilibrium position shifts to use up the heat by producing more products. A ***decrease in temperature*** favours the exothermic reaction in the direction of reactants.

- If the ***temperature*** of a forward **EXOTHERMIC** equilibrium system ***is increased***, the equilibrium position shifts to use up the heat by producing more reactants. ***A decrease in temperatur***e favours the exothermic reaction in the direction of products.

- *Catalyst added*: No change in Equilibrium. Equilibrium is only reached much sooner/ faster.

Note: In an equilibrium involving gases, the addition of another gas that is not part of reaction taking place does not disturb the reaction.

CHANGING THE FACTORS THAT AFFECT A STATE OF DYNAMIC CHEMICAL EQUILIBRIUM AND PREDICTING THE EFFECTS:

Consider the following reaction that is at equilibrium in a closed container:

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad (\Delta H < 0)$$

Factor	Change of Factor	Effect on reaction rate	Reaction favoured	Change in the amount of products	Change in the amount of reactants	Change in K_c
Temperature	Increase in Temperature	Both forward and reverse reaction rates increase BUT **rate of reverse reaction is faster**	Reverse reaction	Amount of product (N_2O_4) **decreases**	Amount of reactants (NO_2) **increases**	Decreses
	Decrease in temperature	Both forward and reverse reaction rates decrease BUT **rate of forward reaction is faster**	Forward reaction	Amount of product (N_2O_4) **increases** BUT takes long time to do so	Amount of reactants (NO_2) **decreases**	Increases
Concentration	Increase in concentration of a reactant [NO_2]	Overall reaction rate increases BUT **rate of forward reaction is faster**	Forward reaction	Amount of product (N_2O_4) **increases**	Amount of reactants (NO_2) **decreases**	Remains the same
	Increase in concentration of a product [N_2O_4]	Overall reaction rate increases BUT **rate of reverse reaction is faster**	Reverse reaction	Amount of product (N_2O_4) **decreases**	Amount of reactants (NO_2) **increases**	Remains the same
	Decrease in concentration of a reactant [NO_2]	Overall reaction rate decreases BUT **rate of reverse reaction is faster**	Reverse reaction	Amount of product (N_2O_4) **decreases**	Amount of reactants (NO_2) **increases**	Remains the same
	Decrease in concentration of a product [N_2O_4]	Overall reaction rate decreases **BUT rate of forward reaction is faster**	Forward reaction	Amount of product (N_2O_4) **increases**	Amount of reactants (NO_2) **decreases**	Remains the same
Pressure	Increase in pressure by decreasing volume of gas in container	Both forward and reverse reaction rates increase BUT **rate of forward reaction is faster**	Forward reaction	Amount of product (N_2O_4) **increases**	Amount of reactants (NO_2) **decreases**	Remains the same
	Decrease in pressure by increasing volume of gas in container	Both forward and reverse reaction rates decrease BUT **rate of reverse reaction is faster**	Reverse reaction	Amount of product (N_2O_4) **decreases**	Amount of reactants (NO_2) **Increases**	Remains the same
Catalyst	Adding a Catalyst	Both forward and reverse reaction rates increase ***equally***	None are favoured	Remains the same	Remains the same	Remains the same

ACTIVITY 1 10 MARKS 10 MINUTES

MULTIPLE-CHOICE QUESTIONS

Various options are provided as possible answers to the following questions. Each question has only ONE correct answer. Write only the letter (A–D) next to the question number (1.1–1.5) in the ANSWER BOOK.

1.1 What is the effect of an increase of temperature on the yield and the equilibrium constant for the following reaction?

$$2H_2(g) + CO(g) \rightleftarrows CH_3OH(\ell) \quad \Delta H = -128 \text{ kJ}$$

	Yield	Equilibrium constant
A	Increases	Increases
B	Increases	Decreases
C	Decreases	Increases
D	Decreases	Decreases

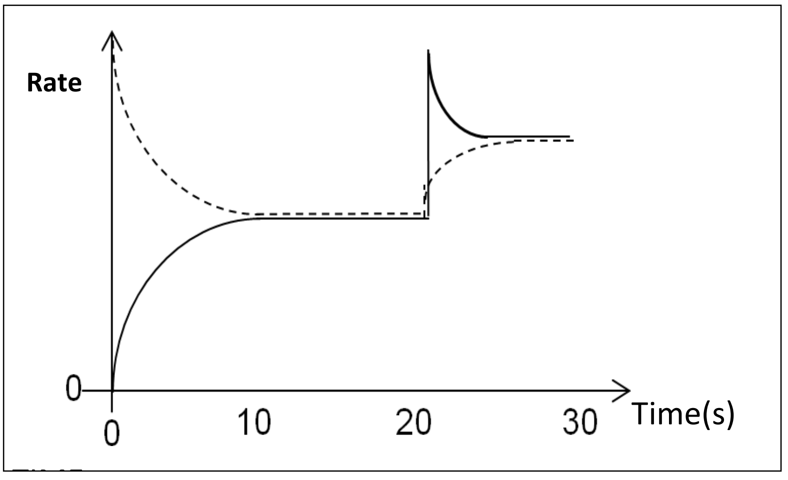
(2)

1.2 Gas X_2Y is introduced into a container, which is then sealed. The gas decomposes and the reaction reaches equilibrium. The balanced chemical equation for the reaction is:

$$2X_2Y(g) \rightleftharpoons 2X_2(g) + Y_2(g) \qquad \Delta H > 0$$

At t = 20 s, a change is made to the reaction in equilibrium. The graph below shows the changes in the **rates** of the forward and reverse reactions with time.

Which one of the following gives the change made at t = 20 s?



A Increase in temperature
B Increase in pressure
C Decrease in temperature
D Decrease in pressure (2)

1.3 Chromate ions and dichromate ions are in equilibrium with each other in an aqueous solution according to the following balanced equation:

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(\ell)$$

yellow **orange**

Which ONE of the following reagents should be added to change the colour of the solution to yellow?

A HNO_3
B $HC\ell$
C NaOH
D CH_3COOH (2)

1.4 Which one of the following is FALSE regarding a reaction that is at chemical equilibrium?

A The concentration of reactants is always equal to the concentration of products.
B The amount of reactants and products always remains constant.
C The rate of the forward reaction is always equal to the rate of the reverse reaction.
D It can only occur in a closed system. (2)

1.5 The following reaction reaches equilibrium in a sealed container:

$$2NOC\ell(g) \rightleftharpoons 2NO(g) + C\ell_2(g) \quad \Delta H < 0$$

Which one of the following changes will NOT affect the equilibrium amount of nitrogen monoxide (NO)?

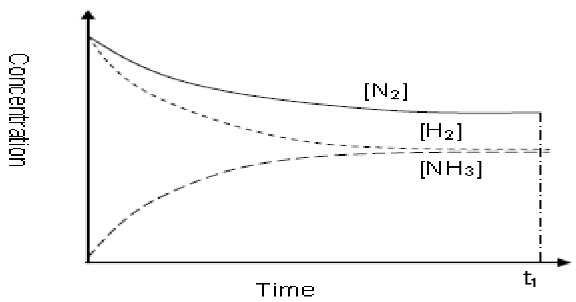
A An increase in temperature.
B The addition of inert argon gas.
C The removal of $C\ell_2$.
D A decrease in the volume of the container. (2)

ACTIVITY 2 **8 MARKS 10 MINUTES**

2.1 When ammonia is prepared in industry, the following **dynamic** equilibrium is established:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92 \text{ kJ}$$

The graph which follows represents the concentration of the substances which form part of the above chemical reaction over time.



2.1.1 Why is the equilibrium said to be "**dynamic**"? (2)

2.1.2 What do the parts of the graph that are parallel with the x-axis represent? (1)

2.1.3 What information can be obtained from the graph with regards to the concentrations of the different substances at the start of the reaction? (2)

2.1.4 What effect will the following changes have on the concentration of NH_3? Write only INCREASES, DECREASES or STAYS THE SAME as your answer.

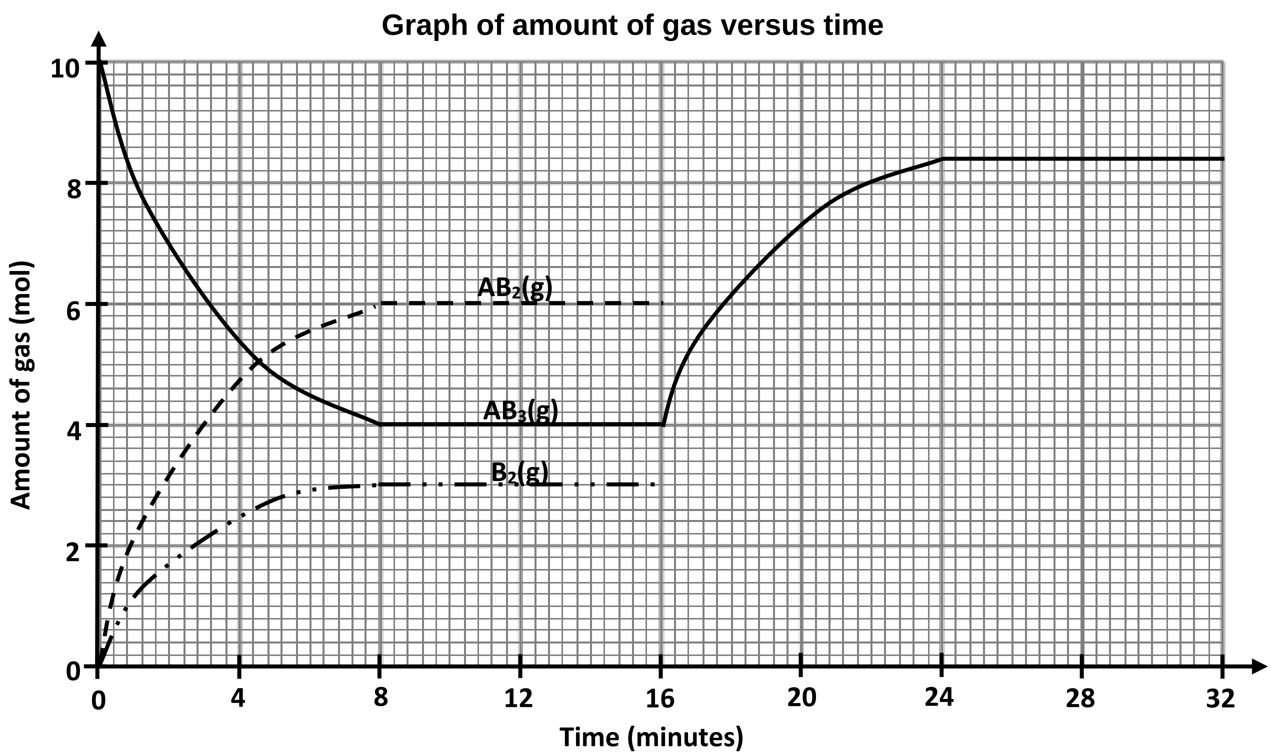
(i) The concentration of H_2 is increased at t_1. (1)
(ii) The temperature is increased at t_1. (1)
(iii) The pressure is increased at t_1. (1)

[8]

ACTIVITY 3 **16 MARKS 20 MINUTES**

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

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



3.1 At 16 minutes, one of the conditions affecting the equilibrium is changed at constant volume and a new equilibrium is thereafter established.

Calculate, the K_c value at the new equilibrium. (8)

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

3.3 Was the condition identified in QUESTION 3.2 INCREASED or DECREASED? (1)

3.4 Use Le Chatelier's principle to explain the answer to QUESTION 3.3. (3)

3.5 How does the equilibrium constant, K_c, between t = 8 minutes and t = 16 minutes compare to that between t = 24 minutes and t = 32 minutes?

Write down only GREATER THAN, SMALLER THAN or EQUAL TO. (1)

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

(1)

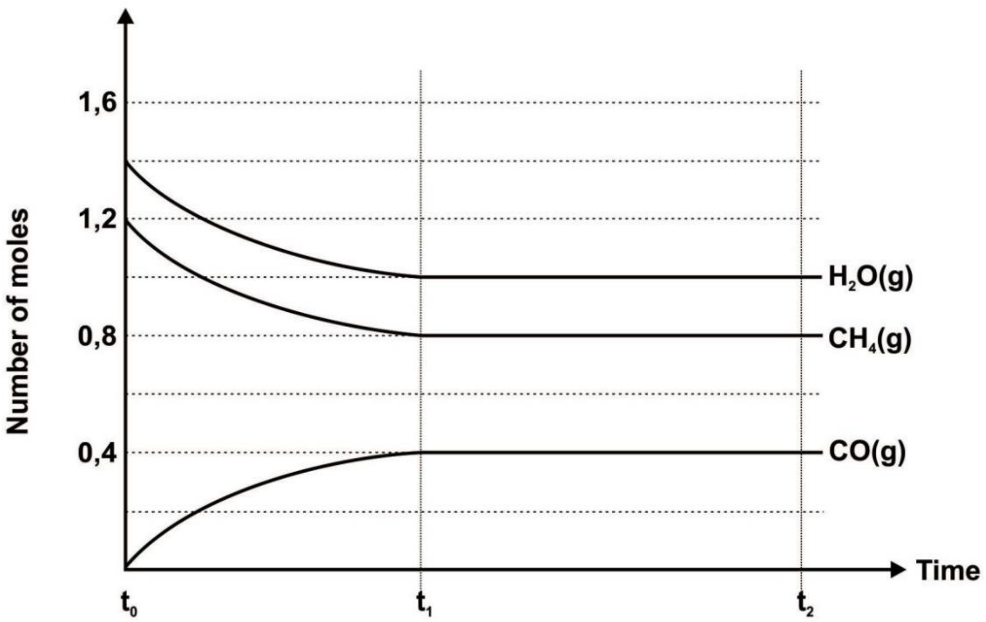
[16]

ACTIVITY 4 **21 MARKS 25 MINUTES**

The hydrogen gas used in the Haber process is prepared by the reaction of methane and steam as shown in the following balanced chemical equation.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \quad \Delta H = +206 \text{ KJ}$$

Initially 1,2 moles of methane and 1,4 moles of steam are placed in a closed container. They react and then dynamic chemical equilibrium is reached at a fixed temperature. The following graph shows the changes in the number of moles of methane, steam and carbon monoxide as the reaction proceeds.



4.1 State why there is no change in the number of moles of each of the gases between times t_1 and t_2. (2)

4.2 The above graph has been reproduced on your ANSWER SHEET. On the graph on your ANSWER SHEET:

4.2.1 Draw a line to show the change in the number of moles of hydrogen gas between t_0 and t_2. **Label this line $H_2(g)$**. (2)

4.2.2 Draw a **dashed line** (- - -) to show how the number of moles of methane gas would change with time if a catalyst had been added to the container at time t_0. (2)

4.3 Calculate the value of the equilibrium constant, K_c, at the fixed temperature used in this reaction. The volume of the container is 2 dm^3. (6)

4.4 What does the Kc value indicate about the yield of products? (1)

4.5 State *Le Chatelier's principle*. (2)

4.6 How will an increase in pressure affect the yield of hydrogen? Explain. (3)

4.7 How will an increase in pressure affect the equilibrium constant, K_c, for this reaction?

Choose from **INCREASES**, **DECREASES or NO CHANGE**. (1)

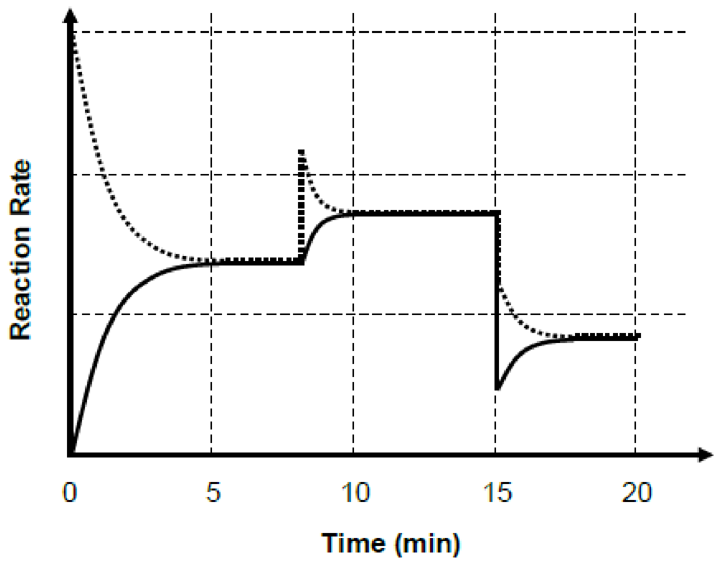
4.8 This reaction is carried out in industry at a temperature of 1 000 °C. State TWO reasons why high temperatures are an advantage. No explanations are required. (2)
[21]

QUESTION 5 — 10 MARKS 10 MINUTES

The reaction represented by the following balanced chemical equation is important in the Contact Process for the industrial production of sulfuric acid:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Dikeledi adds some sulfur dioxide and oxygen to a container and then seals the container. He monitors the rates of the forward and reverse reactions over time and the following graph is obtained:



5.1 After what time was dynamic equilibrium reached for the first time? (1)

5.2 Write down the equation for the reaction represented by the solid line. (2)

5.3 State *Le Châtelier's principle*. (2)

5.4 At 8 minutes, more oxygen gas was added to the container whilst maintaining a constant temperature and volume of container.

With reference to Le Châtelier's principle, fully explain how the amount of sulphur dioxide was affected when the equilibrium was re-established. (3)

5.5 At 15 minutes, the temperature of the reaction mixture was suddenly decreased.

7.5.1 From the graph, determine and write down which reaction (FORWARD or REVERSE) was initially favoured. (1)

7.5.2 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? (1)

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