



KWAZULU-NATAL PROVINCE

EDUCATION
REPUBLIC OF SOUTH AFRICA

CURRICULUM GRADE 10 -12 DIRECTORATE

NCS (CAPS)

LEARNER SUPPORT DOCUMENT



GRADE 12

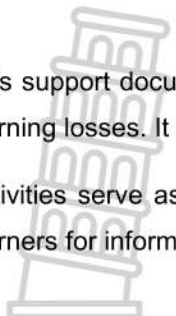
**PHYSICAL SCIENCES WINTER
REVISION DOCUMENT**

2026

PREFACE

This support document serves to assist Physical Sciences learners on how to deal with curriculum gaps and learning losses. It addresses Term 1 and Term 2 topics.

Activities serve as a guide on how various topics are assessed at different cognitive levels and to prepare learners for informal and formal tasks in Physical Sciences. It covers the following topics:



This support document covers the following topics:

No.	Topic	Pages
1.	Vertical Projectile Motion	3-17
2.	Momentum/ Impulse	17-24
3.	Organic Molecules	24-41
4.	Work Energy and Power	41-52
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6.	Rates of Reaction	66-93
7.	Chemical Equilibrium	94-111
8.	Acids and Bases	112-120

VERTICAL PROJECTILE MOTION

Worked Example 1

Scenario 1 - Object thrown upwards and returns to starting point

An object is thrown vertically upwards, at a velocity of $12 \text{ m}\cdot\text{s}^{-1}$ and returns to the thrower's hand.

NOTE:

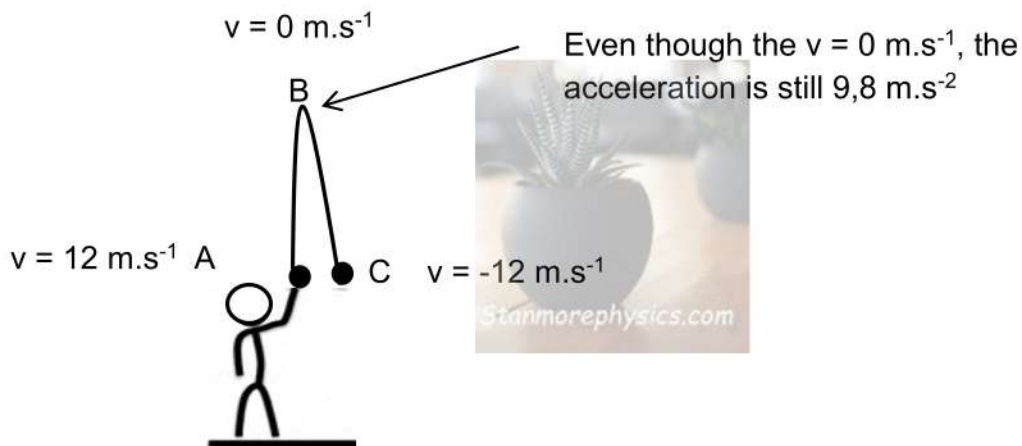
For a free-falling body that is thrown upwards and returns to the thrower's hand:

- The time taken for the upward motion (from the starting point to maximum height) is equal to the time taken for the downward motion (from the maximum height back to the starting point).
- The magnitude of the velocity at which the object leaves the thrower's hand is equal to the velocity at which the object returns to the thrower's hand, although the velocities are in the opposite direction.
- The velocity at the turning point (maximum height) is $0 \text{ m}\cdot\text{s}^{-1}$

Step 1: Choose a positive direction [**DO NOT CHANGE** the positive sign convention during the question].

Upwards Positive [$a = -9.8 \text{ m}\cdot\text{s}^{-2}$]

Step 2 Draw a sketch of the motion, indicating all known values



1.1 Calculate the:

1.1.1 Time taken to reach the highest point.

[Motion from A – B]

$$v_f = v_i + a\Delta t$$

$$0 = 12 + (-9.8) \Delta t$$

$$\Delta t = 1.22 \text{ s}$$

Additional Note:

Since the time from A – B is 1.22 s , the time from B – C will also be 1.22 s

1.1.2 Distance of the maximum height above the thrower's hand.

Solution: [Motion from A – B]

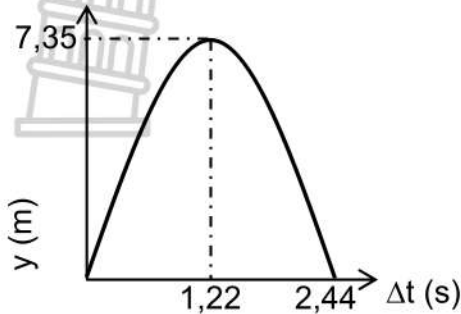
$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

$$\Delta y = 12(1.22) + \frac{1}{2}(-9.8)(1.22)^2$$

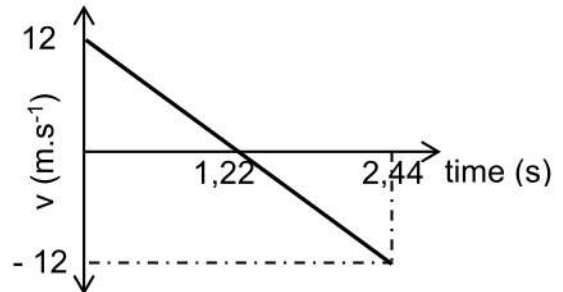
$$\Delta y = 7.35 \text{ m}$$

Graphs for this motion

Position – Time Graph



Velocity – Time Graph



Worked Example 2

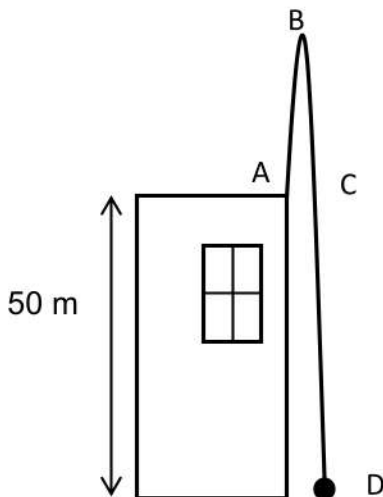
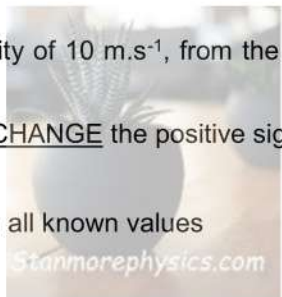
Scenario 2 - Object thrown upwards from some height above the ground (e.g. from the top of a building or a cliff).

An object is thrown vertically upwards, at a velocity of 10 m.s^{-1} , from the edge of a 50 m building and lands at the bottom of the building.

Step 1: Choose a positive direction [DO NOT CHANGE the positive sign convention during the question]

Upwards Positive [$a = -9.8 \text{ m.s}^{-2}$]

Step 2 Draw a sketch of the motion, indicating all known values



From the problem statement:

- $V_A = 10 \text{ m.s}^{-1}$

From previous example:

- $V_B = 0 \text{ m.s}^{-1}$
- $V_C = -10 \text{ m.s}^{-1}$
- Time from A-B = Time from B-C

2.1 Calculate the:

2.1.1 Maximum height the object reaches above the ground

Solution:

[Motion from A – B]



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

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

$$\Delta y = 5,1 \text{ m}$$

[This is only the height from the top of the building to the max. height. Since we require the height above the ground, we have to add the height of the building]

$$\text{Height} = 50 + 5,1 = 55,1 \text{ m}$$

2.1.2 Velocity at which the object strikes the ground.

Solution:

[Motion from A – D]



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

$$v_f^2 = 10^2 + 2(-9,8)(-50)$$

$$v_f = -32,86 \text{ m}\cdot\text{s}^{-1}$$

[Note: the negative answer obtained from the square root was taken since the object is moving downwards]

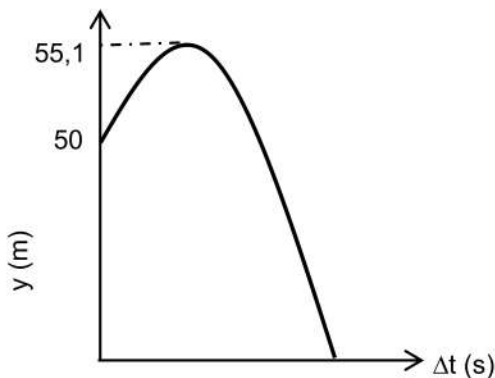
$$v_f = 32,86 \text{ m}\cdot\text{s}^{-1} \text{ downwards}$$



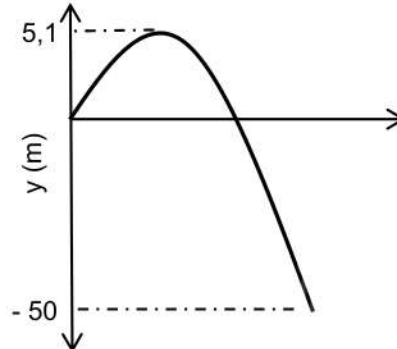
Graphs for this motion

The Position – Time Graph depends on the ZERO REFERENCE position. This indicates the point of the motion where the position of the object is 0 m.

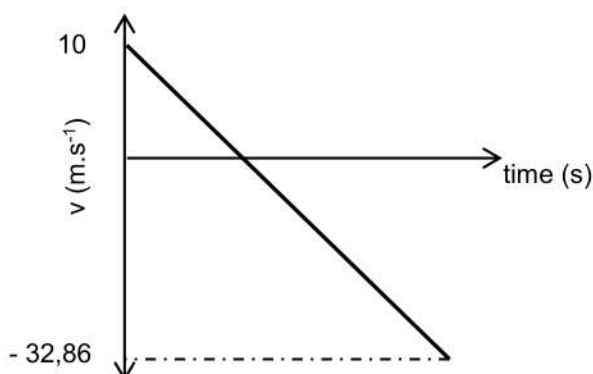
Position – Time Graph (Ground taken as Zero position)



Position – Time Graph (Top of the building taken as Zero position)



Velocity – Time Graph [The velocity- time graph will be the same regardless of the choice of zero position]



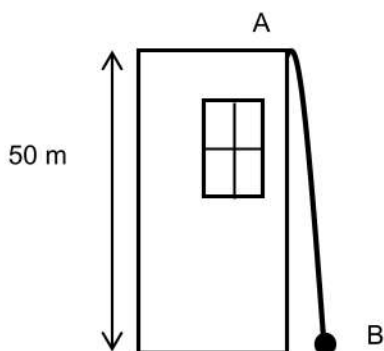
The line below the x-axis must be longer than the line above the x-axis

ADDITIONAL:

The displacement and velocity values used in the equations of motion will depend on the two points between which the object is moving. The acceleration value will stay the same. See the table below:

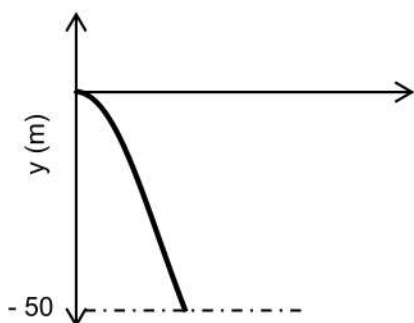
Motion	v_i ($m \cdot s^{-1}$)	v_f ($m \cdot s^{-1}$)	Δy (m)
A to B	$v_A = 10$	$v_B = 0$	5.1
B to C	$v_B = 0$	$v_C = -10$	-5,1
B to D	$v_B = 0$	$v_D = -32,86$	-55,1
A to D	$v_A = 10$	$v_D = -32,86$	-50

Scenario 3 — Object dropped from starting point [Upward taken as positive and the top of the building taken as the zero position]

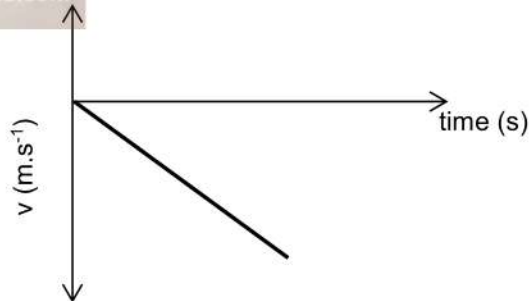


Since the object is DROPPED, the velocity at "A" is $0 m \cdot s^{-1}$.

Position – Time Graph (Top of the building taken as Zero position)



Velocity – Time Graph



NOTE: If an object is thrown downwards from some height above the ground:

Similar to Scenario 3, EXCEPT that the velocity at Point "A" will NOT be $0 m \cdot s^{-1}$. The velocity at "A" will be the velocity at which the object is thrown.

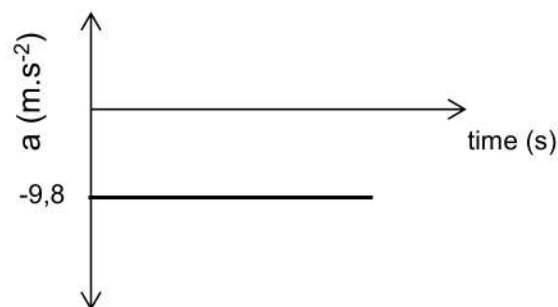
Acceleration – Time Graph

Constant Acceleration - Horizontal lines

Acceleration – Time Graph
Downwards Positive
 $a = 9,8 \text{ m.s}^{-2}$

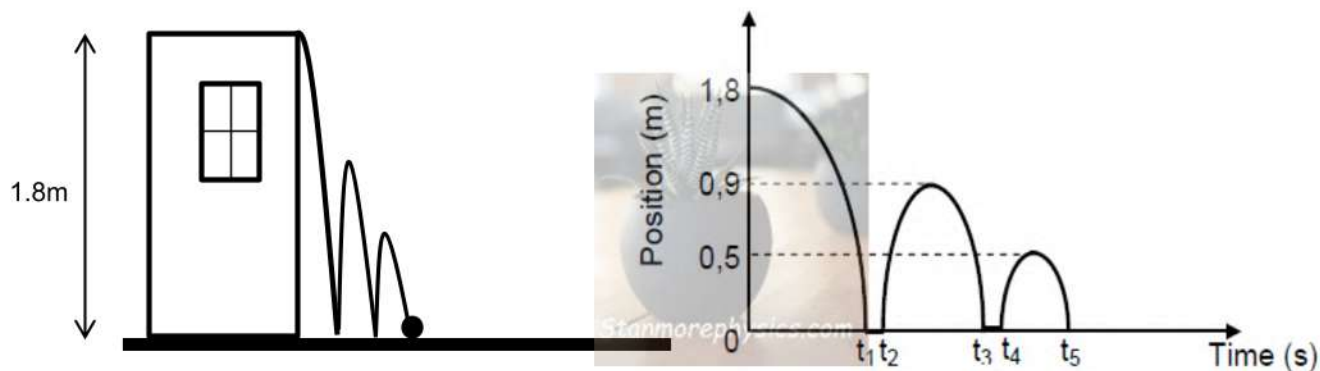


Acceleration – Time Graph
Upwards Positive
 $a = -9,8 \text{ m.s}^{-2}$

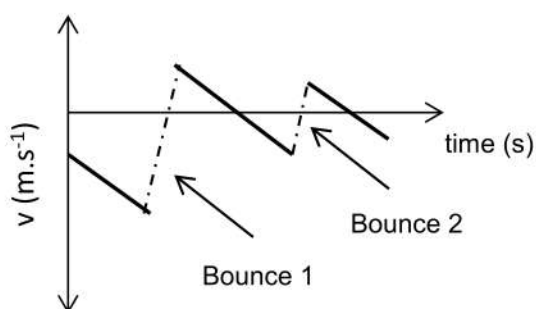


Scenario 4 – Bouncing Ball

An object is projected vertically downwards from the edge of a building and thereafter bounces on the ground below. Upward direction is taken as positive and the ground is taken as the Zero position.



Velocity – Time Graph



Note

(Refer to position – time graph):

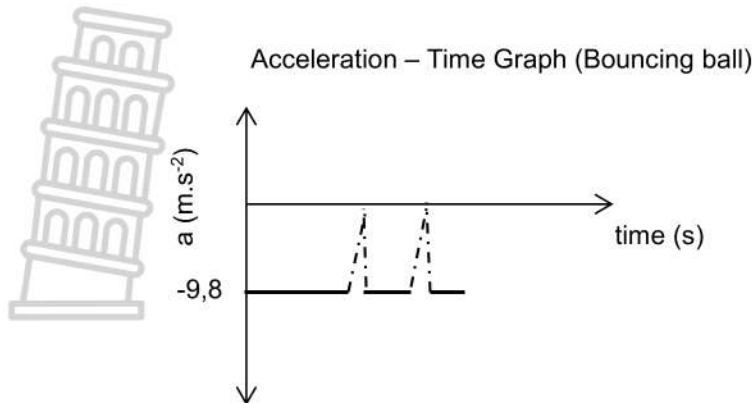
The time from t_1 to t_2 is the contact time for the first bounce.

The time from t_3 to t_4 is the contact time for the second bounce.

Note:

(Refer to the velocity – time graph)

- The lines must be drawn parallel.



MULTIPLE CHOICE QUESTIONS
QUESTION 1

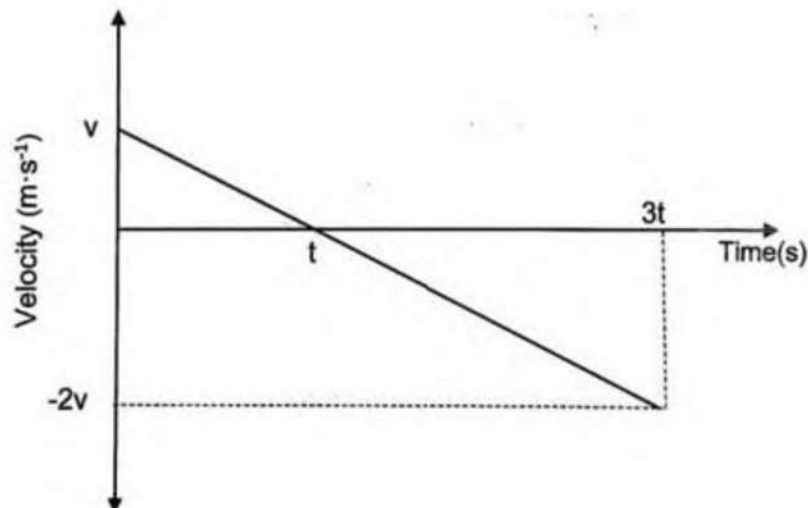
1.1 A ball is thrown vertically upwards and returns to the starting point.

Which ONE of the following statements regarding *the rate of change of velocity* of the ball is TRUE?

- A Its direction when it is moving upward is opposite from the direction when it is moving downwards.
- B It is always directed downwards during the motion.
- C It is zero at the maximum height reached.
- D It is always in the same direction as the velocity of the ball.

(2)

1.2 The velocity-time graph below represents the motion of an object under the influence of gravitational force only.



The displacement of the object after $3t$ seconds is...

- A vt
- B $-vt$
- C $-\frac{3}{2}vt$
- D zero

(2)

1.3 Ball **A** of mass **m** is projected vertically upwards from the ground with an initial velocity **v**. It rises to a maximum height **h** above the ground.

Ball **B** of mass $\frac{1}{2}m$ is now projected vertically upwards from the ground with an initial velocity of **2v**. Ignore the effects of air friction.

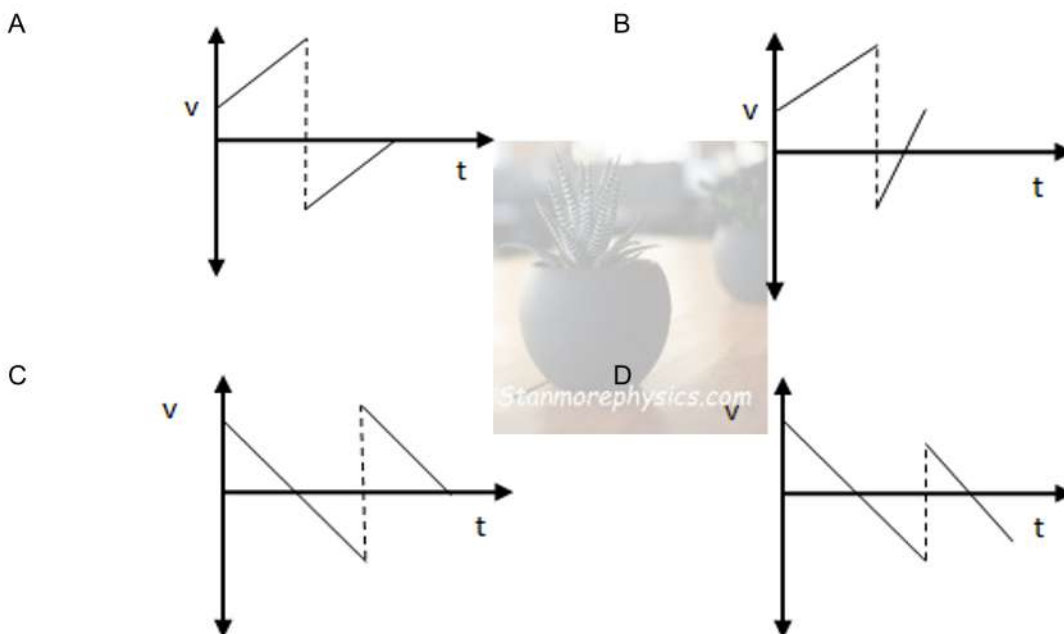
What is the maximum height above the ground to which Ball B rises?

- A h
- B $\sqrt{2}h$
- C 2h
- D 4h

(2)

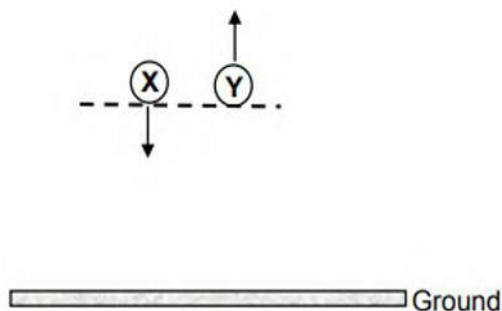
1.4 An object is thrown vertically downwards towards the ground from height **h**, with a velocity **v**. The object strikes the ground and bounces upwards. It is caught when it reaches its maximum height after the bounce.

Which of the following graphs for velocity versus time best represents the motion of the object?



(2)

1.5 Balls X and Y have the same mass and are thrown from a certain height. Ball X is thrown downwards and Ball Y is thrown upwards at the same speed.



How do the speeds, v_X and v_Y , and the kinetic energies, E_{kX} and E_{kY} , of the balls compare when they strike the ground?

	SPEED	KINETIC ENERGIES
A	$v_x < v_y$	$E_{kx} > E_{ky}$
B	$v_x > v_y$	$E_{kx} > E_{ky}$
C	$v_x = v_y$	$E_{kx} = E_{ky}$
D	$v_x < v_y$	$E_{kx} < E_{ky}$

(2)

1.6 A girl throws a ball upwards.

Which ONE of the following combinations give the DIRECTIONS of the ball's velocity, acceleration, and the net force that the ball experiences as it travels upwards just after leaving the girl's hand?

	Velocity	Acceleration	Net Force
A	Upward	Downward	Downward
B	Upward	Upward	Upward
C	Downward	Downward	Downward
D	Upward	Downward	Upward

(2)

1.7 A ball is dropped from a height h and hits the ground with a speed v . The speed of the ball at the moment when it reaches half its initial height is...

- A v
- B $\frac{v}{\sqrt{2}}$
- C $\frac{v}{2}$
- D $\frac{v}{4}$



(2)

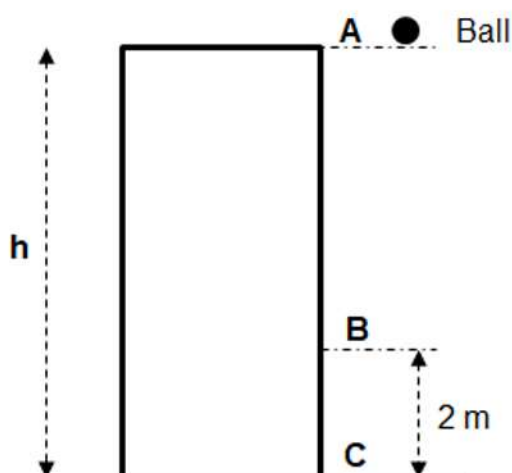
[14]

LONG QUESTIONS

QUESTION 2

An experiment is set up to determine the height h of a building. A tennis ball is dropped from point **A** at the top of the building as shown in the diagram below. Point **B** is 2 m above the ground and the ball takes 0,125 seconds to cover the distance from point **B** to point **C** on the ground.

Ignore the effects of air friction.



2.1 Write down the magnitude of the rate of change of velocity of the ball at point B.

(1)

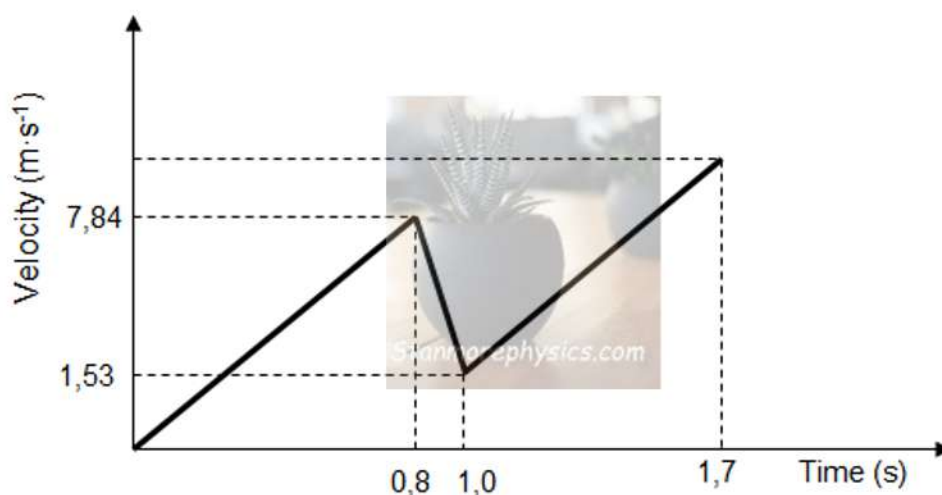
2.2 Calculate the:

- 2.2.1 Height, h , of the building (5)
- 2.2.2 Time taken for the ball to reach the ground (4)
- 2.2.3 Velocity with which the ball strikes the ground (3)
- 2.3 Sketch the velocity versus time graph for the motion of the ball from the moment it was dropped until it strikes the ground. (4)
- Clearly indicate the following on your graph:
- The initial velocity
 - The velocity with which the ball strikes the ground
 - Time when the ball strikes the ground

(4)
[17]

QUESTION 3

A ball of mass 175 g falls from a tree and breaks the glass roof of a wooden cabin directly below it. The ball then continues to fall freely until it strikes the ground. The velocity-time graph below represents the motion of the ball when it left the tree until it strikes the ground.



- 3.1 Define the term *projectile*. (2)
- 3.2 Calculate, WITHOUT USING EQUATIONS OF MOTION, the distance the ball fell from the instant it left the tree until it reaches the glass roof. (4)
- 3.3 Write down the time that the ball was in contact with the glass roof. (1)
- 3.4 Calculate the average net force acting on the ball while it was in contact with the glass roof. (4)
- 3.5 Calculate the speed with which the ball strikes the ground. (3)
- 3.6 How does the magnitude of the force exerted by the ball on the glass roof compare to that of the force exerted by the glass roof on the ball? Choose from GREATER THAN, LESS THAN or EQUAL TO. (1)

[15]

QUESTION 4

Ball **A** is thrown vertically upwards from the top of a building 15 m high. 1,5 seconds later ball **B** is launched upwards from the ground below at $18 \text{ m}\cdot\text{s}^{-1}$. BALL B IS MOVING UPWARDS when they pass each other at point **P**, 12 m above the ground.



4.1 Calculate the initial velocity of ball A.

(Hint: Pay careful attention to the significance of the two time values obtained for ball B at point P). (6)

4.2 Sketch the position-time graph for both balls on the same set of axes. Use the letter A to label the graph for ball A and the letter B to label the graph for ball B. Take the ground as the zero-reference position.

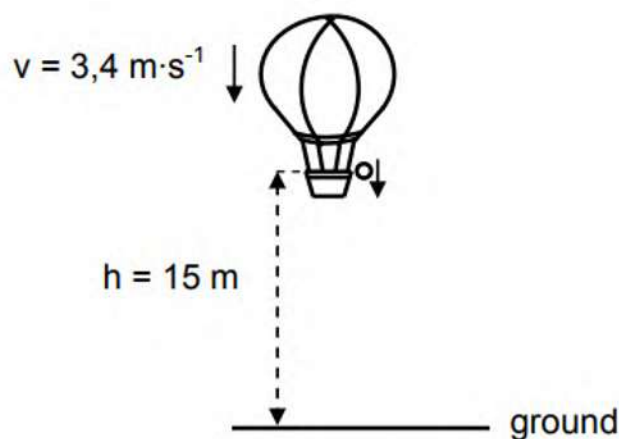
Indicate the following on the graph:
 The initial position of ball A.
 The position at which the balls meet.
 The time when ball B is launched.



(5)
 [11]

QUESTION 5

A hot-air balloon moves vertically downwards at a constant velocity of $3,4 \text{ m}\cdot\text{s}^{-1}$. When the balloon is 15 m above the ground, a small ball is dropped from the balloon. Refer to the diagram below.



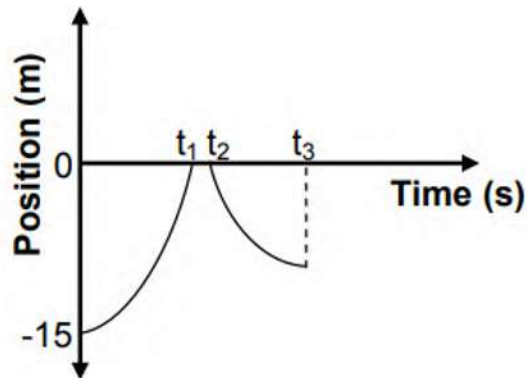
The ball strikes the ground and bounces vertically upwards. The hot-air balloon continues to move downwards at the same constant velocity.

Ignore the effects of air friction acting on the ball.

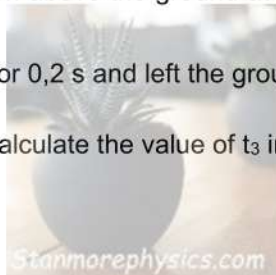
5.1 Define the term *free fall*.

(2)

The sketch graph below (not drawn to scale) represents the positions of the ball relative to the ground from the time the ball is dropped until the time it reaches its maximum height after the first bounce.



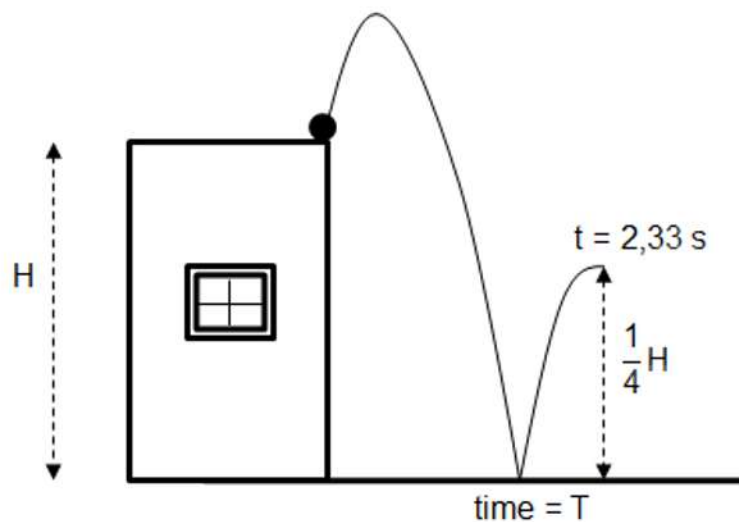
- 5.2 Was the ball in free fall between t_1 and t_2 seconds? Write down either YES or NO. (1)
- 5.3 Use only EQUATIONS OF MOTION to calculate: (3)
- 5.3.1 The value of t_1 indicated on the graph (3)
- 5.3.2 The height of the hot-air balloon above the ground at the instant when the ball struck the ground (4)
- 5.4 The ball was in contact with the ground for 0,2 s and left the ground with a vertical upward velocity of 7,2 m·s⁻¹. (4)
- Use only EQUATIONS OF MOTION to calculate the value of t_3 indicated on the graph. [14]



QUESTION 6

A rubber ball is thrown vertically upwards at $5 \text{ m}\cdot\text{s}^{-1}$ from the top of a building of height H . The ball strikes the ground at time T and immediately bounces to a maximum height of $\frac{1}{4}H$ 2,33 seconds after it was thrown

Ignore the effects of air friction. Neglect the time that the ball is in contact with the ground.



- 6.1 Determine the speed at which the ball leaves the floor in terms of: (4)
- 6.1.1 H (4)
- 6.1.2 T (4)

6.2 Hence show that H in terms of T is written as:

$$H = \frac{(22,834 - 9,8T)^2}{4,9} \quad (1)$$

6.3 Determine the height H in terms of T, for the motion before the ball strikes the ground. (3)

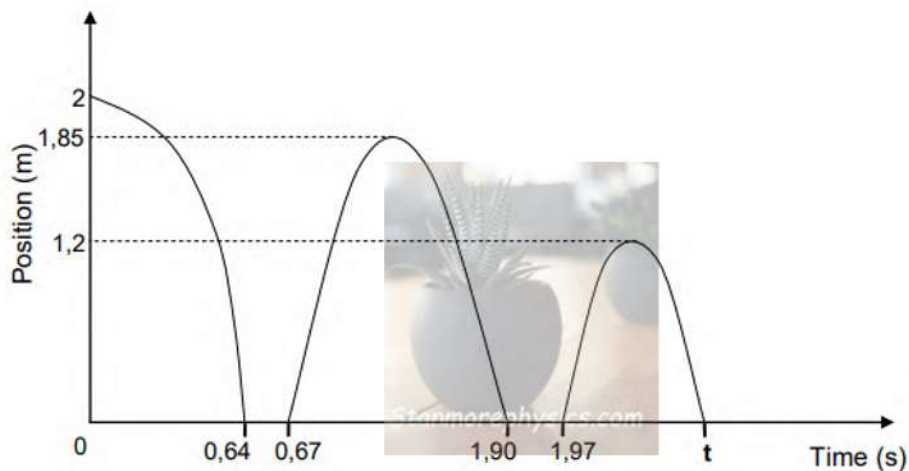
6.4 Hence calculate the value of T. (3)

[15]

QUESTION 7

A small ball is dropped from a height of 2 m and bounces a few times after landing on a cement floor. Ignore air friction.

The position-time graph below, not drawn to scale, represents the motion of the ball.



7.1 Name the force acting on the ball while it is in free fall. (1)

7.2 Use the graph and determine the:

7.2.1 Time that the ball is in contact with the floor before the first bounce (2)

7.2.2 Time it takes the ball to reach its maximum height after the first bounce (2)

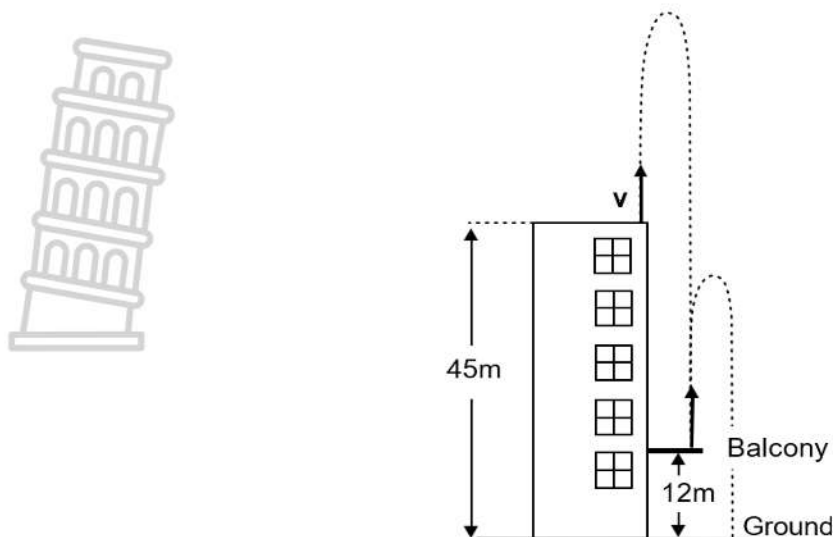
7.2.3 The speed at which the ball leaves the floor at the first bounce (3)

7.2.4 Time t indicated on the graph (6)

[14]

QUESTION 8

A soft ball with a mass of 0,3 kg is projected vertically upwards from the roof of a 45 m tall building with velocity v . It hits the balcony below with a velocity of $29,36 \text{ m}\cdot\text{s}^{-1}$, and bounces off with a velocity of $13,77 \text{ m}\cdot\text{s}^{-1}$. The balcony is 12 m above the ground, as shown below. Ignore the effects of friction.



- 8.1 Define the term *Projectile*. (2)
- 8.2 Calculate the:
- 8.2.1 Magnitude of the velocity v , with which the ball was thrown from the roof of the building. (4)
- 8.2.2 Velocity with which the ball strikes the ground. (3)
- It takes 8,2 s from the time the ball is projected from the roof until it strikes the ground.
- 8.3 Calculate the NET FORCE that acts on the ball when it hits the balcony. (7)

[16]

QUESTION 9

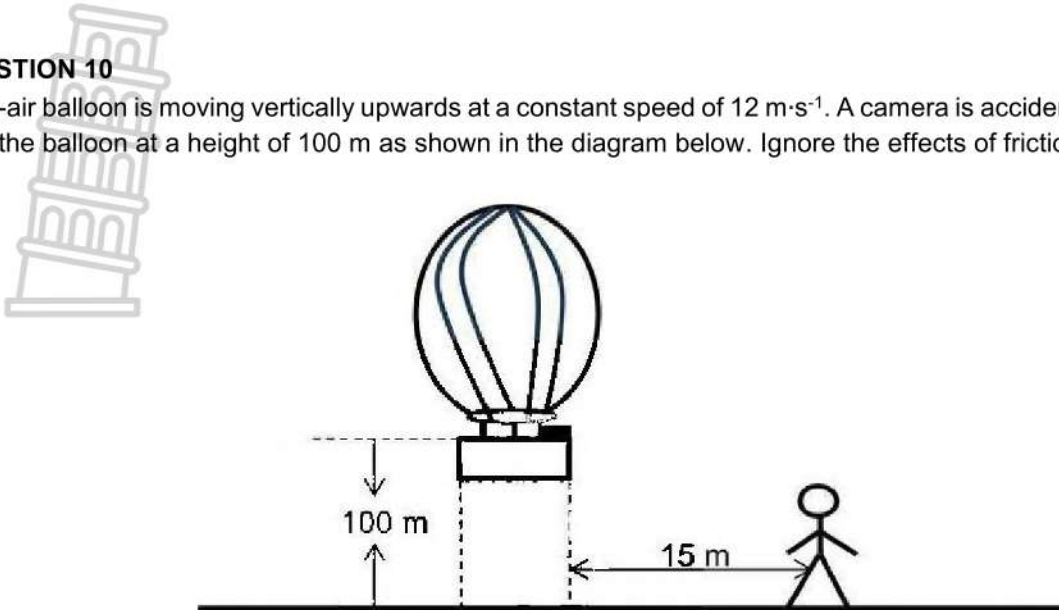
A ball is thrown vertically upwards from the top of a building at a velocity of $20 \text{ m}\cdot\text{s}^{-1}$. The velocity-time graph for the motion of the ball is shown below. Ignore air resistance.



- 9.1 Define a *projectile*. (2)
- 9.2 Write down the magnitude and direction of the acceleration of the ball. (2)
- 9.3 Determine the:
- 9.3.1 Time taken for the ball to reach the maximum height (3)
- 9.3.2 Maximum height reached by the ball above the building (3)
- The ball continues in its motion and hits the ground 5 seconds after it was thrown.
- 9.4 Calculate the:
- 9.4.1 Speed with which the ball hits the ground (3)
- 9.4.2 Height of the building (4)

QUESTION 10

A hot-air balloon is moving vertically upwards at a constant speed of $12 \text{ m}\cdot\text{s}^{-1}$. A camera is accidentally dropped from the balloon at a height of 100 m as shown in the diagram below. Ignore the effects of friction.



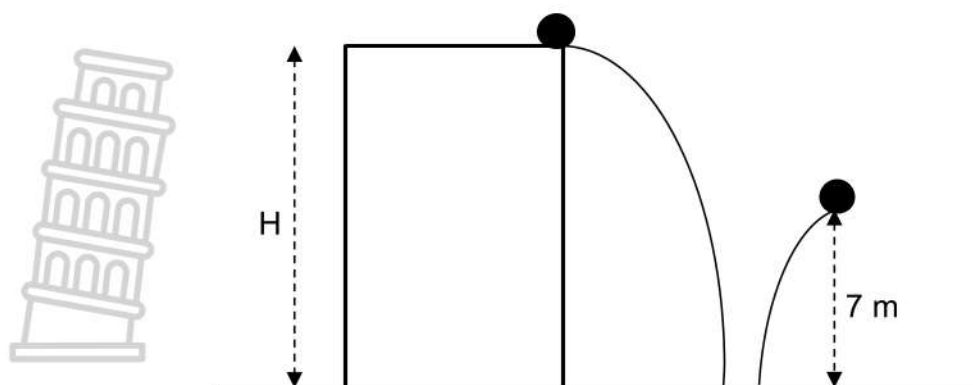
- 10.1 Is the hot-air balloon a projectile while it is moving upwards? Write YES or NO and give a reason for your answer. (2)
- 10.2 What is the velocity of the camera immediately after it is dropped from the hot-air balloon? (3)
- 10.3 Calculate the: (3)
 - 10.3.1 Time taken by the camera to reach its maximum height (3)
 - 10.3.2 Vertical distance between the hot-air balloon and the camera when the camera is at its maximum height (5)
- 10.4 A jogger running at a constant speed of $3 \text{ m}\cdot\text{s}^{-1}$, is 15 m away from the hot-air balloon as shown in the above diagram. If the jogger sees the camera at the same instant it is dropped from the balloon, will be able to catch the camera before it strikes the ground? (6)

Support your answer by means of a calculation.
- 10.5 Draw a sketch graph of velocity versus time for the entire motion of the camera. Indicate the following on the graph: (3)
 - Initial velocity
 - Time taken to reach the maximum height.

[21]

QUESTION 11

A ball of mass 1.5 kg is thrown down from the top of the building with a velocity of $12 \text{ m}\cdot\text{s}^{-1}$. The ball hits the ground and bounces off to the maximum height of 7 m. Ignore the effect of air resistance.



11.1 Write down the acceleration of the ball at 7 m above the ground. (2)

11.2 Calculate the velocity which the ball leaves (bounces) the ground with. (4)

When the ball was in contact with the ground, $344,1\text{ J}$ of its kinetic energy was converted into the other forms of energy.

11.3 Determine the:

11.3.1 Speed with which the ball hits the ground (4)

11.3.2 Time the ball will take to travel distance H (3)

[13]



MOMENTUM AND IMPULSE

Definitions and Key Concepts

- **Momentum** is the product of an object's mass and its velocity.
- **Linear momentum** is a vector quantity with the same direction as the velocity of the object.
- State the principle of **conservation of linear momentum**: The total linear momentum of an isolated system remains constant (is conserved)
- State **Newton's second law of motion in terms of momentum**: The net (or resultant) force acting on an object is equal to the rate of change of momentum of the object in the direction of the net force.
- **Impulse** is the product of the resultant/net force acting on an object and the time the net force acts on the object.
- An **isolated system** (in Physics), i.e. a system on which the net external force is zero.
- **Elastic collision** is a collision where both total momentum and total kinetic energy are conserved.
- **Inelastic Collision** is a collision where only total momentum is conserved but not kinetic energy.

Summary of notes

Calculate the momentum of a moving object using.

$$p = mv$$

- S.I units for momentum ($\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$) and it is a vector quantity(both magnitude and direction)
- Describe the vector nature of momentum and draw vector diagrams.
- State Newton's Second Law in terms of momentum:
- Use Momentum-Impulse theorem:
- Impulse S.I unit (N.s)

$$F_{\text{net}} = \frac{\Delta p}{\Delta t}$$

- Explain how the concept of impulse applies to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds.
- Apply the conservation of momentum to the collision of two objects moving in one dimension (along a straight line) with the aid of an appropriate sign convention.

$$\Sigma p_i = \Sigma p_f$$

$$m_1v_i + m_2v_i = m_1v_f + m_2v_f \text{ (two objects collide and then separate)}$$

$$m_1v_i + m_2v_i = (m_1 + m_2)v_f \text{ (two objects collide and stick together)}$$

$$(m_1 + m_2)v_i = m_1v_f + m_2v_f \text{ (two moving objects initially joined then separated)}$$

- Distinguish between elastic collisions and inelastic collisions by calculation.

ELASTIC & INELASTIC COLLISION.

- If the collision is Elastic $\Sigma E_{ki} = \Sigma E_{kf}$ (Total kinetic Energy before = total kinetic Energy after).
- If the collision is Inelastic $\therefore \Sigma E_{ki} \neq \Sigma E_{kf}$ (Total kinetic Energy before \neq Total kinetic Energy after).

$$\Sigma E_{ki} = \frac{1}{2}m_A v_i^2 + \frac{1}{2}m_B v_i^2$$

(total kinetic energy before)

S.I unit :Joule(J)

Worked Examples

WORK EXAMPLE 1

A ball is kicked along the ground towards the wall. It hits the wall travelling at $4,5 \text{ m}\cdot\text{s}^{-1}$ horizontally. The ball bounces off the wall with a horizontal velocity of $2 \text{ m}\cdot\text{s}^{-1}$ away from the wall. The ball is in contact with the wall for $0,26$ seconds. The ball has a mass of $0,8 \text{ kg}$.

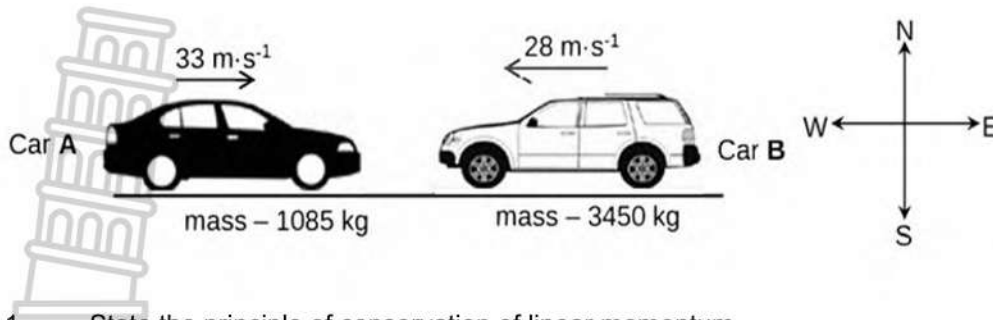
- 1.1 Define impulse. (2)
- 1.2 Determine the change in momentum of the ball as it bounces off the wall and state the direction of the change in momentum. (3)
- 1.3 Calculate the net force experienced by the ball as it bounces off the wall. (3)
- 1.4 If the time of contact between the ball and the wall was reduced, would the magnitude of the force that the ball experiences be, GREATER THAN, THE SAME AS or LESS THAN the magnitude of the force that you have calculated in Question 1.3? (1)

SOLUTION

- 1.1 the product of the resultant/net force acting on an object and the time the net force acts on the object. $\checkmark\checkmark$ (2)
- 1.2 $\Delta p = m(v_f - v_i) \checkmark$
 $= (0,8)(-2 - 4,5) \checkmark$
 $= -5,2$
 $= 5,2 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$ in the opposite direction \checkmark (3)
- 1.3 $F_{\text{net}} \Delta t = \Delta p \checkmark$
 $F_{\text{net}}(0,26) = -5,2 \checkmark$
 $F_{\text{net}} = -20$
 $F_{\text{net}} = 20\text{N}$ in the opposite direction \checkmark (3)
- 1.4 GREATER THAN \checkmark (1)

WORK EXAMPLE 2

Car A of mass 1085 kg travelling east at a speed of $33 \text{ m}\cdot\text{s}^{-1}$, collides head on with car B of mass 3450 kg travelling west at a speed of $28 \text{ m}\cdot\text{s}^{-1}$. Immediately after the collision, car A moves west at a speed of $5 \text{ m}\cdot\text{s}^{-1}$. Ignore friction.



- 2.1 State the principle of conservation of linear momentum. (2)
 Calculate the:
- 2.1.1 Velocity of car B after collision (5)
 2.1.2 Magnitude of the impulse on car B during the collision (3)
- 2.2 Airbags serves as a safety feature during collision.
 2.2.1 Use the relevant laws of physics to explain the purpose of air bags in cars. (3)
 2.2.2 Which driver sustains more injuries during above collision? Choose from CAR A or CAR B (2)

[14]

SOLUTION

- 2.1 The total linear momentum of an isolated system remains constant (is conserved) ✓✓ (2)

2.1.1 **OPTION: 1**

$$\Sigma p_i = \Sigma p_f$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} \checkmark$$

$$1085(+33) + 3450(-28) \checkmark = 1085(-5) + 3450 v_{2f} \checkmark$$

$$v_{2f} = -15,05 \text{ m}\cdot\text{s}^{-1}$$

$$v_{2f} = 15,05 \text{ m}\cdot\text{s}^{-1} \checkmark \text{ west/ forward} \checkmark$$



OPTION:2

$$\Sigma p_i = \Sigma p_f$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} \checkmark$$

$$1085(-33) + 3450(+28) \checkmark = 1085(+5) + 3450 v_{2f} \checkmark$$

$$v_{2f} = +15,05 \text{ m}\cdot\text{s}^{-1}$$

$$v_{2f} = 15,05 \text{ m}\cdot\text{s}^{-1} \checkmark \text{ west/ forward} \checkmark$$

(5)

2.1.2 **OPTION 1: CAR B** Motion to the west(+) (5)

$$\text{Impulse} = \Delta p = m \Delta v \checkmark$$

$$= 3450(16,05 - 28) \checkmark$$

$$= -41227,5$$

$$41\,227,5 \text{ N}\cdot\text{s} \checkmark$$

(3)

2.2

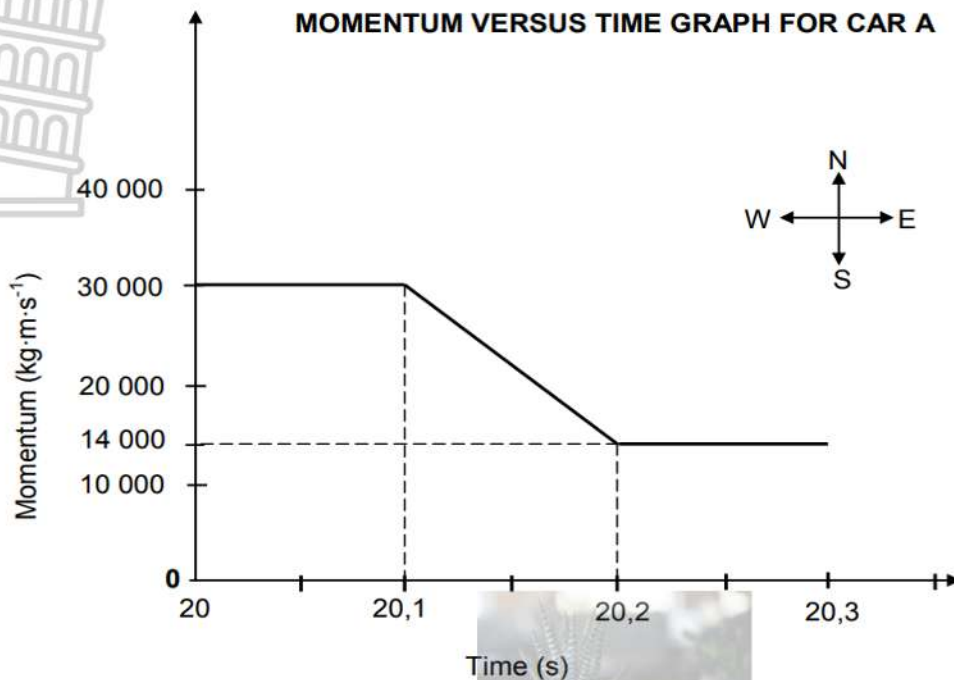
2.2.1 According to Newton's second law ✓ / $F_{\text{net}} = \frac{\Delta p}{\Delta t}$ Air bag causes an increase in collision time ✓ which results in a lesser / smaller force (for the driver/passenger) ✓ (3)

2.2.2 Car A ✓ (1)

WORK EXAMPLE 3

The graph below shows how the momentum of car A changes with time just before and just after a head-on collision with car B.

Car A has a mass of 1 500 kg, while the mass of car B is 900 kg. Car B was travelling at a constant velocity of 15 m·s⁻¹ west before the collision. Take east as positive and consider the system as isolated.



- 3.1 What do you understand by the term isolated system as used in physics? (1)
Use the information in the graph to answer the following questions.
- 3.2 Calculate the: (3)
- 3.2.1 Magnitude of the velocity of car A just before the collision (3)
- 3.2.2 Velocity of car B just after the collision (5)
- 3.2.3 Magnitude of the net average force acting on car A during the collision (4)
- 3.2.4 Determine, by means of calculation whether this collision is elastic or inelastic. (5)

SOLUTION

- 3.1 A system on which the resultant/net external force is zero. ✓ (1)
- 3.2.1 $p = mv$ ✓
 $30\,000 = (1500)v$ ✓
 $v = 20\text{ m}\cdot\text{s}^{-1}$ ✓ (3)
- 3.2.2 $\sum p_i = \sum p_f$
 $m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$ ✓
 $30\,000 + (900)(-15)$ ✓ = $14\,000 + 900v_B$ ✓
 $\therefore v_B = 2,78\text{ m}\cdot\text{s}^{-1}$ ✓ east ✓ (5)
- 3.2.3 $F_{\text{net}}\Delta t = \Delta p$ ✓
 $F_{\text{net}}(0,1)$ ✓ = $14\,000 - 30\,000$ ✓
 $F_{\text{net}} = -160\,000\text{ N}$
 $F_{\text{net}} = 160\,000\text{ N}$ ✓ (4)
- 3.2.4 $\sum E_{ki} = \frac{1}{2}mv_i^2 + \frac{1}{2}mv_i^2$ ✓
= $\frac{1}{2}(1500)(20)^2 + \frac{1}{2}(900)(-15)^2$ ✓
= 401250 J
 $\sum E_{kf} = \frac{1}{2}m_1v_f^2 + \frac{1}{2}m_2v_f^2$
= $\frac{1}{2}(1500)(9,33)^2 + \frac{1}{2}(900)(2,78)^2$ ✓
= 68805,56 J (5)

$$\sum E_{ki} \neq \sum E_{kf} \checkmark$$

\therefore the collision is inelastic \checkmark

MULTIPLE CHOICE QUESTIONS

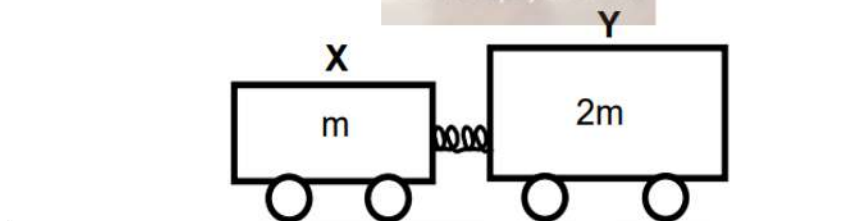
- 1.1 Impulse is equal to the ...
- A initial momentum of a body.
 - B final momentum of a body.
 - C change in momentum of a body.
 - D rate of change in momentum of a body.
- (2)

- 1.2 A person drops a glass bottle onto a concrete floor from a certain height and the bottle breaks. The person then drops a second, identical glass bottle from the same height onto a thick, woollen carpet, but the bottle does not break.

Which ONE of the following is CORRECT for the second bottle compared to the first bottle for the same momentum change?

- | | AVERAGE FORCE ON SECOND BOTTLE | TIME OF CONTACT WITH CARPET | |
|---|---------------------------------------|------------------------------------|-----|
| A | Larger | Smaller | (2) |
| B | Smaller | Smaller | |
| C | Larger | Larger | |
| D | Smaller | Larger | |

- 1.3 Two trolleys, X and Y, of masses m and $2m$ respectively, are held together by a compressed spring between them. Initially they are stationary on a horizontal floor, as shown below. Ignore the effects of friction.



The spring is now released and falls to the floor while the trolleys move apart. The magnitude of the MOMENTUM of trolley X while it moves away is ...

- A zero.
 - B half the magnitude of the momentum of trolley Y.
 - C twice the magnitude of the momentum of trolley Y.
 - D the same as the magnitude of the momentum of trolley Y.
- (2)

- 1.4 A ball of mass m , falling vertically downwards, hits the floor at a speed v and bounces vertically upwards at a speed $0,75v$.

Which ONE of the following combinations regarding the change in momentum of the ball during the collision is CORRECT?

- | | MAGNITUDE | DIRECTION | |
|---|------------------|------------------|-----|
| A | $0,25mv$ | Upwards | (2) |
| B | $0,25mv$ | Downwards | |
| C | $1,75mv$ | Upwards | |
| D | $1,75mv$ | Downwards | |

- 1.5 A ball is dropped from height h and strikes the floor with momentum p . The ball is then dropped from the height $\frac{1}{2}h$.

Ignore the effects of air friction.

Which ONE of the following represents the momentum of the ball when it strikes the floor after being dropped from height $\frac{1}{2}h$?

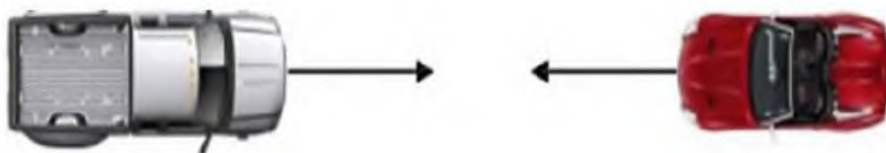
- A p
- B $\frac{1}{\sqrt{2}}p$
- C $\frac{1}{2}p$
- D $2p$

(2)

LONG QUESTIONS

QUESTION 2

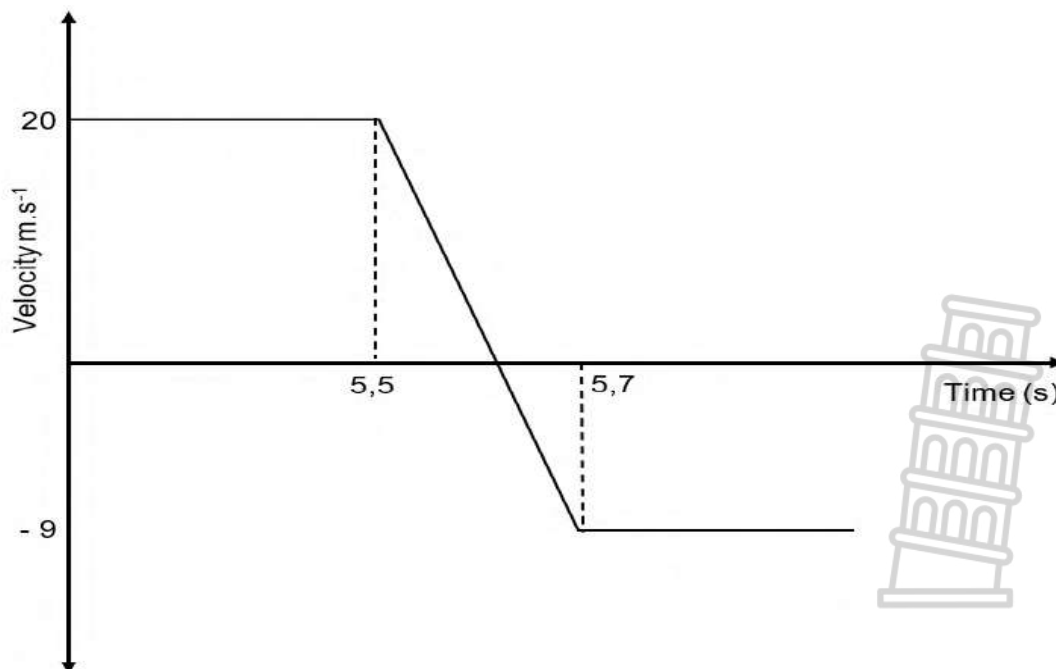
A car of mass, 1300kg moves to the left on a narrow road. It collides heads on with the up truck, mass 2500kg moving in the opposite direction as shown. After the collision the two vehicles moves together.



$$m_t = 2500\text{kg}$$

$$m_c = 1300\text{kg}$$

The following velocity-time graph is plotted for the car:



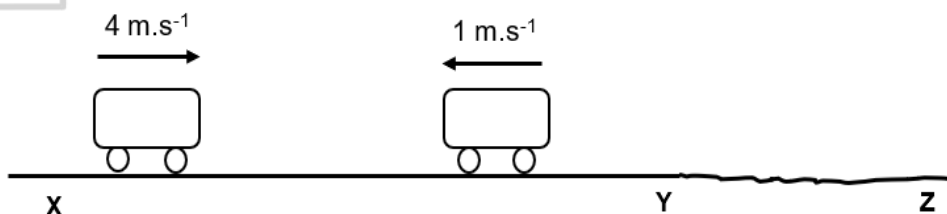
- 2.1 Calculate the momentum of the car before the collision. (3)
- 2.2 Calculate the magnitude of the velocity pick truck before the collision. (4)
- 2.3 Calculate the magnitude of the net force on the car. (4)
- 2.4 Determine, by means of calculation whether this collision is elastic or inelastic. (5)

[16]

QUESTION 3

The diagram below shows two sections, **XY** and **YZ**, of a horizontal flat surface. Section **XY** is frictionless, while section **YZ** is rough.

A 5kg trolley, moving with a velocity of $4\text{m}\cdot\text{s}^{-1}$ to the right, collides head-on with a 2kg trolley moving with the velocity of $1\text{m}\cdot\text{s}^{-1}$ towards the 5kg trolley. After the collision, the two trolleys stick together and move to the right pass point **Y**.



- 3.1 State the principle of conservation of linear momentum in words. (2)
- 3.2 Calculate the magnitude of the velocity of the combined trolleys at point **Y**. (4)
- The combined trolleys travel for 0,3s from point **Y** before coming to stop at point **Z**.
- 3.3 Calculate the magnitude of the net force acting on the combined trolleys while they move through section **YZ**. (4)

[10]

QUESTION 4

A truck of mass **x**, travelling at a velocity of $20\text{m}\cdot\text{s}^{-1}$ to the right on a straight horizontal road, collides head-on, with a car of mass **y** travelling at $10\text{m}\cdot\text{s}^{-1}$ to the left. The collision between the vehicles is INELASTIC.



The vehicles stick together during the collision and move to the right. The vehicles have a combined mass of 2300 kg and a kinetic energy of 258750 J.

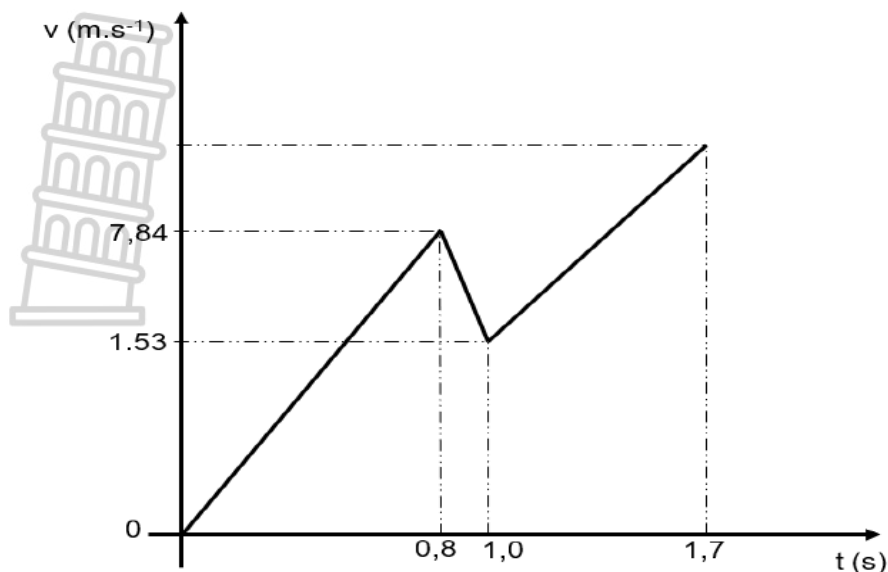
- 4.1 State the principle of conservation of linear momentum in words. (2)
- 4.2 Calculate the speed of the vehicles after the collision. (3)
- 4.3 Show by means of a calculation that the truck has a mass of 1916,67 kg. (4)
- 4.4 Hence, determine the magnitude of impulse experienced by the truck. (3)

[12]

QUESTION 5

A learner tests the strength of a piece of glass by dropping a steel ball of mass 5 kg from a height of 3 m onto the glass.

The velocity-time graph below represents the motion of the steel ball from the moment the learner drops the ball until it reaches the group.



- 5.1 Define momentum. (2)
- 5.2 Calculate the net force exerted by the glass on the steel ball. (4)
- 5.3 Is this an ELASTIC or INELASTIC collision? Refer to the data in the graph and relevant principle to explain the answer. (4)
- 5.4 The glass does not break when the learner drops a soft rubber ball of similar mass from the same height onto the glass. Use Physics principles to explain this phenomenon. (3)
- [13]**

MATTER AND MATERIALS

ORGANIC MOLECULES

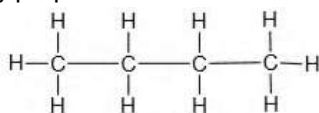
- **Hydrocarbon:** Organic compounds that consist of hydrogen and carbon only.
- **Saturated compounds:** Compounds in which there are no multiple (double or triple) bonds between C atoms in their hydrocarbon chains.
- **Unsaturated compounds:** Compounds with one or more multiple (double or triple) bonds between C atoms.
- **Molecular formula:** A chemical formula that indicates the type of atoms and the correct number of each in a molecule.
- **Structural formula:** A structural formula of a compound shows which atoms are attached to which within the molecule.
- **Condensed structural formula:** This notation shows the way in which atoms are bonded together in the molecule, but DOES NOT SHOW ALL bond lines.
- **Homologous series:** A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with CH₂ group.
- **Functional group:** A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

HOMOLOGOUS SERIES	FUNCTIONAL GROUP	NAME OF FUNCTIONAL GROUP	GENERAL FORMULA	SUFFIX IN NAMING

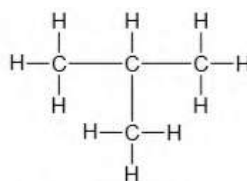
Alkanes		Single bond between carbon atoms	C_nH_{2n+2}	-ane
Alkenes		Double bond between carbon atoms	C_nH_{2n}	-ene
Alkynes		Triple bond between carbon atoms	C_nH_{2n-2}	-yne
Haloalkanes/ Alkyl halides	 (X = F, Cl, Br, I)	Halogen atom bonded to C atom in an alkane	$C_nH_{2n+1}X$	Chloro-ane, bromo-ane
Alcohols		Hydroxyl group	$C_nH_{2n+1}OH$	-ol
Carboxylic Acids		Carboxyl group	$C_nH_{2n+1}COOH$	--anoic acid
Esters		-	RCOOR	-yl -anoate
Aldehydes		Formyl group	RCHO	-al
Ketones		Carbonyl group bonded to C-atoms	RCOR'	-one

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

- Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.
- Restrict structural isomers to chain isomers, positional isomers and functional isomers.
 - Chain isomers:** Same molecular formula, but different types of chains, e.g. butane and 2-methylpropane.

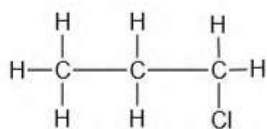


butane

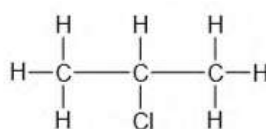


2-methylpropane

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

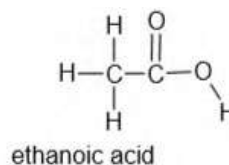
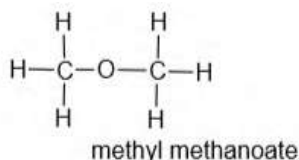


1-chloropropane



2-chloropropane

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



IUPAC naming and formulae

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

Structure and Physical Properties (Boiling Point, Melting Point, Vapour Pressure) Factors that influence the strength of IMF

1. Surface area

Length of the carbon chain and branched molecules. For compounds that belong to the same homologous series, the larger the surface area the higher the Melting point, the Boiling point, the Viscosity and the lower the vapour pressure.

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

2. The type of functional group OR homologous series

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

London forces (Only)	Dipole-dipole forces In addition to London forces	Hydrogen bonds in addition to dipole-dipole and London forces
Alkanes Alkenes Alkynes	Ketones Aldehydes Esters Haloalkanes	Alcohols (ONE site of hydrogen Bonds) Carboxylic acids (TWO sites of hydrogen bonds)

Stronger Intermolecular forces	Weaker Intermolecular forces
--------------------------------	------------------------------

- | | |
|---|--|
| <ul style="list-style-type: none"> • Higher boiling point • Higher melting point • More energy needed to overcome the Intermolecular forces • Lower vapour pressure | <ul style="list-style-type: none"> • Lower boiling point • Lower melting point • Less energy needed to overcome the Intermolecular forces • Higher vapour pressure |
|---|--|

Guideline for answering questions

1. State homologous series and type of intermolecular force
2. Compare the strength of intermolecular forces
3. Energy required
4. Conclusion

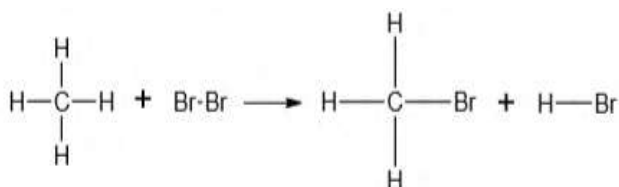
ORGANIC REACTIONS

- Identify reactions as elimination, substitution or addition.
- Write down, using structural formulae, equations and reaction conditions for the following addition reactions of alkenes:
 - Hydrohalogenation: The addition of a hydrogen halide to an alkene
 - Halogenation: The reaction of a halogen (Br_2 , Cl_2) with a compound
 - Hydration: The addition of water to a compound
 - Hydrogenation: The addition of hydrogen to an alkene
- Write down, using structural formulae, equations and reaction conditions for the following elimination reactions:
 - Dehydrohalogenation of haloalkanes: The elimination of hydrogen and a halogen from a haloalkane.
 - Dehydration: The elimination of water from an alcohol.
 - Cracking of alkanes: (1) Thermal or (2) Catalytic
- Write down, using structural formulae, equations and reaction conditions for the following substitution reactions:
 - Hydrolysis of haloalkanes Hydrolysis: The reaction of a compound with water
 - Reactions of HX ($\text{X} = \text{Cl}, \text{Br}$) with alcohols to produce haloalkanes
 - Halogenation of alkanes: The reaction of a halogen (Br_2 , Cl_2) with a compound
- Distinguish between saturated and unsaturated hydrocarbons using bromine water.

REACTIONS OF ALKANES

1. SUBSTITUTION

Alkane \rightarrow haloalkane



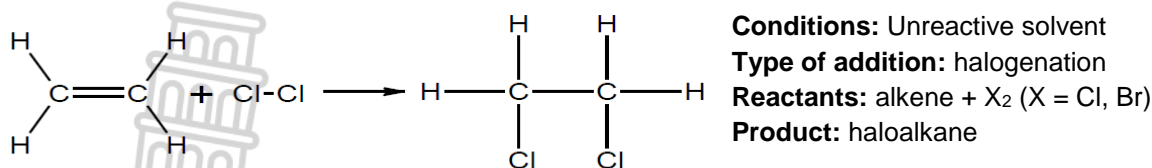
Conditions: Heat/ Sunlight (UV/ hf)

Reactants: Alkane + X_2 (F_2 , Cl_2 , I_2 , Br_2)

Type of substitution: Halogenation/ bromination.
Substitution reaction will only occur when the compound is saturated.

REACTIONS OF ALKENES

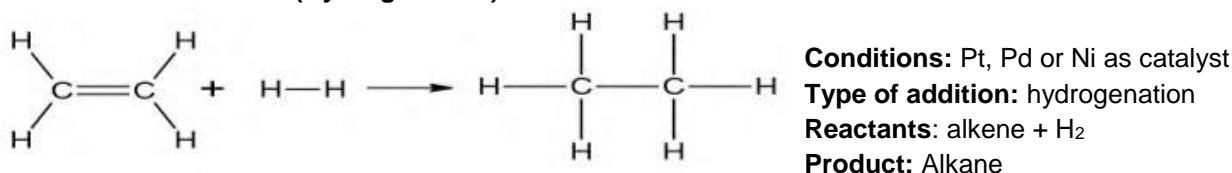
1. ADDITION REACTION (Halogenation)



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

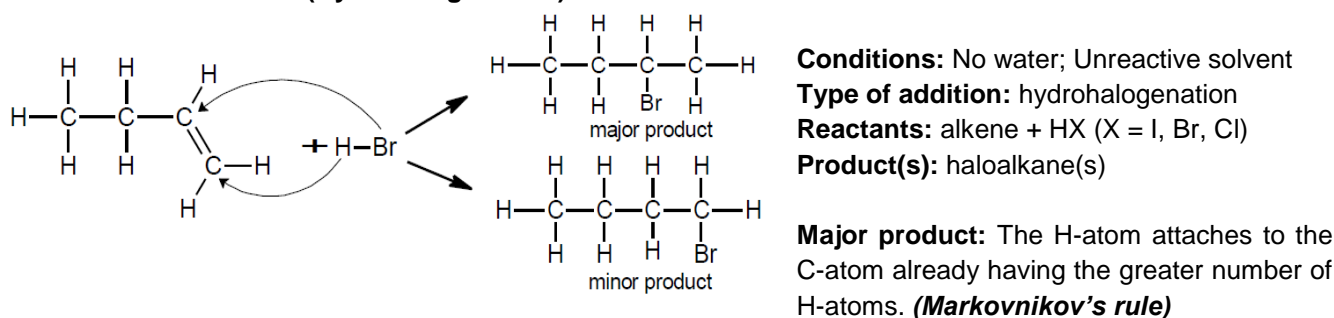
- Add bromine water (orange-brown) to unknown molecules.
- If bromine water discolours the molecule immediately, the molecule is an alkene.
- $\text{CH}_2\text{CH}_2 + \text{Br}_2 \rightarrow \text{CH}_2\text{BrCH}_2\text{Br}$

ADDITION REACTION 2 (Hydrogenation)

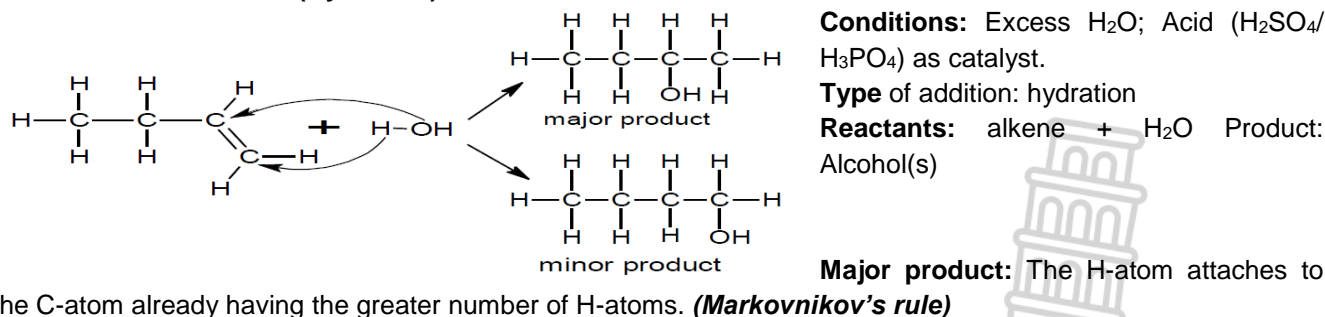


Application: Hydrogenation of unsaturated vegetable oils is used to manufacture margarine.

ADDITION REACTION 3 (Hydrohalogenation)



ADDITION REACTION 4 (Hydration)

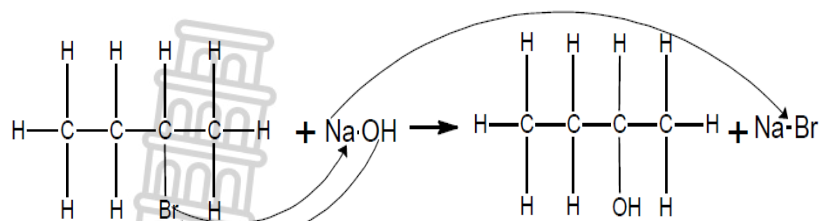


Addition reaction will only occur when the compound is unsaturated.

REACTIONS OF HALOALKANES

1. SUBSTITUTION:

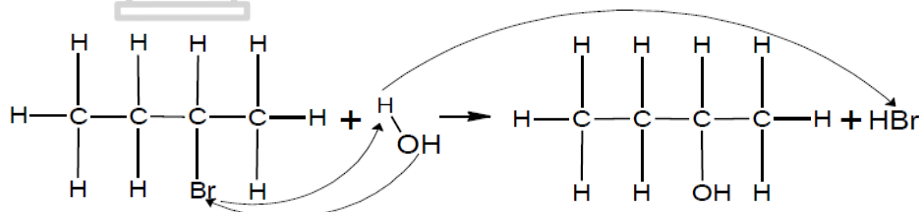
Haloalkane → alcohol



Conditions: Diluted strong base (NaOH/KOH/LiOH) + mild heat
Type of substitution: hydrolysis/hydration

Reactants: Haloalkane in ethanol + diluted strong base

Products: Alcohol + NaBr/KBr/LiBr



Conditions: Excess H₂O + mild heat
Type of substitution: hydrolysis

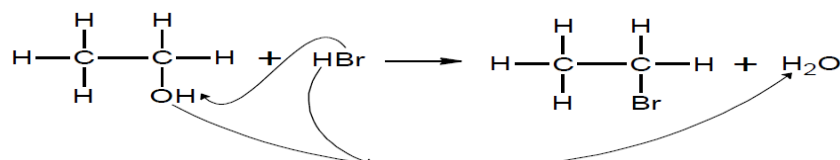
Reactants: Haloalkane + H₂O

Products: Alcohol + HBr

REACTIONS OF ALCOHOL

1. SUBSTITUTION

Alcohol → haloalkane



Conditions: Heat
Reactants needed: Alcohol + HX

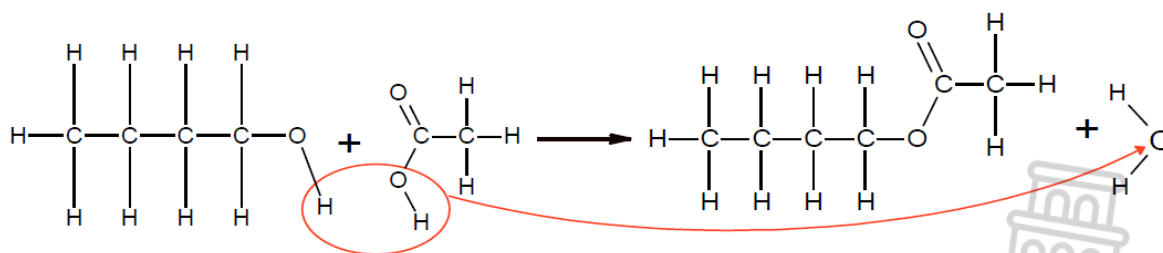
For primary & secondary alcohols:

NaBr + conc. H₂SO₄ is used to prepare HBr in reaction flask.

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

Products: Haloalkane + H₂O

ESTERIFICATION



Conditions: Concentrated H₂SO₄ as catalyst + heat

Reactants: Alcohol + carboxylic acid in the presence of H₂SO₄ catalyst

Products: Ester + water

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

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

WORKED EXAMPLES

EXAMPLE 1

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

<p>A</p> $ \begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3 - \text{C} - \text{CH} - \text{Br} \\ \quad \\ \text{CH}_3 - \text{CH}_2 \quad \text{CH}_2 \\ \\ \text{CH}_3 \end{array} $	<p>B</p> $ \begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} - \text{H} \\ \\ \text{CH}_3 - \text{C} - \text{C} \equiv \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{CH}_3 \quad \quad \quad \text{H} \\ \quad \quad \quad \quad \\ \quad \quad \quad \quad \text{H} \end{array} $
<p>C</p> $ \begin{array}{c} \text{O} \\ \\ \text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{C} \\ \\ \text{H} \end{array} $	<p>D</p> $ \begin{array}{c} \text{O} \\ \\ \text{CH}_3 - \text{CH}_2 - \text{C} \\ \\ \text{CH}_3 \end{array} $
<p>E</p> $ \begin{array}{c} \text{O} \\ \\ \text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{C} \\ \\ \text{OH} \end{array} $	<p>F</p> $ \begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 \\ \\ \text{OH} \end{array} $

- 1.1 Write down the:
- 1.1.1 Letters that represent TWO organic compounds that are isomers of each other (1)
 - 1.1.2 Type of isomers (CHAIN, FUNCTIONAL or POSITIONAL) identified in QUESTION 1.1.1 (1)
 - 1.1.3 GENERAL FORMULA of the homologous series to which compound **B** belongs (1)
 - 1.1.4 NAME of the functional group of compound **F** (1)
- 1.2 Write down the IUPAC name of:
- 1.2.1 Compound A (3)
 - 1.2.2 Compound B (2)
 - 1.2.3 Compound C (2)

Example 2

2.1 The melting points of some organic compounds are given in the table below.

COMPOUND	IUPAC NAME	MELTING POINTS (°C)
A	Propanone	-95,4
B	Butanone	-86,9
C	Pentan-2-one	-77,8
D	3-methylbutanone	-92

- 2.1.1 To which homologous series do the above compounds belong? (1)
The melting points of compounds **A**, **B** and **C** are compared.
- 2.1.2 Write down the controlled variable for this comparison. (1)
The melting points of compounds **C** and **D** are compared.
- 2.1.3 Fully explain the difference in the melting points of these two compounds. (4)

- 2.2 The table below shows the results obtained from an experiment to determine the vapour pressure of different STRAIGHT CHAIN primary alcohols at 300 K.

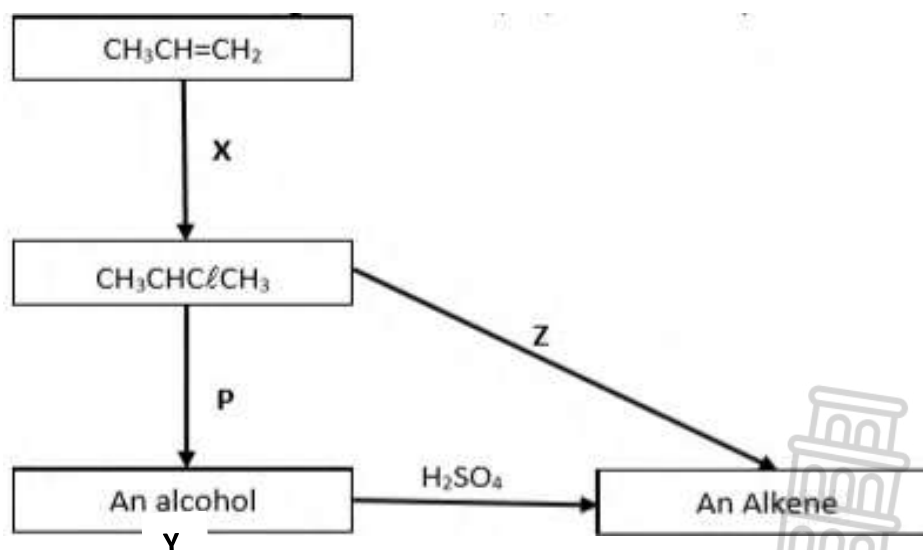


ALCOHOL	VAPOUR PRESSURE (kPa)
CH ₃ OH	16,8
C ₂ H ₅ OH	7,88
C ₃ H ₇ OH	2,8
C ₄ H ₉ OH	0,91
C ₅ H ₁₁ OH	0,88
C ₆ H ₁₃ OH	0,124

- 2.2.1 Define the term *vapour pressure*. (2)
- 2.2.2 Write down a suitable conclusion for this investigation. (2)
- 2.2.3 Write down the IUPAC name of the alcohol with the HIGHEST boiling point. (2)
- 2.2.4 The experiment is now repeated at 320 K. Will the vapour pressure of each compound INCREASE, DECREASE or REMAIN THE SAME? (1)

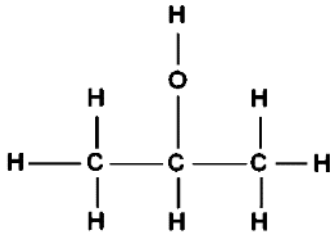
EXAMPLE 3

The flow diagram below shows the preparation of the organic compounds using CH₃CH=CH₂ as starting material. X, Y, Z and P represent different organic reactions.



- 3.1. To which homologous series does CH₃CH=CH₂ belong? (1)
- 3.2. Write down the:
- 3.2.1 Type of reaction of which X is an example (1)
- 3.2.2 Structural formula and IUPAC name of the alcohol produced during reaction P. (3)
- 3.2.3 The type of reaction of which Y is an example. (1)
- 3.2.4 Function of the acid in reaction Y. (1)
- 3.3. For reaction Z, write down:
- 3.3.1 The NAME of the inorganic reagent needed. (1)
- 3.3.2 TWO reaction conditions needed. (2)

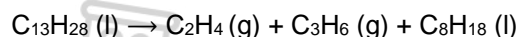
WORKED EXAMPLES SOLUTIONS

- 1.1.1 C and D ✓ (1)
- 1.1.2 Functional isomers ✓ (1)
- 1.1.3 C_nH_{2n-2} ✓ (1)
- 1.1.4 Hydroxyl ✓ (1)
- 1.2.1 4-bromo-3,3-dimethylhexane ✓✓✓ (3)
- 1.2.2 4,4-dimethylpent-2-yne ✓✓ (2)
- 1.2.3 Butanal ✓✓ (2)
- 2.1.1 Ketone ✓ (1)
- 2.1.2 Functional group/ homologous series ✓ (1)
- 2.1.3 **Pentan -2-one/C** (4)
- **Structure:**
Longer chain length/less branched/less compact/less spherical/larger surface area
 (over which intermolecular forces act). ✓
 - **Intermolecular forces:**
Stronger intermolecular forces/Van der Waals forces/London forces/ dipole-dipole
 forces. ✓
 - **Energy:**
More energy needed to overcome the intermolecular forces/Van der Waals
forces/dipole-dipole forces. ✓
- Higher melting point. ✓
- 2.2.1 The pressure exerted by a vapour at equilibrium with its liquid in a closed system. ✓✓ (2)
- 2.2.2 Vapour pressure decreases ✓ with increase in number of C atoms/chain length. ✓ (2)
- 2.2.3 Hexan-1-ol/1-Hexanol ✓✓ (2)
- 2.2.4 Increases ✓ (1)
- 3.1 Alkene ✓ (1)
- 3.2.1 Addition/ Hydrohalogenation ✓ (1)
- 3.2.2 (3)
- 

Propan-2-ol ✓✓✓
- 3.2.3 Elimination/ dehydration ✓ (1)
- 3.2.4 It serves as a dehydrating agent. ✓ (1)
- 3.3.1 Sodium hydroxide/ Potassium hydroxide ✓ (1)
- 3.3.2 Concentrated strong base (NaOH/ KOH) ✓, Heat under reflux ✓ (2)

QUESTION 1 (MULTIPLE CHOICE QUESTIONS)

- 1.1 Which ONE of the compounds below is an aldehyde? (2)
- A CH_3CHO
- B CH_3COCH_3
- C CH_3COOH
- D CH_3OH
- 1.2 The reaction represented by the equation below takes place in the presence of a catalyst.

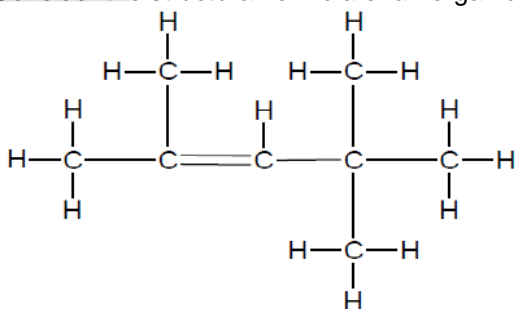


This reaction is an example of ...

- A Addition
- B Cracking
- C substitution
- D Oxidation

(2)

1.3 Consider the structural formula of an organic compound below.



Which ONE of the following is the correct IUPAC name of this compound?

- A 2,2,4-trimethylpent-2-ene
- B 2,2,4-trimethylpent-3-ene
- C 2,4,4-trimethylpent-2-ene
- D 2,4,4-trimethylpent-3-ene

(2)

1.4 Which ONE of the following compounds has dipole-dipole forces between its molecules?

- A Ethanal
- B Ethane
- C Ethene
- D Ethyne

(2)

1.5 Which ONE of the following is the correct formula of methylbutanoate?

- A $\text{CH}_3\text{CH}(\text{OH})\text{CH}(\text{CH}_3)\text{CH}_3$
- B $\text{HCOOCH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
- C $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CHO}$
- D $\text{CH}_3\text{COCH}(\text{CH}_3)\text{CH}_3$

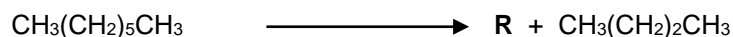
(2)

1.6 How many types of Van der Waals forces are present between the molecules of $\text{CH}_3\text{CH}_2\text{Br}$?

- A 1
- B 2
- C 3
- D 4

(2)

1.7 A compound $\text{CH}_3(\text{CH}_2)_5\text{CH}_3$ undergoes the following reaction:



Which ONE of the following combinations CORRECTLY describes the type of reaction and the IUPAC name of compound R?

	TYPE OF REACTION	IUPAC NAME
A	Elimination	Propane
B	Addition	Propene
C	Cracking	Propane
D	Cracking	Propene

(2)

LONG QUESTIONS**QUESTION 2**

2.1 The boiling points of straight chain aldehydes and straight chain carboxylic acids are compared. The table below shows the results obtained.

	INVESTIGATION 1	INVESTIGATION 2
Number of carbon atoms in the compound	Boiling point of aldehydes (°C)	Boiling point of carboxylic acids (°C)
1	-19	101
2	20	118
3	49	141
4	75	164

2.1.1 Define the term *homologous series*. (2)

2.1.2 Write down the:

(a) NAME of the FUNCTIONAL GROUP of the aldehydes. (1)

(b) IUPAC NAME of the compound with the highest vapour pressure in this comparison (2)

2.1.3 For INVESTIGATION 2:

(a) Write down the controlled variable. (1)

(b) Describe the trend in the boiling points. (1)

(c) Fully explain the answer to QUESTION 7.1.3(b) (2)

2.1.4 Write down the boiling point butanal. (1)

2.2 The vapour pressures of compounds A and B are compared.

A	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ OH
B	CH ₃ CH ₂ CH ₂ COOH


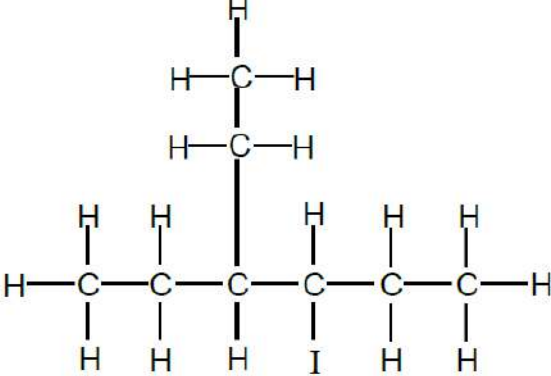
How does the vapour pressure of compound A compare to that of compound B? choose from HIGHER THAN, LOWER THAN or EQUAL TO.

Fully explain the answer. (4)

[14]**QUESTION 3**

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



A	 $C_5H_{10}O$	B	
C	Butanoic acid	D	$(CH_3)_3COH$
E	$CH_2C(CH_3)_2$	F	$HCOOCH_2CH_2CH_3$

- 3.1 Define the term *unsaturated compound*. (2)
- 3.2 Write down the LETTER that represents EACH of the following: (1)
- 3.2.1 An unsaturated compound (1)
- 3.2.2 A functional isomer of compound C (2)
- 3.3 Name the TWO homologous series to which A belongs. (2)
- 3.4 Is compound D a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)
- 3.5 Write down the IUPAC name of: (3)
- 3.5.1 Compound B (2)
- 3.5.2 The POSITIONAL isomer of compound D (2)
- 3.6 Ethanol reacts with compound C to form an organic compound Z. Write down the: (1)
- 3.6.1 Type of reaction (2)
- 3.6.2 STRUCTURAL FORMULA of compound Z (1)
- 3.7 Write down the: (2)
- 3.7.1 Empirical formula of compound F (1)
- 3.7.2 STRUCTURAL FORMULA of the CHAIN ISOMER of compound E. (2)

[19]

QUESTION 4

The letters **A** to **H** in the table below represent eight organic compounds.



A		B	
C	Butanone	D	$C_4H_{10}O$
E	$CH_3C(CH_3)_2CCCH_3$	F	$CH_3COO(CH_2)_2CH_3$
G	$C_4H_8O_2$	H	$CH_3C(CH_3)_2CH_2CH_3$

- 4.1 Write down the LETTER that represents EACH of the following:
- 4.1.1 An alcohol (1)
- 4.1.2 A compound with a formyl group (1)
- 4.1.3 An unsaturated compound (1)
- 4.2 Write down the IUPAC name of compound:
- 4.2.1 B (3)
- 4.2.2 E (3)
- 4.3 Two different compounds in the above table are functional isomers.
- 4.3.1 Define the term *functional isomer*. (2)
- 4.3.2 Write down the LETTERS that represent these functional isomers. (1)
- 4.4 Compound F is formed when a carboxylic acid reacts with another organic compound, X, in the presence of a catalyst.
- Write down the:
- 4.4.1 NAME or FORMULA of the catalyst (1)
- 4.4.2 Type of reaction (1)
- 4.4.3 STRUCTURAL FORMULA of compound F (2)
- 4.4.4 IUPAC name of compound X (2)

[18]

QUESTION 5

The vapour pressures of different organic compounds are determined at 20 °C. The vapour pressures of compounds A, B, and C are not shown in the table.

COMPOUND	IUPAC NAME	MOLAR MASS ($g \cdot mol^{-1}$)	VAPOUR PRESSURE (kPa) AT 20 °C
A	Pentane	72	
B	2-methylbutane	72	
C	2,2-dimethylpropane	72	
D	Propanoic acid	74	0,32
E	Butanal	72	12,2

- 5.1 Define the term *vapour pressure*. (2)
 5.2 The vapour pressures of compounds **A**, **B** and **C** are given in random order below

79 kPa	146 kPa	58 kPa
--------	---------	--------

- 5.2.1 Write down the vapour pressure of compound **C** (1)
 5.2.2 Fully explain your answer to QUESTION 5.2.1 (3)
 5.3 Compounds **D** and **E** are compared.
 5.3.1 Which compound has the lower boiling point? (1)
 5.3.2 Fully explain the difference in the vapour pressures between compounds **D** and **E**. (4)

[11]

QUESTION 6

The boiling points of some organic compounds are shown in the table below. The atmospheric pressure is 101,3 kPa.

	ORGANIC COMPOUND	BOILING POINT (°C)
A	CH ₃ CH ₂ CH ₂ CH ₂ Cl	78
B	CH ₃ CH(CH ₃)CH ₂ Cl	46
C	CH ₃ CH ₂ CH ₂ CH ₂ OH	118
D	CH ₃ CH ₂ CH ₂ CHO	X

- 6.1 Define the term boiling point. (2)
 6.2 Which ONE of compounds A, B or C is mainly in the liquid phase at 100 °C? (1)
 6.3 Explain the difference in the boiling points of compounds A and B. (3)
 6.4 Consider the boiling points below.

75 °C	120 °C	126 °C
-------	--------	--------

- 6.4.1 Which ONE of these values represents X, the boiling point of compound D? (1)
 6.4.2 Fully explain the answer to QUESTION 5.4.1. (2)
 6.5 The atmospheric pressure is now changed to 83 kPa.
 How will the boiling points of these organic compounds be affected? Choose from INCREASE, DECREASE or REMAIN THE SAME. (1)

[10]

QUESTION 7

The letters **A** to **H** in the table below represent eight organic compounds.



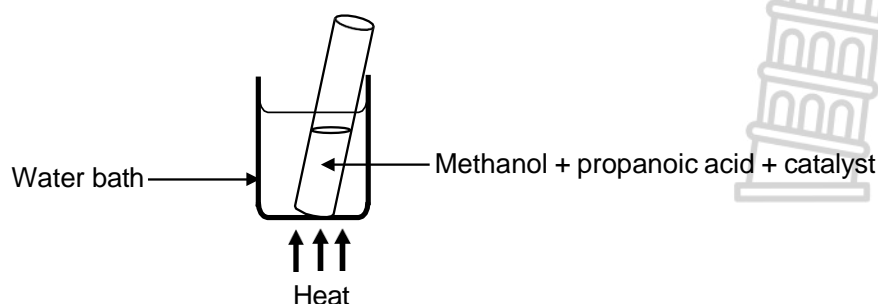
A	Butan-2-ol	B	$\text{CH}_3\text{C}(\text{CH}_3)_2(\text{CH}_2)_2\text{CH}_3$
C	3-ethylpent-1-yne	D	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$
E	$\begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{CH} \\ \quad \quad \quad \parallel \\ \text{CH}_3 - \text{CH}_2 - \text{C} - \text{CH}_2 - \text{CH}_3 \end{array}$	F	Butan-1-ol
G	$\begin{array}{c} \text{CH}_3 \quad \text{Cl} - \text{CH} \\ \quad \quad \\ \text{CH}_3 - \text{C} - \text{CH}_2 - \text{CH} - \text{CH}_3 \\ \\ \text{Cl} \end{array}$	H	$\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3 - \text{C} - \text{CH}_3 \\ \\ \text{C} = \text{O} \\ \\ \text{H} \end{array}$

- 7.1 Define the term *hydrocarbon*. (2)
- 7.2 Write down the letter(s) for: (1)
- 7.2.1 TWO compounds that are UNSATURATED hydrocarbons (1)
- 7.2.2 TWO compounds that are CHAIN ISOMERS of each other (2)
- 7.2.3 A secondary alcohol (1)
- 7.3 Write down the: (2)
- 7.3.1 STRUCTURAL formula of the FUNCTIONAL ISOMER of compound **D** (2)
- 7.3.2 General formula of the homologous series to which compound **B** belongs (1)
- 7.3.3 STRUCTURAL formula of compound **C** (2)
- 7.4 Write down the IUPAC name of compound: (3)
- 7.4.1 E (3)
- 7.4.2 G (2)
- 7.4.3 H (3)
- 7.5 Compound **B** undergoes complete combustion. Using MOLECULAR FORMULAE, write down the balanced equation for this reaction. (3)

[22]

QUESTION 8

- 8.1 In an experiment, a test tube containing methanol, propanoic acid and a catalyst is heated in a water bath.

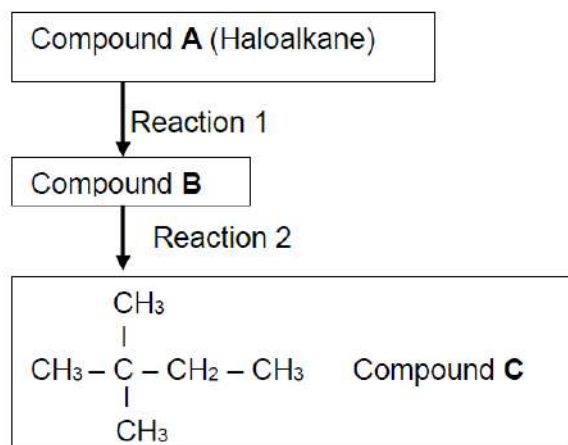


Write down:

- 8.1.1 The NAME or FORMULA of the catalyst (1)
- 8.1.2 The type of reaction taking place (1)
- 8.1.3 TWO reasons why the use of a water bath is preferred in this (2)

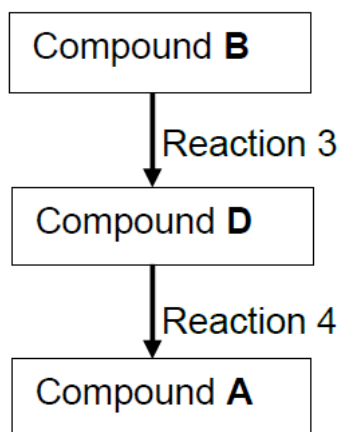
experiment

- 8.1.4 The balanced equation for this reaction using STRUCTURAL FORMULAE (5)
- 8.1.5 The IUPAC name of the organic product for this reaction (2)
- 8.2 Compound A, a six-carbon branched haloalkane, is used in a two-step reaction to prepare compound C. Reaction 2 is an ADDITION reaction.



Write down:

- 8.2.1 The NAME or FORMULA of the inorganic reactant in reaction 2 (1)
- 8.2.2 The IUPAC name of compound B (2)
- 8.2.3 The type of reaction represented by reaction 1 (1)
- Compound B is now used in a two-step reaction to prepare compound A.
Reaction 4 is a SUBSTITUTION reaction.



Write down

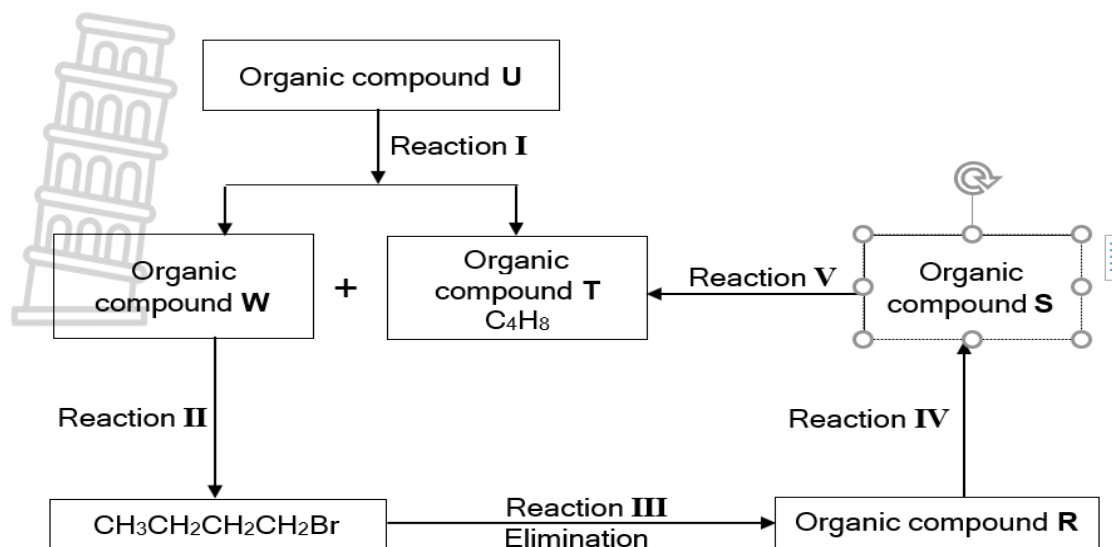
- 8.2.4 The NAME or FORMULA of the catalyst used in reaction 3 (1)
- 8.2.5 The IUPAC name of compound D (2)
- 8.2.6 The type of reaction represented by reaction 3 (1)
- 8.2.7 The type of haloalkane represented by compound A (Choose from primary, secondary or tertiary.) (1)

[20]

QUESTION 9

Study the flow diagram below.

Reaction I is a CRACKING REACTION forming two organic compounds, **W** and **T**, as the ONLY products



- 9.1 Define the term *cracking reaction*. (2)
- 9.2 Is the product in reaction II a PRIMARY, SECONDARY or TERTIARY haloalkane? Give a reason for the answer. (2)
- 9.3 Write down the:
- 9.3.1 STRUCTURAL FORMULA of compound W (3)
- 9.3.2 MOLECULAR formula of compound U (1)
- 9.4 For reaction II, write down:
- 9.4.1 The NAME or FORMULA of the inorganic reactant (1)
- 9.4.2 The type of reaction (Choose from SUBSTITUTION, ADDITION or ELIMINATION.) (1)
- 9.4.3 ONE reaction condition (1)
- 9.5 Write down the TYPE of elimination in reaction III. (1)
- 9.6 Compounds R and T are positional isomers.
The inorganic reagents shown below are available for reactions IV and V.

Br ₂	H ₂ SO ₄ (conc.)	NaOH(conc.)	HBr	H ₂
-----------------	--	-------------	-----	----------------

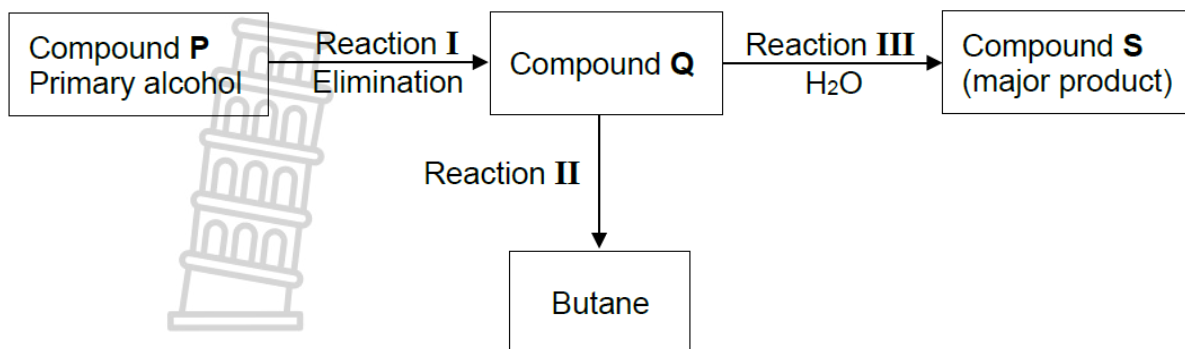
Write down:

- 9.6.1 The balanced equation for reaction IV, using STRUCTURAL FORMULAE and the correct inorganic reagent shown above (5)
- 9.6.2 The balanced equation for reaction V, using STRUCTURAL formulae and the correct reagent shown above (3)
- 9.6.3 The IUPAC name of compound T (2)

[20]

QUESTION 10

In the flow diagram below, a primary alcohol P is used as a starting reactant to form different organic compounds under different reaction conditions.



- 10.1 Write down the TYPE of
- 10.1.1 Addition reaction represented by reaction II. (1)
 - 10.1.2 Elimination reaction represented by reaction I. (1)
- 10.2 Write down the IUPAC name of compound P. (5)
- 10.3 Consider reaction III. Write down:
- 10.3.1 The balanced equation using CONDENSED structural formulae (4)
 - 10.3.2 The NAME or FORMULA of a suitable catalyst (1)
- 10.4 Butane can be converted to compound P in a TWO-STEP reaction. Use STRUCTURAL FORMULAE and write down the balanced equations for these TWO reactions. (5)
- 10.5 Write down a balanced equation using MOLECULAR FORMULAE for the complete combustion of butane. (3)
- [17]**

Work Energy and Power

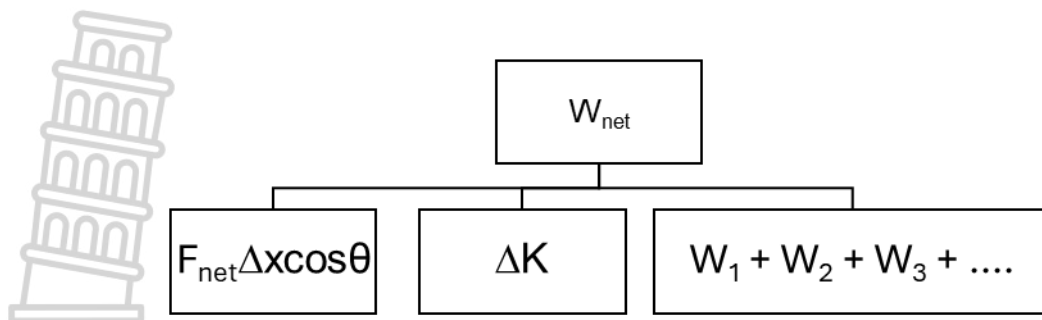
WORK, ENERGY AND POWER

- The work done on an object by a constant force F is $F\Delta x \cos\theta$, where F is the magnitude of the force (N)
 - Δx is the magnitude of the displacement (m)
 - θ the angle between the force and the displacement.

ZERO WORK	POSITIVE WORK	NEGATIVE WORK
<ul style="list-style-type: none"> • The net work done on an object that is moving at constant velocity is zero. • No work is done when a force is exerted on the object, but the object does not move. <p>No work is done by forces acting perpendicular to the surface. ($\theta = 90^\circ$)</p>	<ul style="list-style-type: none"> • Occurs when an object moves in the direction of the force. • It occurs when $\theta = 0^\circ$ • θ lies between $= 0^\circ$ & 90° <p>When positive work is done on an object, the energy of the object increases.</p>	<ul style="list-style-type: none"> • Is done by the force which acts against the motion of an object, e.g., frictional force. • $\theta = 180^\circ$ <p>When negative work is done on an object, the energy of the object decreases.</p>

NET WORK (W_{net})

- It is the total work done by all the forces acting on an object.
- Use any one of the methods given below.



METHOD ONE:

- Draw a force / free-body diagram of all the forces acting on the object.
- Determine the angle θ between each force and the direction of motion / displacement.
- Use $W = F\Delta x \cos\theta$ to determine the work done by each force.
- Calculate the sum of the work done by all the forces, i.e.: $W_{net} = W_1 + W_2 + W_3 + \dots$

METHOD TWO:

- Draw a force / free-body diagram of all the forces acting along the plane of motion of the object.
- Ignore the forces that act perpendicular to the plane because they do zero work on the object.
- Calculate the net force / the sum of the forces acting parallel to the plane, i.e.:

$$F_{net} = F_1 + F_2 + F_3 + \dots$$

$$\therefore W_{net} = F_{net} \Delta x \cos \theta$$

WORK-ENERGY THEOREM

- States: The net work done on an object is equal to the change in the object's kinetic energy.

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

- Work is ONLY done by forces acting parallel to the direction of motion of an object.
- The net work done on an object that is moving at constant velocity is zero.
- The net work done changes the motion of a body.

CONSERVATIVE FORCE

- **A conservative force** is a force for which the work done in moving an object between two points is independent of the path taken.
- If a conservative force is the only force acting on an object during its motion, the mechanical energy of the object is conserved.

$$(U + k)_A = (U + K)_B$$

$$(mgh + \frac{1}{2}mv^2)_A = (mgh + \frac{1}{2}mv^2)_B$$

- **Examples of conservative forces** are the gravitational force and electrostatic force.

- **NON-CONSERVATIVE FORCE**

- **A non-conservative force** is a force for which the work done in moving an object between two points depends on the path taken.
- If a non-conservative force acts on an object, the mechanical energy of the object will not be conserved.
- **Examples of non-conservative forces** are Frictional force, air resistance, an Applied pulling or pushing force or Tension in a rope. (**FAT**)
- Work done by all non-conservative forces is equal to the change in the total mechanical energy of the object.
- $W_{nc} = \Delta E_p + \Delta E_k$

POWER

- **Power** is the rate at which work is done.

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

- It is a scalar quantity with SI Units Watts (W)
- The average power is the product of the force and the average speed of an object.

$$P_{av} = Fv_{av}$$

Average power is required to keep an object moving at a constant velocity.

ENERGY PRINCIPLES

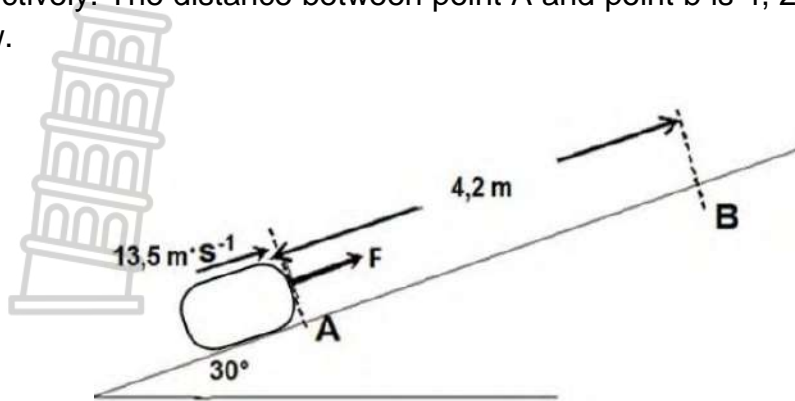
There are THREE energy principles.

Work-energy theorem	Principle of Conservation of Mechanical Energy	Work done by non-conservative forces
<ul style="list-style-type: none"> • $W_{net} = \Delta K$ This one considers all forces acting on the object (conservative and non-conservative forces)	<ul style="list-style-type: none"> • The total mechanical energy in an isolated system remains constant. • A system is isolated when the net external force (excluding the gravitational force) acting on the system is zero. • $(U + K)_A = (U + K)_B$ This is ONLY applicable if all other forces are ignored, and the gravitational force is the only force acting.	<ul style="list-style-type: none"> • $W_{nc} = \Delta K + \Delta U$ • This one ignores conservative forces. Only considers non-conservative forces.

EXAMPLE 1

A constant force **F** is applied to a crate of mass 20 kg to move it upwards along a frictionless inclined plane. The speed of the crate at point A and point B is **13, 5 m·s⁻¹** and **12, 2 m·s⁻¹**

respectively. The distance between point A and point B is 4,2 m as shown in the diagram below.



- 1.1 Draw a labelled free-body diagram showing ALL the forces acting on the crate while it is moving up the incline. (*Hint: Inclined plane*) (3)
 - 1.2 Is the mechanical energy conserved during this motion? Write down YES or NO and briefly explain your answer. (*Hint: when is mechanical energy conserved? is this system isolated?*) (2)
 - 1.3 Write down the name of the conservative force that acts on the crate. (*Hint: definition of a conservative force*) (1)
 - 1.4 Give a reason why the normal force does no work on the crate during its movement up the incline. (*Hint: direction of the Normal force/ value of θ*) (1)
 - 1.5. In which direction does the net force act on the crate as it moves up the incline? Write only **FROM A TO B** or **FROM B to A**. (1)
 - 1.6. Use energy principles to calculate the magnitude of the force F. (*use the free-body diagram in 1.1*) (5)
- [13]**

SOLUTIONS

- 1.1

(3)
- 1.2 NO ✓, it is not an isolated system. ✓ OR
NO ✓, there is an external force (applied force) acting on the object ✓. (2)
- 1.3 Gravitational force ✓/ force of gravity /weight (1)
- 1.4 The force is perpendicular to the displacement ✓ therefore, $\cos \theta = 90^\circ$ ✓ (2)
- 1.5. From B to A ✓ (1)

1.6.

OPTION/OPSIE 1

$$W_{\text{net}} = \Delta K$$

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

$$W_{\parallel} + W_F = \Delta K$$

$$F_{\text{gl}} \cdot \Delta x \cdot \cos\theta + F \cdot \Delta x \cdot \cos\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Any one/Enige een ✓

$$(20 \times 9,8 \times \sin 30^\circ)(4,2) \cos 180^\circ + F(4,2) \cos 0^\circ = \frac{1}{2}(20)(12,2)^2 - \frac{1}{2}(20)(13,5)^2$$

$$411,6(-1) + F(4,2)(1) = 1488,4 - 1822,5$$

$$F = 18,45 \text{ N}$$

OPTION/OPSIE 2

$$W_{\text{nc}} = \Delta E_k + \Delta E_p$$

$$F \cdot \Delta x \cdot \cos\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mgh_f - mgh_i$$

$$F(4,2) \cos 0^\circ = [\frac{1}{2}(20)(12,2)^2 - \frac{1}{2}(20)(13,5)^2] + [(20)(9,8)(4,2 \sin 30^\circ) - 0]$$

Any one/Enige een ✓

$$F(4,2)(1) = 1488,4 - 1822,5 + (196)(4,2)(0,5)$$

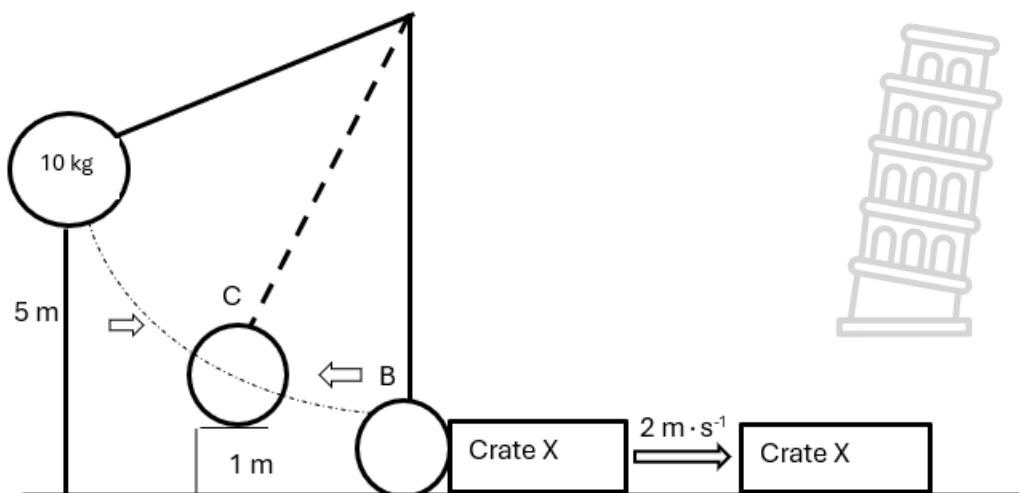
$$F = 18,45 \text{ N}$$

(5)

[13]

EXAMPLE 2

A metal sphere of mass 10 kg is suspended from a chain at a height of 5 m above the ground, at position A. The sphere is held in position A by means of an electromagnet as shown in the sketch below. When the electromagnet is switched off, the sphere swings down to position B, striking a stationary crate, X, of unknown mass. The crate, X, moves to the right with a velocity of $2 \text{ m} \cdot \text{s}^{-1}$. The pendulum swings to the left and reaches a height of 1 m at position C. Ignore ALL friction forces.



2.1 State in words, the *principle of conservation of mechanical energy*.

(2)

- 2.2 Calculate the kinetic energy of the sphere at position B, just before it collides with the crate. (4)
- 2.3 Show that the kinetic energy of crate X, when the sphere reaches point C, is 392 J. (3)
- 2.4 Hence, calculate the mass of the crate. (3)
- 2.5 After moving a short distance, crate X collides with a second crate, Y, of mass 150 kg which was moving towards it (to the left) at a velocity of $0,5 \text{ m}\cdot\text{s}^{-1}$. After the collision crate Y moves off to the right with a velocity of $1 \text{ m}\cdot\text{s}^{-1}$. Assume the surface to be frictionless.



- 2.5.1 State in words, the *principle of conservation of linear momentum*. (2)
- 2.5.2 Calculate the velocity of crate, X, immediately after the collision. (4)

[18]

SOLUTIONS

- 2.1 The total mechanical energy of an isolated system remains constant ✓✓ (2)
- 2.2 $E_{M(A)} = E_{M(B)}$
 $(K + U)_A = (K + U)_B$
 $W_{nc} = \Delta U + \Delta K$
 $(\frac{1}{2}mv^2 + mgh)_A = (\frac{1}{2}mv^2 + mgh)_B$ } ✓
 $\frac{1}{2}(10)(0)^2 + (10)(9,8)(5) \checkmark = E_k + (10)(9,8)(0) \checkmark$
 $E_{kB} = 490 \text{ m}\cdot\text{s}^{-1} \checkmark$ (4)
- 2.3 $(E_{\text{mech}})_{\text{ball at C}} = E_p + E_k$
 $= (10)(9,8)(1) + 0 \checkmark$
 $= 98\text{J}$
 $E_{\text{system}} = (E_{\text{mech}})_{\text{ball at C}} + (E_k)_{\text{crate at B}} \checkmark$
 $490 = 98 + (E_k)_{\text{crate at B}} \checkmark$
 $(E_k)_{\text{crate at B}} = 392 \text{ J} \checkmark$ (3)
- 2.4 In an isolated system the total linear momentum remains constant ✓✓ (2)
- 2.5 $\sum p_{\text{before}} = \sum p_{\text{after}} \checkmark$
 $m_1v_{i1} + m_2v_{i2} = m_1v_{f1} + m_2v_{f2}$
 $(196)(2) + (150)(-0,5) \checkmark = (196)(v_1) + (150)(1) \checkmark$
 $v_1 = 0,85 \text{ m}\cdot\text{s}^{-1} \text{ to the right} \checkmark$ (4)

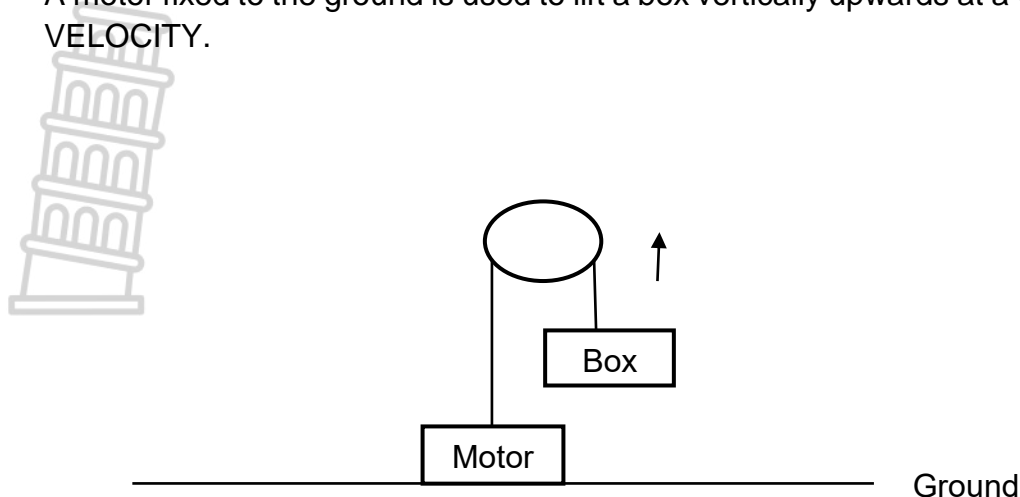
[18]

LONG QUESTIONS

MULTIPLE CHOICE QUESTIONS

QUESTION 1

- 1.1. A motor fixed to the ground is used to lift a box vertically upwards at a CONSTANT VELOCITY.



Consider the statements below for the upward motion of the box.

- (i) The rate at which work is done by the motor on the box increases.
- (ii) The rate at which work is done by the motor on the box is constant.
- (iii) The mechanical energy of the box increases.
- (iv) The mechanical energy of the box is constant.

Which of the statements above are CORRECT?

- A (i) and (iii) only
 - B (ii) and (iv) only
 - C (ii) and (iii) only
 - D (i) and (iv) only (2)
- 1.2. An object moves in a straight line on a ROUGH horizontal surface. If the net work done on the object is ZERO, then...
- A The object moves at constant speed.
 - B The object has ZERO kinetic energy.
 - C The object moves with constant acceleration.
 - D There is no frictional force acting on the object. (2)
- 1.3. An object moving with a constant speed v has a kinetic energy E . Which one of the following will be true for the energy if the object has a constant velocity of $2v$?
- A $\frac{1}{2} E$
 - B E
 - C $2E$
 - D $4E$ (2)
- 1.4. Engine P has a greater maximum power output than engine Q. Which ONE of the following statements is CORRECT when P and Q each operate at their maximum power output?
- A Q does more work than P in the same amount of time
 - B P and Q do the same amount of work in the same amount of time
 - C P and Q do the same amount of work, but Q does it in a shorter time than P.
 - D P and Q do the same amount of work, but P does it in a shorter time than Q (2)

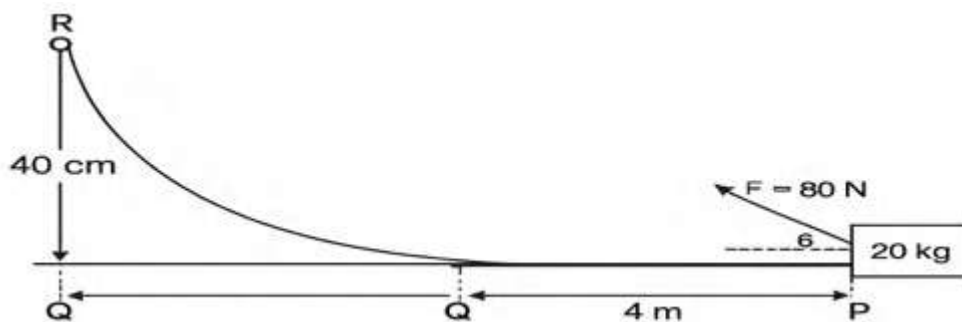
1.5. The speed of a bicycle increases from $2 \text{ m}\cdot\text{s}^{-1}$ to $8 \text{ m}\cdot\text{s}^{-1}$, its kinetic energy increases by a factor of...

- A 4
- B 16
- C 8
- D 10

(2)
[10]

QUESTION 2

A Force of 80 N pulls a 20 kg object at an unknown angle θ along the 4 m horizontal rough surface from rest at point P to point Q while experiencing a constant frictional force of 45 N . when the object reaches point Q, the force is removed and the object continue to move up a curved frictionless surface to a stop at point R at the height of 40 cm above the horizontal surface as shown in the diagram below. Ignore the effect of air resistance.



- 2.1 State the *principle of conservation of mechanical energy* in words. (2)
 - 2.2 Is mechanical energy of the object CONSERVED or NOT CONSERVED while the objects is moving from point P to Point Q along the horizontal surface? (2)
Give a reason for your answer.
 - 2.3 Calculate the : (2)
 - 2.3.1. Magnitude of the angle θ , shown in the diagram above, using energy principles ONLY. (5)
 - 2.3.2. Power delivered by a force F if the time taken for the object to move from point P to point Q is $2,86$ seconds. (3)
- [12]

QUESTION 3

An 8 kg steel ball initially at rest is pulled upwards by an electric motor with a constant applied force of 45 N . The ball moves at constant speed in each of the section XY and YZ along a **rough** inclined slope as shown below. Each section is 4 meters long and exerts a different frictional force of the steel ball as it move up the incline. The incline makes an angle of 25° with the horizontal. (see **DIAGRAM 1**)

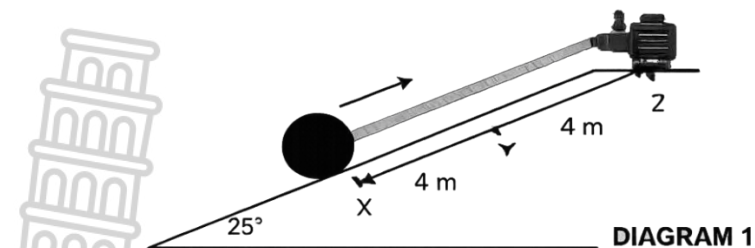


DIAGRAM 1

The graph below shows the kinetic energy of the object versus the distance for the entire motion until point 2. (See **DIAGRAM 2**)

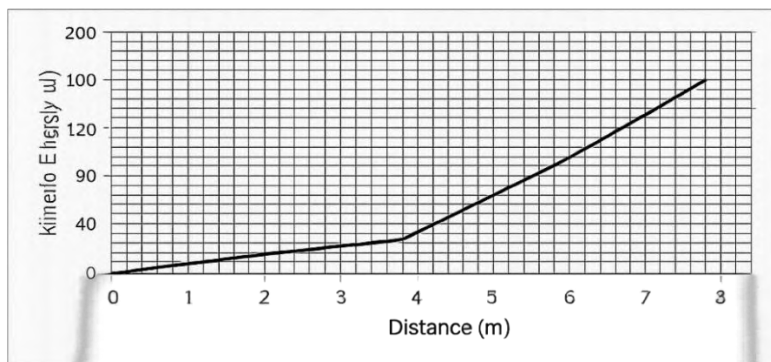


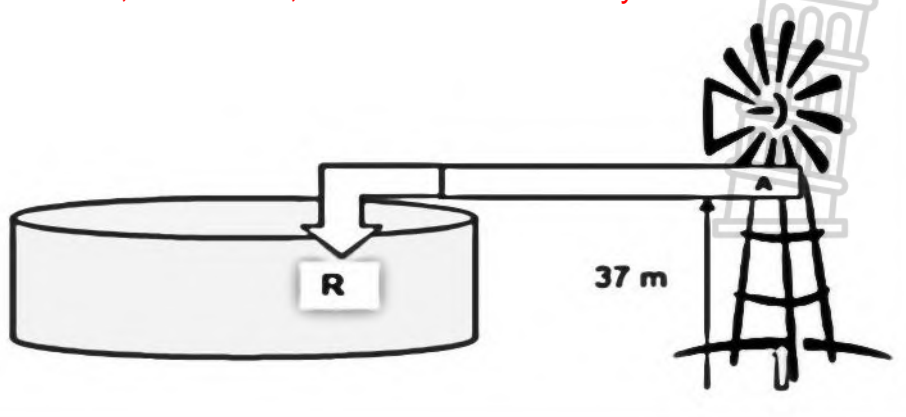
DIAGRAM 2

- 3.1 Define the term *non-conservative force*. (2)
- 3.2 Use a suitable formula to show the physical quantity represented by the slope of the graph. (2)
- 3.3. Calculate:
 - 3.3.1. The net force experienced by the steel ball as it moves from **Y** to **Z** (3)
 - 3.3.2. The magnitude of the frictional force experienced by the block as it moves from **Y** to **Z** (4)
 - 3.3.3. The power dissipated by the block from **X** to **Z** (4)
- 3.4. Which region, **XY** or **YZ**, has the largest frictional force? Explain your answer. (2)

[17]

QUESTION 4

A windmill is used on a farm to pump water out of a well. The water flows past point **A**, 37m above the well water level, to the dam, with a constant velocity of $2 \text{ m}\cdot\text{s}^{-1}$.



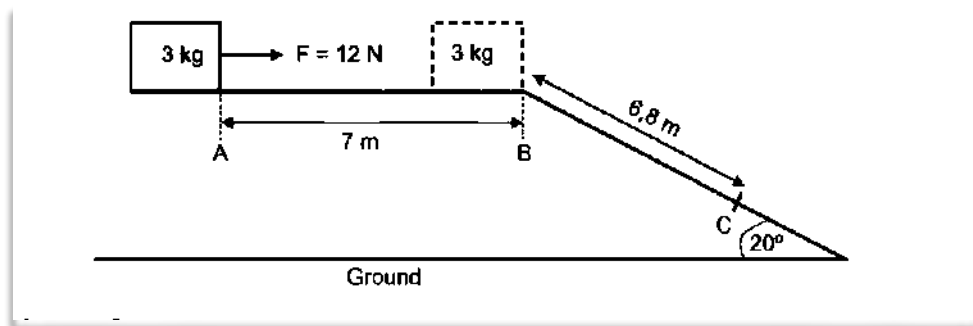
- 4.1 Calculate how much energy is necessary to pump 90kg of water out of the well to point **A**. (4)

- 4.2 It is necessary to pump 90kg of water per minute. What is the maximum power that the windmill must produce? (3)
- 4.3 The farmer wants to modernise the farm. The farmer decides to buy a 0,5 kW petrol water pump.
- 4.3.1 Will the petrol water pump be able to produce the required power? (**YES or NO**) (1)
- 4.3.2 Give a reason for your answer in question 4.3.1. (2)
- 4.3.3 Why would you advise the farmer to rather use a windmill instead of a petrol water pump? (2)

[12]

QUESTION 5

A crate of mass 3kg is at rest at point **A** on a frictionless horizontal surface. A constant horizontal force F of 12 N acts on the crate and moves it from **A** to point **B**. The crate then moves down a rough plane, inclined at 20° to the horizontal. The distance from point **A** to point **B** is 7 m and from **B** to point **C** is 6,8 m, as shown in the diagram below.

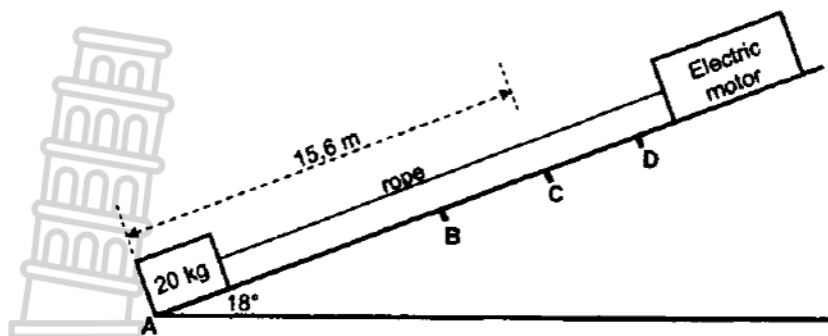


- 5.1. State the *work-energy theorem* in words. (2)
- 5.2. Using ENERGY PRINCIPLES ONLY, calculate the kinetic energy of the crate at point **B**. (3)
- Force F is removed when the crate reaches point **B**. the crate then experiences a constant frictional force of 21 N as it moves down the incline.
- 5.3. Draw a free-body diagram showing ALL the forces acting on the crate as it moves down the incline. (3)
- 5.4. Using ENERGY PRINCIPLES ONLY, determine whether the crate will pass point **C**. (5)

[13]

QUESTION 6

An electric motor pulls a 20 kg crate from rest at point **A** up an inclined plane by means of a light inextensible rope. The inclined plane makes an angle of 18° with the horizontal. **B**, **C** and **D** are points on the inclined plane and the distance between points **A** and **C** is 15,6 m, as shown in the diagram below.



The motor exerts a constant force of $96,8\text{ N}$ parallel to the inclined plane on the rope. A constant frictional force of $13,5\text{ N}$ acts on the crate as it moves on the inclined plane.

- 6.1. Define a *non-conservative force*. (2)
- 6.2. Use ENERGY PRINCIPLES to calculate the speed of the crate when it reaches point **C**. (5)
- 6.3. Calculate the minimum average power dissipated by the electric motor to pull the crate from point **A** to point **C**. (3)

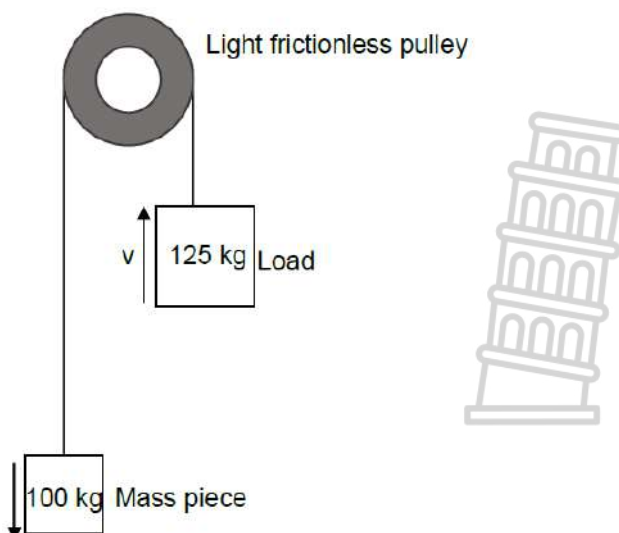
When the crate reaches point **C**, the rope breaks. The crate continues moving up the inclined plane, comes to a stop at point **D**, and then slides down the plane past point **B**.

- 6.4. Draw a labelled free-body diagram for the crate as it slides down the plane past point **B**. (3)
- 6.5. Draw a velocity-time graph for the entire motion of the crate starting from point **A** until it passes point **B** again on its motion down the inclined plane. (4)

[17]

QUESTION 7

A pulley system with a mass piece is operated by an electric motor. It is used to lift a load of 120 kg vertically upwards at a CONSTANT SPEED, as shown in the diagram below.



The load covers $6,8\text{ m}$ in $1,7$ minutes. Neglect all the effects of friction.

- 7.1 Define, in words, the term power as applied in Physics. (2)
- 7.2 Calculate the work done by the:
 - 7.2.1 Gravitational force on the load. (3)

- 7.2.2 Mass piece on the load. (3)
- 7.3 Determine the average power output required by the electric motor to lift the load through 6, 8 m in 1, 7 minutes. (6)

[14]



Doppler Effect

DOPPLER EFFECT

DOPPLER EFFECT WITH SOUND

Revision of Grade 10/11

Wavelength (λ): The distance between two successive points in phase.

Frequency (f): The number of wave pulses per second.

- Frequency is a measure of the pitch of sound. High frequency; high pitch. Low frequency; low pitch.
- Frequency and wavelength are inversely proportional to each other. $f \propto \frac{1}{\lambda}$

Period (T): The time taken for one complete wave pulse.

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

Speed of a wave (v): The distance travelled by a point on a wave per unit time.

$$\text{Speed } (v) = \frac{\text{distance covered } (\Delta x)}{\text{time } (\Delta t)} = \frac{\lambda}{T} \quad \left(\frac{1}{T} = f\right)$$

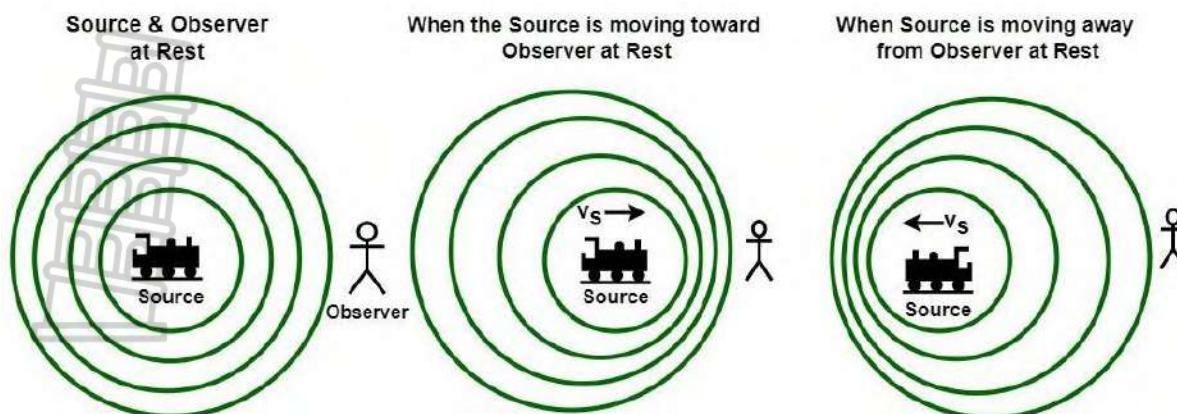
$$\therefore v = f\lambda$$

The speed of sound in air is usually $340 \text{ m}\cdot\text{s}^{-1}$

Quantity Name	Quantity Symbol	SI Unit Name	SI Unit Symbol
Wavelength	λ	metre	m
Frequency	f	hertz	Hz
Period	T	second	s



Doppler Effect: the change in frequency (or pitch) of the sound detected by a listener, because the sound source and the listener have different velocities relative to the medium of sound propagation.



Source & Observer at Rest - sound waves are emitted in regular equidistant patterns.

When the Source is moving towards the Observer at Rest -the sound waves go through compressions which means the distance between two consecutive points becomes smaller (λ is shorter), frequency increases, which means the pitch increases.

When Source is moving away from Observer at Rest - the sound waves go through rarefactions which means the distance between two consecutive points becomes bigger (λ is longer), frequency decreases, which means the pitch decreases.

Calculations involving the Doppler Effect

The Doppler equation can be used to calculate the frequency of the sound a listener hears when the sound source and/or the observer/ listener move towards or away from one another.

$$f_L = \frac{v \pm v_L}{v \pm v_S} f_S$$

Quantity Name	Quantity Symbol	SI Unit Name	SI Unit Symbol
Frequency of Listener/Observer	f_L	hertz	Hz
Frequency of Source	f_S		
Velocity of Listener/Observer	v_L		
Velocity of Source	v_S	metre per second	$\text{m}\cdot\text{s}^{-1}$
Speed of Sound	v		

Doppler expressions to use after writing the Doppler effect formula

Using the plus (+) or minus (-) signs depends on the relative motions of the source and observer.

SOURCE moving towards stationary LISTENER

$$f_L = \frac{v}{v - v_S} f_S$$

SOURCE moving away from stationary LISTENER

$$f_L = \frac{v}{v + v_S} f_S$$

LISTERNER moving towards stationary
SOURCE

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

LISTERNER moving away from stationary
SOURCE

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

Applications of the Doppler Effect

- **MEDICAL APPLICATIONS:** (i) To determine the blood flow rate (Doppler flow meter) (ii) To detect the heartbeat of an unborn foetus (Doppler ultra-sound)
- **IN ASTRONOMY:** To study the motion of galaxies and stars, to determine their relative velocities.
- **SONAR TECHNOLOGY:** For underwater navigation, fish finding, and submarine detection by measuring shift in sound waves reflected off moving objects.
- **SPEED ENFORCEMENT:** Doppler radar traffic cameras measure the speed of moving vehicles for enforcing speed limits.

Doppler Effect with Light

Light travels with a speed $c = 3 \times 10^8 \text{ m.s}^{-1}$.

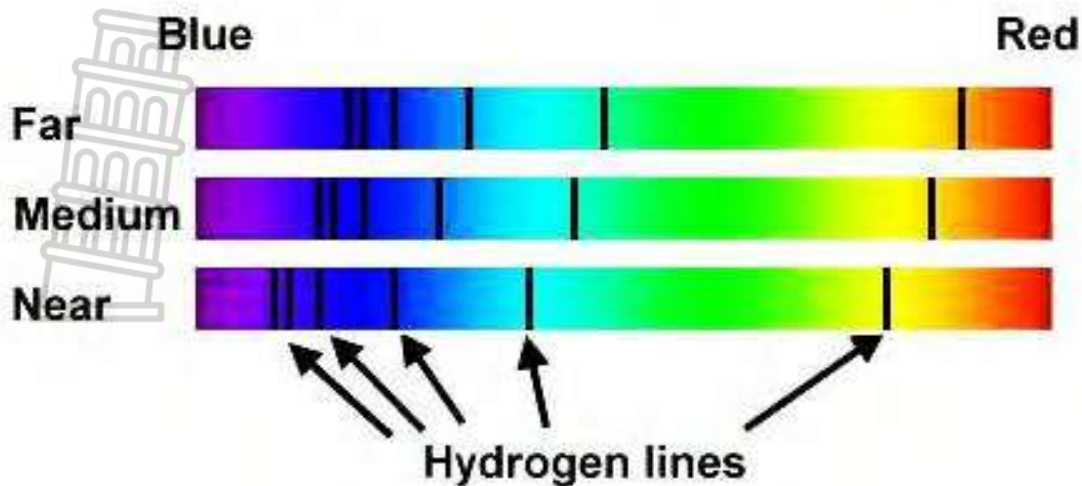
- Red light has the longest wavelength and the lowest frequency, while blue light has a shorter wavelength and a higher frequency.
- A change in the frequency of light is observed as a colour change.
- If the frequency/ colour of light being observed differs from that which is emitted, it is called a shift.

Red Shift and the Explanation of an Expanding Universe

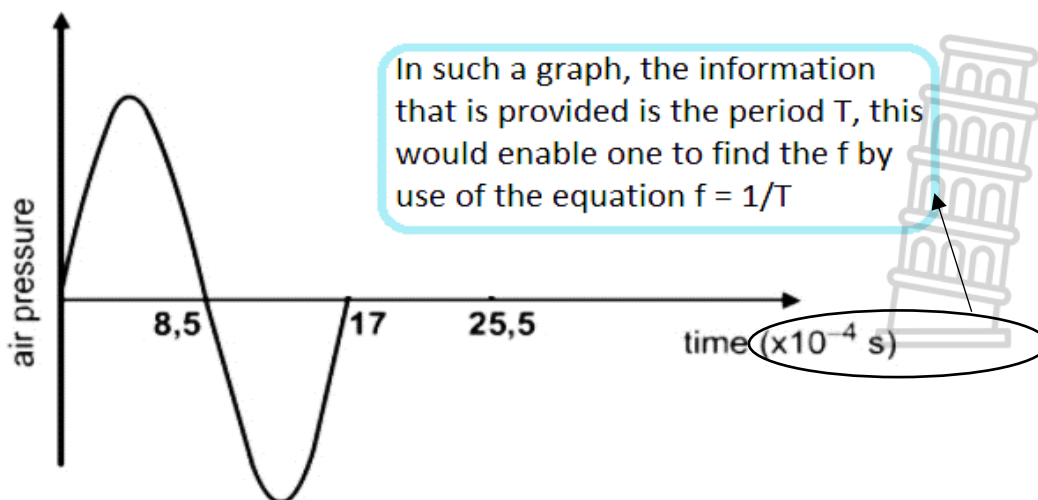
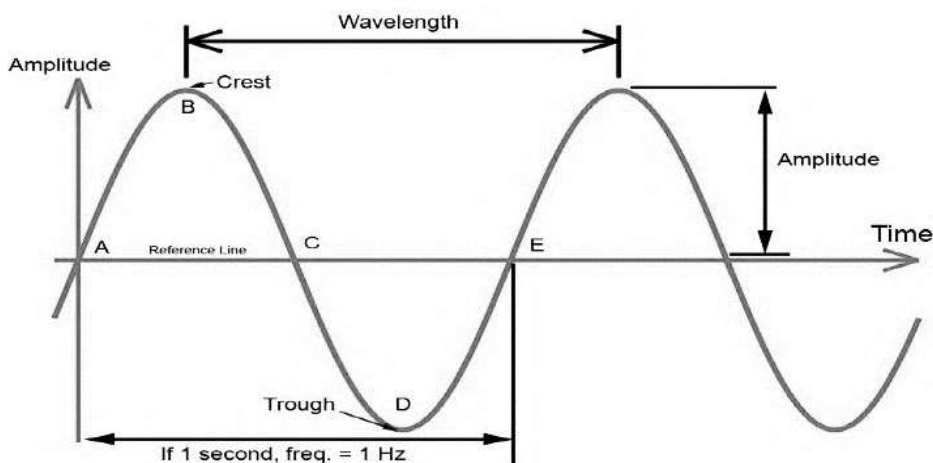
The Big Bang Theory is the leading explanation about how the universe began.

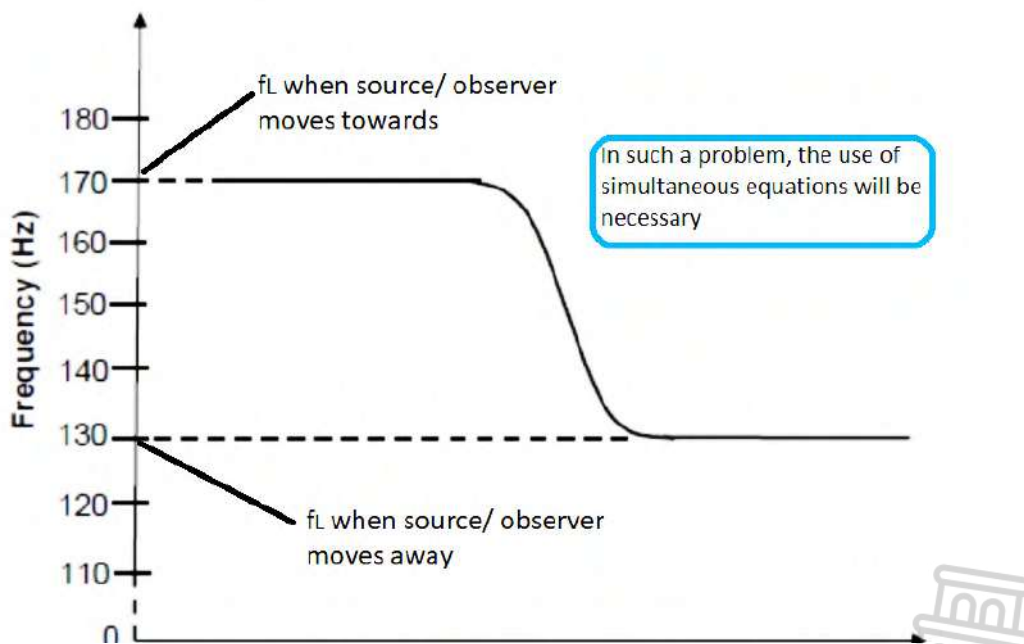
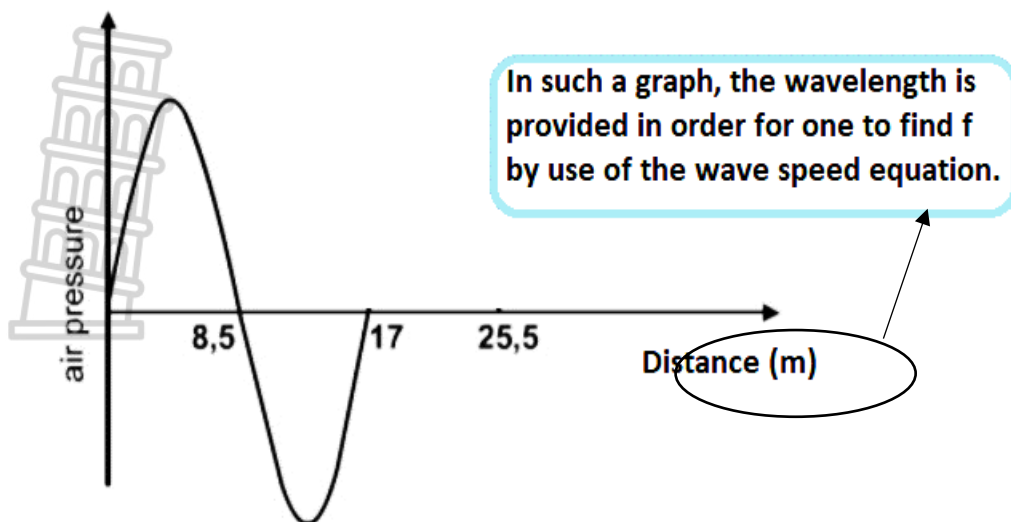
- The further away the light source is, in the form of a distant galaxy, the greater the degree of shift towards the red end of the spectrum.
- The further away a galaxy is from us, the faster it is moving away from us; resulting in a red shift in the spectrum; suggesting that the universe is expanding.
- If a star is moving away from earth, there will be a shift of the spectral lines to a lower frequency (longer wavelength) i.e. a RED SHIFT takes place.
- If a star is moving towards earth, there will be a shift of the spectral lines to higher frequencies (shorter wavelength), i.e., a BLUE SHIFT takes place.

Note: The greater the shift, the greater the speed of the star.



Interpretation of Graphs





WORKED EXAMPLE 1

1.1 The siren of a police car, moving in front of a truck, emits sound waves of frequency f . Both vehicles are travelling at the same constant velocity.

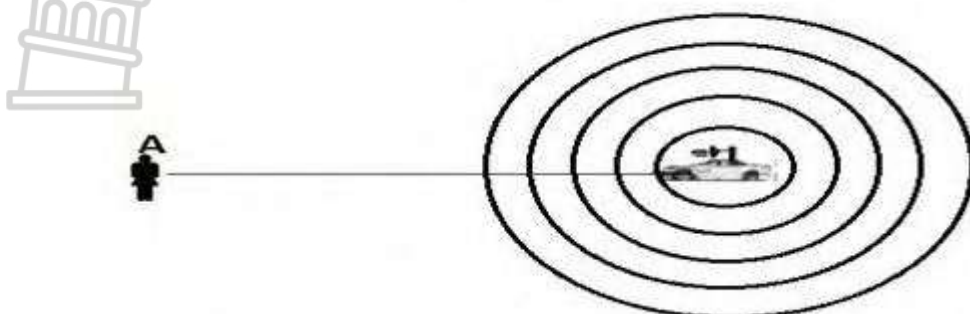
The frequency of the sound heard by the driver of the truck is

- A f
- B zero
- C greater than f
- D smaller than f

(2)

- 1.2 A car that is initially at rest has its radio playing music. The diagram below (not drawn to scale) represents the sound wave fronts arising from a musical note of frequency 440 Hz, spreading out from the car.

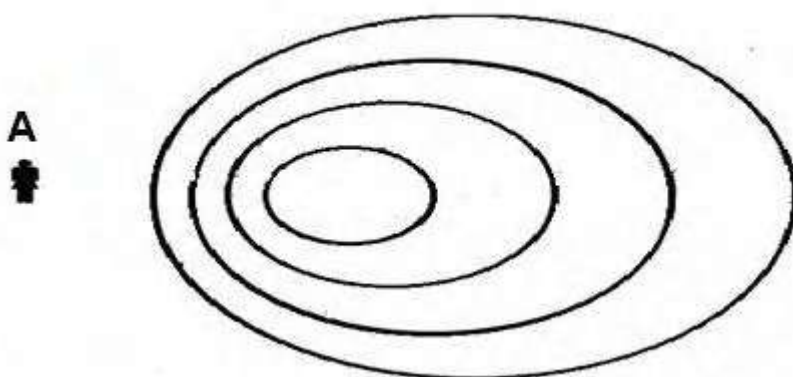
The speed of sound in air is $330 \text{ m}\cdot\text{s}^{-1}$



STATIONARY SOURCE

- 1.2.1 Calculate the wavelength of the sound wave. (3)
- 1.2.2 What is the frequency of the note as heard by an observer at point A? (1)

The car now moves at a constant speed of $8 \text{ m}\cdot\text{s}^{-1}$. The wave fronts reach the stationary observer at A as shown in the diagram below.



MOVING SOURCE

- 1.2.3 State the Doppler effect in words. (2)
- 1.2.4 At what speed are the wave fronts progressing towards the observer? (1)
- 1.2.5 Calculate the frequency of the note as heard by the observer at point A. (5)

[14]

WORKED EXAMPLE 1 SOLUTION

- 1.1 A ✓✓ (2)
- 1.2.1 $v = f\lambda$ ✓
- $330 = (440)\lambda$ ✓ (3)

$$= 0,75 \text{ m } \checkmark$$

1.2.2 $440 \text{ Hz } \checkmark$ (1)

1.2.3 The (apparent) change in frequency/pitch \square of the sound detected by a listener because the listener and the sound source have different velocities relative to the medium of sound propagation. \square (2)

1.2.4 $330 \text{ m}\cdot\text{s}^{-1} \checkmark$ (1)

1.2.5 $f_L = \frac{v \pm v_L}{v \pm v_S} f_S \checkmark$
 $= \frac{330 \checkmark}{330 - 8 \checkmark} 440 \checkmark$
 $= 450.93 \text{ Hz } \checkmark$ (5)

[14]

WORKED EXAMPLE 2

- 2.1 For light, a red shift indicates the light source moves ...
 A away from you
 B towards you
 C at right angles with you
 D parallel to you (2)

2.2 A stationary source emits a sound wave of frequency 5000 Hz. An object approaches this source with an unknown velocity. The sound wave is reflected from the moving object which is detected by the source.

(Take the speed of sound in the air as $340 \text{ m}\cdot\text{s}^{-1}$)

- 2.2.1 State the definition of Doppler effect. (2)
 2.2.2 Calculate the wavelength of the waves being generated by the source. (3)
 2.2.3 Calculate the velocity of the object if the detected wave, by the source, has frequency of 5104 Hz. (6)
 2.2.4 State TWO applications of the Doppler Effect in Medical Science. (2)

[15]

WORKED EXAMPLE 2 SOLUTION

2.1 A (2)

2.2.1 The change in frequency (or pitch) of the sound detected by a listener because the sound source and the listener have different velocities relative to the medium of sound propagation. ✓✓ (2)

2.2.2 $\lambda = \frac{v}{f}$ ✓

$\lambda = \frac{340}{5000}$ ✓

$\lambda = 0,068 \text{ m}$ ✓ (3)

2.2.3 Shift 1 Shift 2

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

$5104 \checkmark = \left(\frac{340}{340+v_o}\right) \checkmark \left(\frac{340-v_o}{340}\right) (5\ 000) \checkmark$

$f_L = \frac{340-v_o}{340} (5\ 000) \checkmark$

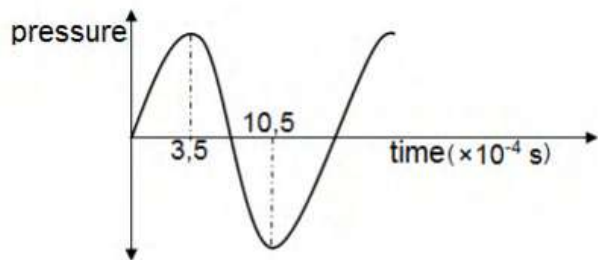
$v = 3,50 \text{ m}\cdot\text{s}^{-1}$ towards the source ✓ (6)

2.2.4 To measure heartbeat of the unborn foetus in the womb. ✓

To measure blood flow rate. ✓ (2)

WORKED EXAMPLE 3

A man mounts a siren on the roof of his car. The siren produces a constant frequency of 600 Hz. He drives the car at a constant speed up and down a straight road while a stationary listener takes some readings. After a while, the listener obtains the following pressure-time graph from the readings taken.



Take the speed of sound in air as $340 \text{ m}\cdot\text{s}^{-1}$.

3.1 Which ONE of the following can be explained by the Doppler effect?

- A A stethoscope is used to listen to a person's heartbeat.
- B An echo is heard when sound waves are reflected off a cliff.
- C The spectrum of light from an approaching star is shifted towards shorter wavelengths.
- D Sound intensity decreases when the sound source moves away from a stationary listener.

(2)

3.2 How many waves are depicted in the diagram above?

(1)

- 3.3 Determine the period of the detected wave. (2)
- 3.4 Calculate the frequency of the detected sound wave (3)
- 3.5 Calculate the speed of the moving car. (5)

WORKED EXAMPLE 3 SOLUTION

3.1 $C \checkmark \checkmark$ (2)

3.2 1,25 or $1 \frac{1}{4} \checkmark$ (1)

3.3 $14 \times 10^{-4} \text{ s} \checkmark \checkmark$ (2)

3.4 $f = \frac{1}{T} \checkmark$

$$f = \frac{1}{14 \times 10^{-4}} \checkmark$$

$f = 714,29 \text{ Hz} \checkmark$ (3)

3.5 $f_L = \frac{v \pm v_L}{v \pm v_s} f_s \checkmark$

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

$$(714,29) \checkmark = \left(\frac{340}{340 - v_s} \right) \checkmark (600) \checkmark$$

$v_s = 54,40 \text{ m} \cdot \text{s}^{-1} \checkmark$ (5)

DOPPLER EFFECT MULTIPLE CHOICE QUESTIONS

QUESTION 1

- 1.1 An observer stands at a distance x from a stationary ambulance blowing its siren at a certain frequency at an accident scene. The pitch of sound that the observer hears compared to the pitch of sound produced from the siren will be ...

- A Equal to
- B Greater Than
- C Less Than
- D Zero

(2)

- 1.2 The spectrum of helium emitted from a star moving away from Earth is compared to the spectrum of helium found on Earth.

Which ONE of the following statements is CORRECT?

The observed spectral lines from the moving star will have a ...

- A lower frequency and a longer wavelength.
- B lower frequency and a shorter wavelength.
- C higher frequency and a shorter wavelength



D higher frequency and a shorter wavelength (2)

1.3 A learner standing at a roadside records the frequency of sound waves produced by the siren of an ambulance moving at constant velocity along a straight horizontal road.

The frequency-time graph for the detected sound is shown below.

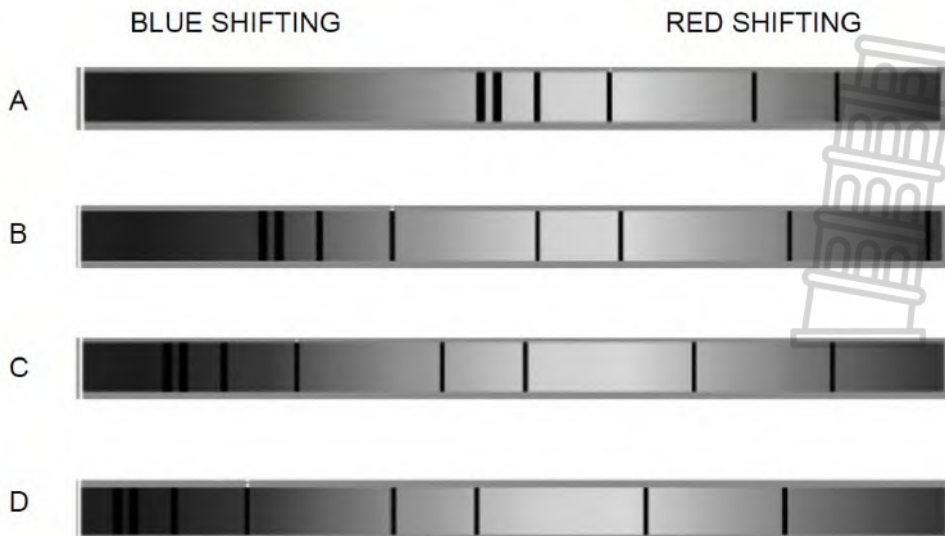


Which ONE of the following statements concerning the motion of the ambulance is CORRECT?

The ambulance ...

- A approaches the learner and then passes the learner.
- B moves away from the learners, then turns and approaches the learners.
- C approaches the learner, then turns and moves away from the learner.
- D moves away from the learner and then increases speed. (2)

1.4 The diagram below shows the absorption spectrum of an element on hypothetical star A and D as observed from the Earth. Which star is moving away from the Earth with the highest velocity?



(2)

1.5 An observer moving at a constant speed away from a stationary sound source, observes that the pitch of the sound waves decreases. This is because the following happens:



	WAVELENGTH	FREQUENCY
A	Increases	Decreases
B	Decreases	Remains the same
C	Increases	Increases
D	Decreases	Increases

(2)

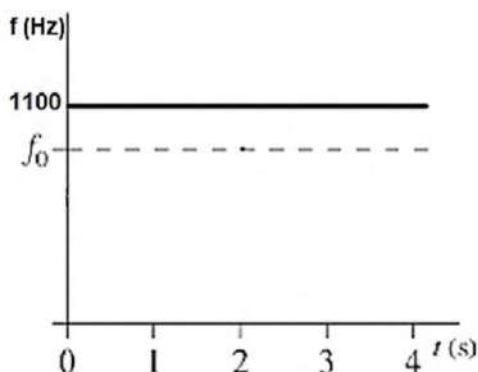
[10]

DOPPLER EFFECT LONG QUESTIONS

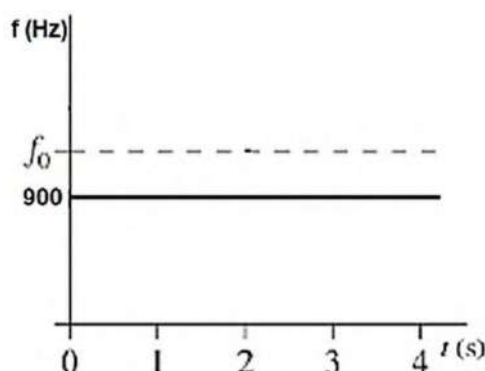
QUESTION 1

An observer with a detector, standing on the side of a straight road, records the frequency of a police car siren moving in a straight line on two separate occasions. The police car moves at the same CONSTANT SPEED on both occasions. The results are shown on graphs A and B drawn below.

GRAPH A



GRAPH B



1.1 State the Doppler effect in words.

(2)

1.2 Which graph, A or B, shows the police car moving away from the observer?

Give a reason for your answer.

(2)

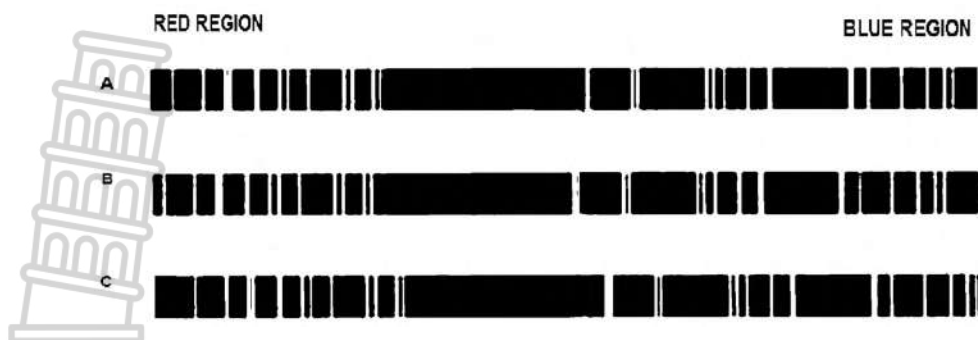
1.3 Calculate the speed of the police car.

(Take the speed of sound in air to be $340 \text{ m}\cdot\text{s}^{-1}$.)

(5)

1.4 Study the emission spectra A, B and C of a distant star as observed from Earth. Spectrum A is the laboratory reference spectrum of the same star.





1.4.1 Which spectrum B or C indicates that the star is moving away from earth? (1)

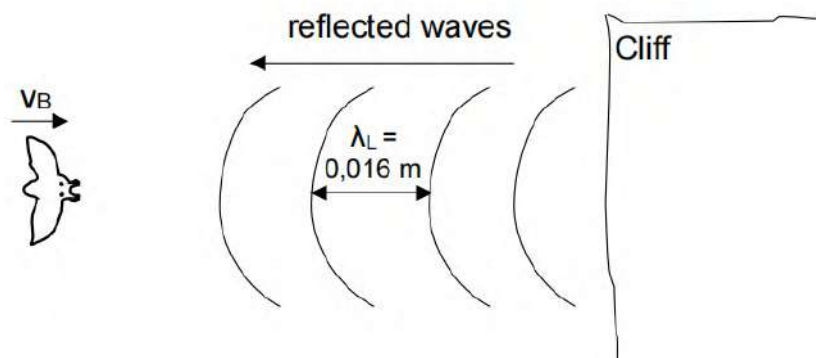
1.4.2 If the blue part of a star spectrum is being observed from Earth, describe the frequency and wavelength of this light. (2)

[12]

QUESTION 2

A bat emits sound waves with a frequency f_s as it flies at a constant speed v_B towards a vertical cliff. The waves reflect off the cliff with the same frequency that they strike the cliff, and with a wavelength of $\lambda_L = 0,016$ m, as shown in the simplified diagram below.

Take the speed of sound in air to be $340 \text{ m}\cdot\text{s}^{-1}$.



2.1 NAME and STATE the phenomenon that results in a change in frequency of the detected sound waves. (3)

2.2 Show that f_s , the frequency of the sound waves emitted by the bat, is $(21\,250 - 62,5v_B)$. (4)

2.3 The frequency of the reflected sound waves detected by the bat is 850 Hz higher than the frequency of the sound waves emitted by the bat. Calculate the speed of the bat, v_B . (5)

[12]

QUESTION 3

The siren of a fire truck moving at a constant speed $20 \text{ m}\cdot\text{s}^{-1}$ along a straight

horizontal road emits sound with a wavelength of 0,34 m. A detector on the same road records sound waves from the fire truck with a lower frequency than the sound emitted by the siren. Take the speed of sound in air as $340 \text{ m}\cdot\text{s}^{-1}$.

- 3.1 Define Doppler effect in words. (2)
- 3.2 Is the fire truck driving TOWARDS or AWAY FROM the detector? Give a reason for your answer. (2)
- 3.3 Explain in terms of wave motion why the detector records sound waves with lower frequency. (3)
- 3.4 Calculate the:
- 3.4.1 Frequency of the siren (3)
- 3.4.2 Frequency recorded by the detector (6)
- 3.5 The speed of the fire truck now increased to $25 \text{ m}\cdot\text{s}^{-1}$. How will the increase in speed affect the following?
- Choose from INCREASE, DECREASE or STAYS THE SAME.
- 3.5.1 The frequency of the sound waves emitted by the siren. (1)
- 3.5.2 The frequency of the sound waves recorded by the detector. (1)
- [18]

QUESTION 4

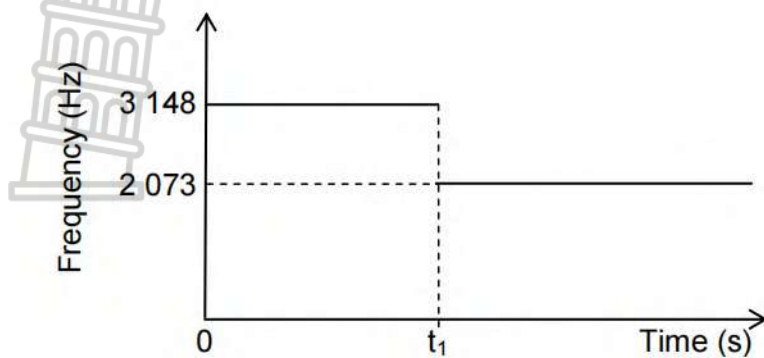
A stationary listener records the frequency of the sound emitted by the siren of a police car. When the car which is travelling at a constant velocity of $26 \text{ m}\cdot\text{s}^{-1}$, approaches the listener, the recorded frequency is 615 Hz. The car passes the listener at time t_1 and then moves away from the listener. The recorded frequency now is 526 Hz.

Ignore the effects of wind.

- 4.1 State the Doppler effect in words. (2)
- 4.2 Use the information given to calculate the speed of sound in air. (5)
- 4.3 Calculate the wavelength of the sound emitted by the police siren. (4)
- 4.4 Sketch the graph of recorded frequency versus time for the motion of the car as it moved towards the listener, passed the listener and then moved away from the listener. (3)
- Label time t_1 on the graph.
- No values need to be indicated on the frequency axis.
- [14]

QUESTION 5

The siren of a train, moving at a constant speed along a straight horizontal track, emits sound with a constant frequency. A detector, placed next to the track, records the frequency of the sound waves. The results obtained are as shown in the graph below.



- 5.1 State the Doppler effect in words. (2)
- 5.2 Does the detector record the frequency of 3 148 Hz when the train moves TOWARDS the detector or AWAY from the detector? (1)
- 5.3 Calculate the speed of the train. Take the speed of sound in air as $340 \text{ m}\cdot\text{s}^{-1}$. (6)
- 5.4 The detector started recording the frequency of the moving train's siren when the train was 350 m away.
- Calculate time t_1 indicated on the graph above.

(2)
[11



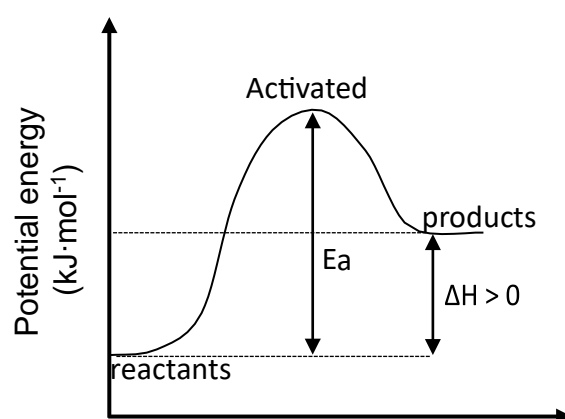
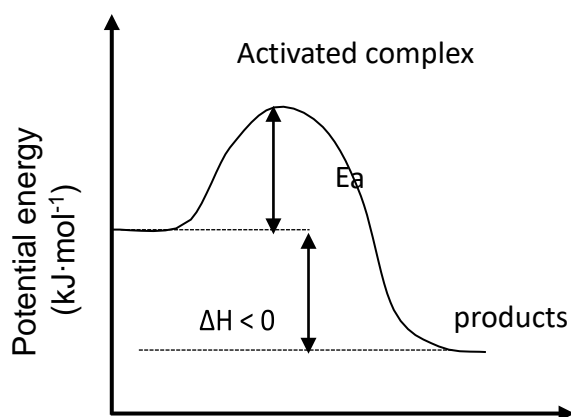


Rates of Reaction





REACTION RATES AND ENERGY IN CHEMICAL REACTIONS



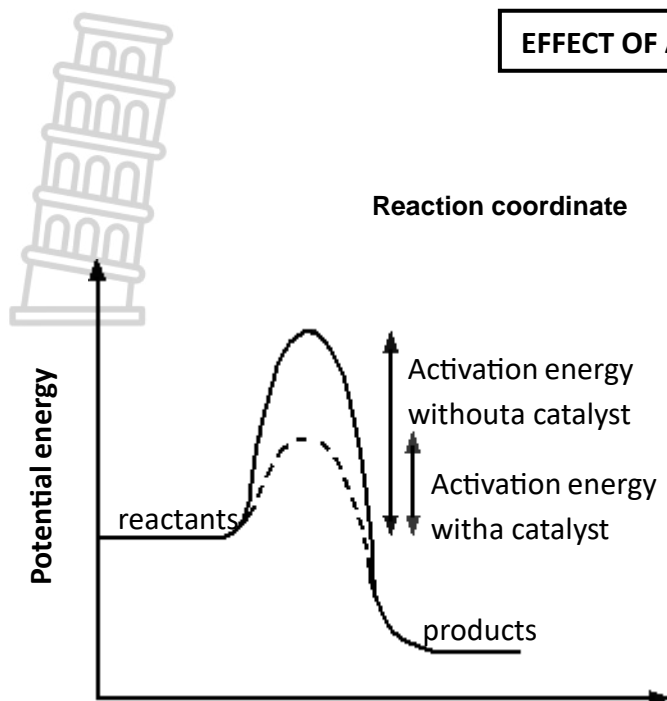
Course of reaction

Course of reaction

The unstable transition state from reactants to products.



EFFECT OF A CATALYST

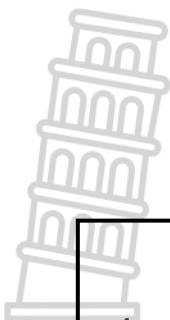


Catalyst

Increases reaction rate without undergoing a permanent change.

Mechanism of catalyst: Increase reaction rate by lowering the total activation energy



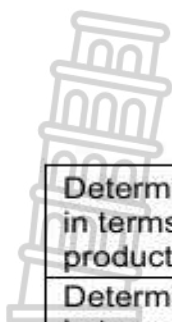


REACTION RATE
 Change in concentration of reactants or products per unit time.

- FACTORS AFFECTING REACTION RATES**
1. The nature of reactants
 2. Concentration – higher concentration, faster rate
 3. Surface Area – greater surface area, faster rate
 4. Temperature – higher temperature, faster rate
 5. Catalyst – increases reaction rate without undergoing a permanent change

PRACTICAL SKILLS

Independent variable	The variable that is changed/manipulated during an investigation e.g. an increase in temperature. (It is the input.)
Dependent variable	The variable that changes due to a change in the independent variable e.g., reaction rate changes due to a change in temperature. (It is the output.)
Controlled variable	The variable(s) that are kept constant e.g. concentration and surface area are kept constant to measure the effect of temperature on reaction rate.
Investigative question	A question about the relationship between the dependent and independent variables. Must have both the independent and dependent variable and is a question about the relationship between them. Example: What is the relationship between temperature and reaction rate?
Hypothesis	A prediction on the answer to the investigative question prior to the investigation. Must have both the independent and dependent variable and predict the relationship between them. Example: When temperature increases, reaction rate will decrease. OR When temperature increases, reaction rate will increase.
Conclusion	The conclusion is drawn after the investigation and answers the investigative question. Must have both the independent and dependent variable and state the relationship between them. Example: When temperature increases, the reaction rate increases.



CALCULATING REACTION RATE

Determine rate in terms of products	Rate = $\frac{\Delta c}{\Delta t}$	Rate = $\frac{\Delta m}{\Delta t}$	Rate = $\frac{\Delta V}{\Delta t}$	Rate = $\frac{\Delta n}{\Delta t}$
Determine rate in terms of reactants	Rate = $-\frac{\Delta c}{\Delta t}$	Rate = $-\frac{\Delta m}{\Delta t}$	Rate = $-\frac{\Delta V}{\Delta t}$	Rate = $-\frac{\Delta n}{\Delta t}$

Unit of reaction rate: Any unit of the above quantities per second

Examples: mol·dm⁻³·s⁻¹ OR g·s⁻¹ OR dm⁻³·s⁻¹ OR mol·s⁻¹

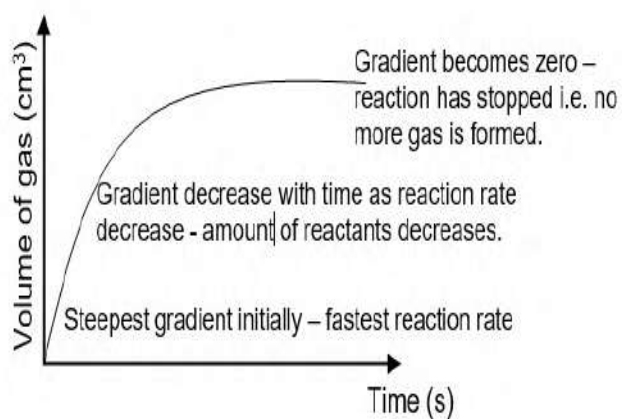
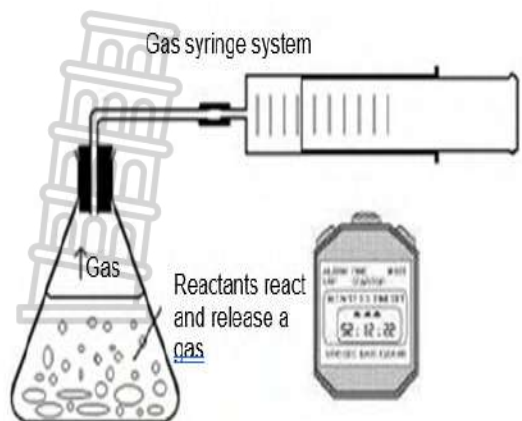
MEASURING REACTION RATE

If we do an experiment to establish the speed (rate) of a reaction under different conditions, we can measure how fast the reaction is proceeding in a number of different ways:

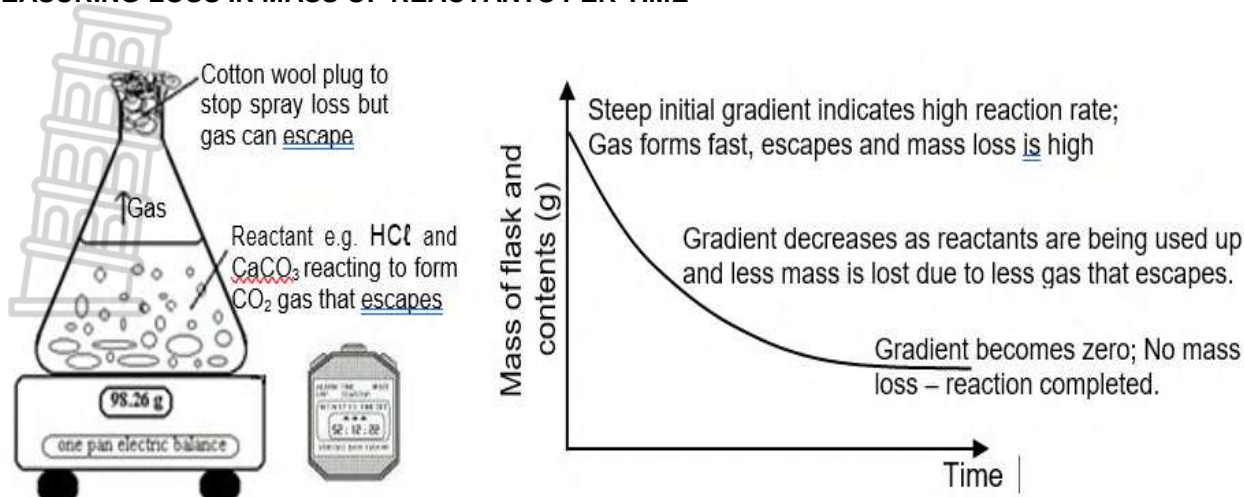
- gas volume produced
- volume of solid formed
- mass changes
- how reactants disappear or products appear
- colour changes (colour cards or spectrophotometers)
- concentration of ions (conductivity)

MEASURING VOLUME OF GAS RELEASED PER TIME



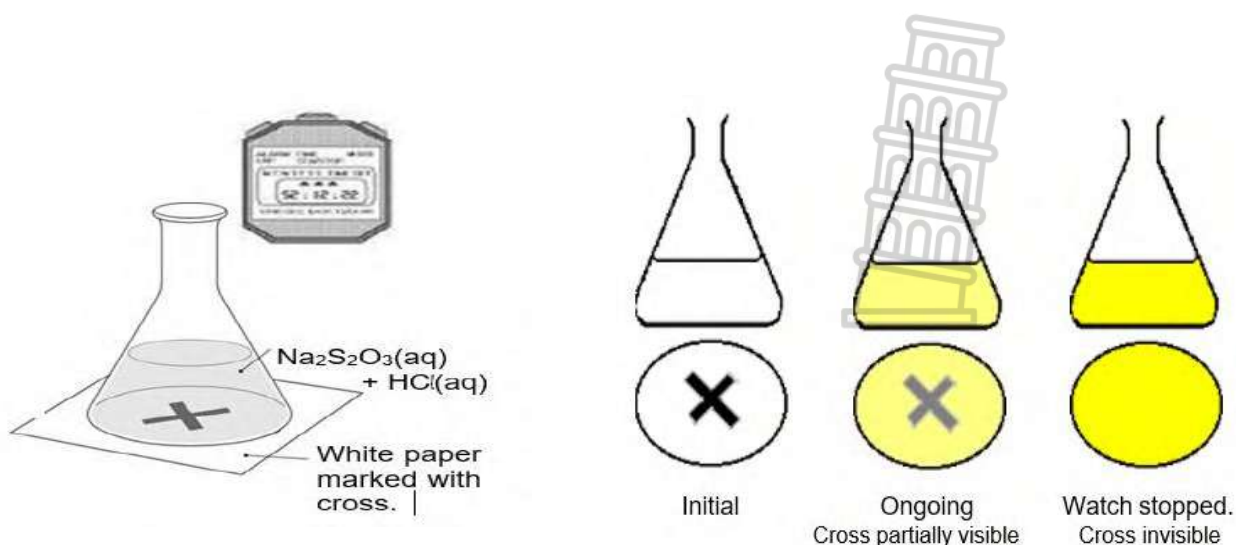


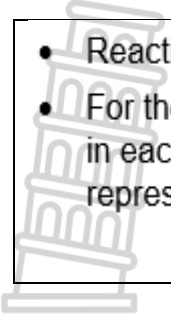
MEASURING LOSS IN MASS OF REACTANTS PER TIME



MEASURING THE TIME FOR THE FORMATION OF AN AMOUNT OF PRECIPITATE

- When sodium thiosulphate (Na₂S₂O₃) reacts with HCl, a yellow precipitate of Sulphur is formed.
- The time how long it takes a certain amount of Sulphur to form, is measured.
- The reaction is observed from the top through a conical flask, viewing a black cross (X) on white paper.
- The X is eventually obscured by the Sulphur precipitate and the time noted.
- The reaction can be repeated at:
 - **Different temperatures** (same concentration of Na₂S₂O₃ and HCl), to measure the effect of temperature on rate
 - **Different concentrations** of Na₂S₂O₃ at the same temperature to measure the effect of



- 
- Reaction rate is calculated as $\frac{1}{\text{time}}$
 - For the cross to become invisible, the same amount of precipitate (Sulphur) is formed in each experiment and therefore the mass of S formed is the same (constant) and is represented by the 1.

THE COLLISION THEORY

The collision theory explains the factors influencing reaction rate.

The collision theory states that for a chemical reaction to occur, the reacting particles must collide with one another. The rate of the reaction depends on the frequency of collisions i.e. the number of collisions per unit time. The theory also tells us that reacting particles often collide without reacting.

For collisions to be successful or effective, reacting particles must:

- **Collide with sufficient kinetic energy**
- **Have the correct orientation**

FACTORS THAT AFFECT THE RATE OF REACTION

1. Temperature

Temperature is a measure of the average kinetic energy of the particles.

When the temperature is increased, the reaction rate also increases. When the temperature decreases, the reaction rate also decreases. This is why:

- An increase in temperature increases the average kinetic energy of the particles.
- More particles with enough kinetic energy
- More effective collisions per unit time.
- The reaction rate increases.

NB: vice versa when the temperature is decreased

2. Concentration

Concentration is the number moles of solute per unit volume of solvent

When the concentration of a substance is increased, the rate of reaction also increases. When the concentration of a substance is decreased, the rate of reaction also decreases. This is why:

- An increase in concentration increases the number of particles per unit volume.
- More particles with sufficient kinetic energy and correct orientation
- More effective collisions of particles per unit time.
- The reaction rate increases.

3. Surface area / State of division (SOLIDS ONLY)

When the solid is divided into smaller pieces the surface area is greater than when it is not divided. This means powders have greater surface area than granules, lumps and ribbons. When the surface area is increased, the rate of reaction increases. This is why:

- An increase in surface area increases in the number of particles exposed for collisions to occur
- More particles with correct orientation
- More effective collisions per unit time.
- The reaction rate increases.

4. Pressure (GASES ONLY)

When pressure of a gas is increased (by decreasing the volume of the container), the rate of reaction increases.

This is why:

- An increase in pressure of a gas increases the number of gas particles per unit volume.
- More effective collisions of particles with enough energy and correct orientation per unit time.
- The reaction rate increases.

5. Nature of reacting substances

Some chemical compounds are more reactive than others because of their differences in (for example) bond strength, reactivity trends, electronegativity and molecular mass (size). The more reactive a substance is, the faster it will react, the higher the reaction rate. Eg. Simple and complex molecules, strong and weak acids, pure and impure substances.

6. Catalyst

A **catalyst** is a substance that increases the rate of chemical reaction without itself undergoing any permanent change

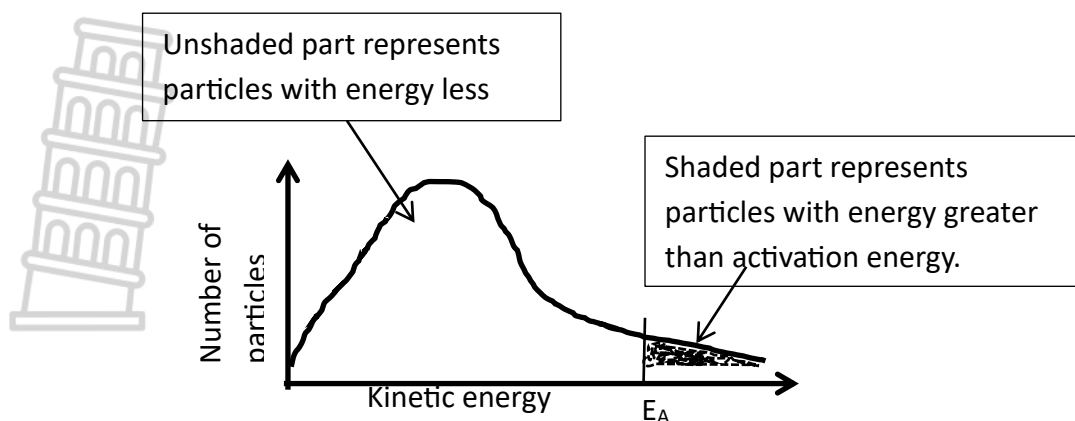
When a catalyst is added, the rate of a chemical reaction increases. This is why:

- The catalyst provides an alternative path of lower activation energy.
- More particles have average kinetic energy greater than activation energy
- More effective collisions of particles per unit time.
- Reaction rate increases.

Adding a catalyst doesn't change the value of heat of reaction.

BOLTZMANN-MAXWELL DISTRIBUTION CURVE OR ENERGY DISTRIBUTION CURVE

As energy is one of the determining factors for a reaction, it is necessary to know which **number of particles (e.g. molecules) have kinetic energies equal to or greater than the activation energy**. Particles in any system represent a variety of kinetic energies. This distribution of kinetic energies can be shown on a curve known as the Maxwell-Boltzmann distribution curve.



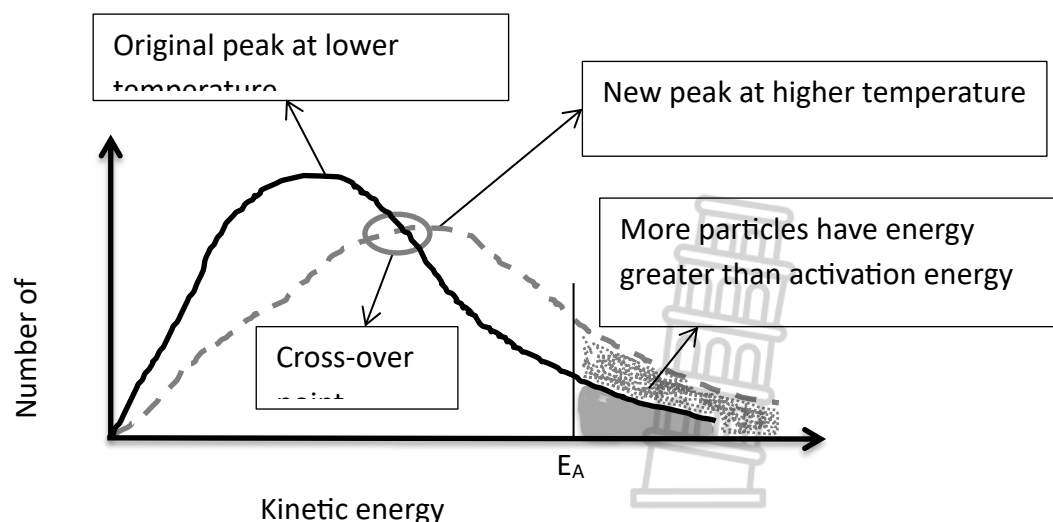
The Maxwell-Boltzmann distribution curve is affected by changes in **temperature**, **Concentration** and **catalyst**.

Maxwell-Boltzmann distribution curve: The effect of temperature

An increase in temperature increases the average kinetic energy of the particles. This means that particles will move to the left of the energy scale or x-axis (higher energy values). The graph below shows the effect of an increase in temperature on the curve.

Take note of all the visible changes:

- The two curves cross-over to show that temperature is the factor that was changed
- The number of particles remains the same
- The peak of the curve at represents the average kinetic energy.

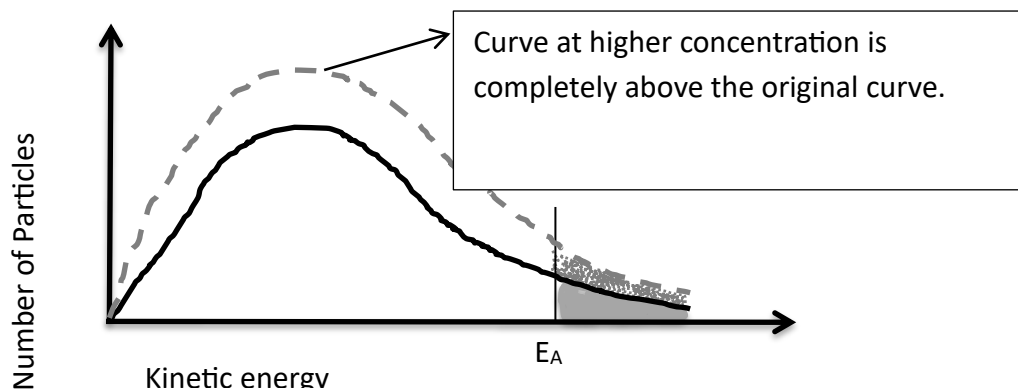


Maxwell-Boltzmann distribution curve : The effect of concentration

An increase in concentration of the particles increases the number of particles per unit volume. This means that there will be more particles per energy value on the energy scale. This means the curve will shift vertically upwards.

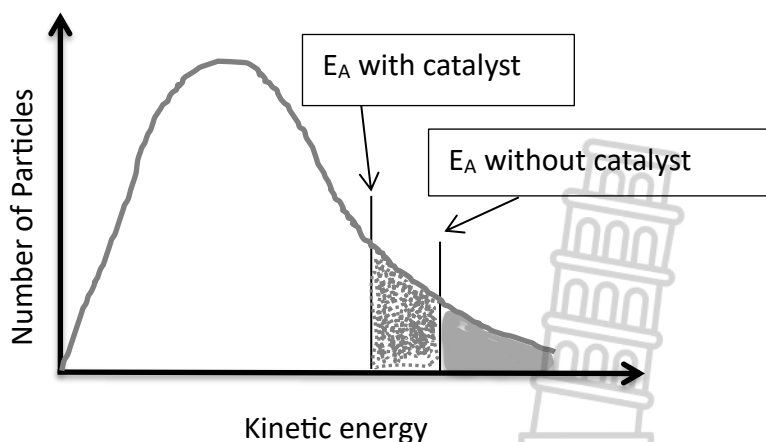
Take note of all the visible changes:

- The two curves do not cross-over like in temperature, but the curve at higher concentration is above the curve at lower concentration at all points
- The new peak does not shift to the right as in temperature.



Maxwell-Boltzmann distribution curve :The effect of the catalyst

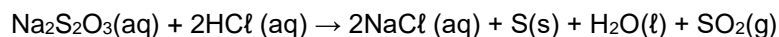
The addition of a catalyst provides an alternative path of low activation energy in the reaction. The addition of a catalyst will not affect the curve, but this will only affect the activation energy mark on the curve. The activation energy mark will shift to the left in the presence of a catalyst and to the right in the absence of a catalyst. In the presence of a catalyst, there will be more particles that have energy greater than the activation energy.



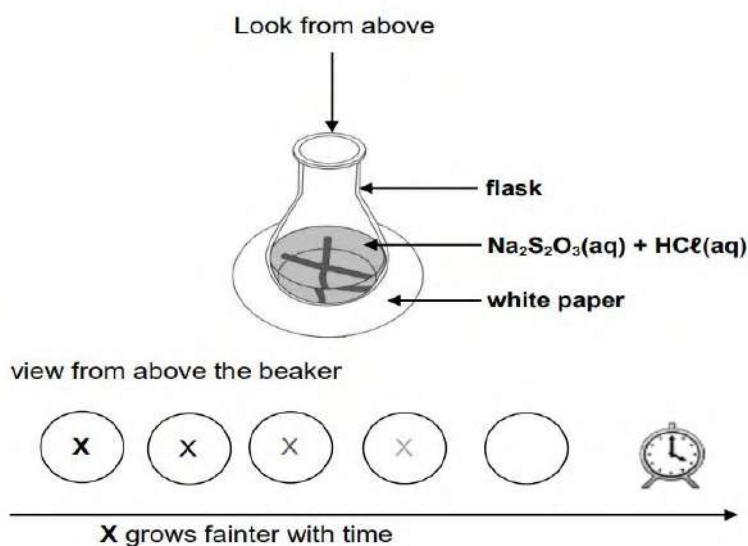
LONG QUESTIONS

Worked example

A group of learners were investigating the factors affecting the reaction rate. In one of their reactions sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) and hydrochloric acid (HCl) are reacted according to the balanced equation given below:



During the reaction one of the products formed causes the solution to turn cloudy. Due to this, the mark X drawn on paper, on which the reaction mixture is placed, were not visible after the reaction is completed. Refer the sketch below.



In the investigation the learners took sodium thiosulphate of different concentration and reacted it with hydrochloric acid of constant concentration. They recorded the time taken for the mark X on the paper to disappear. Their result is tabulated below.

Trial	1	2	3	4
Concentration $\text{Na}_2\text{S}_2\text{O}_3(\text{mol.dm}^{-3})$	0,15	0,09	0,06	0,03
Time taken for the X to disappear in (s)	43	66	100	240

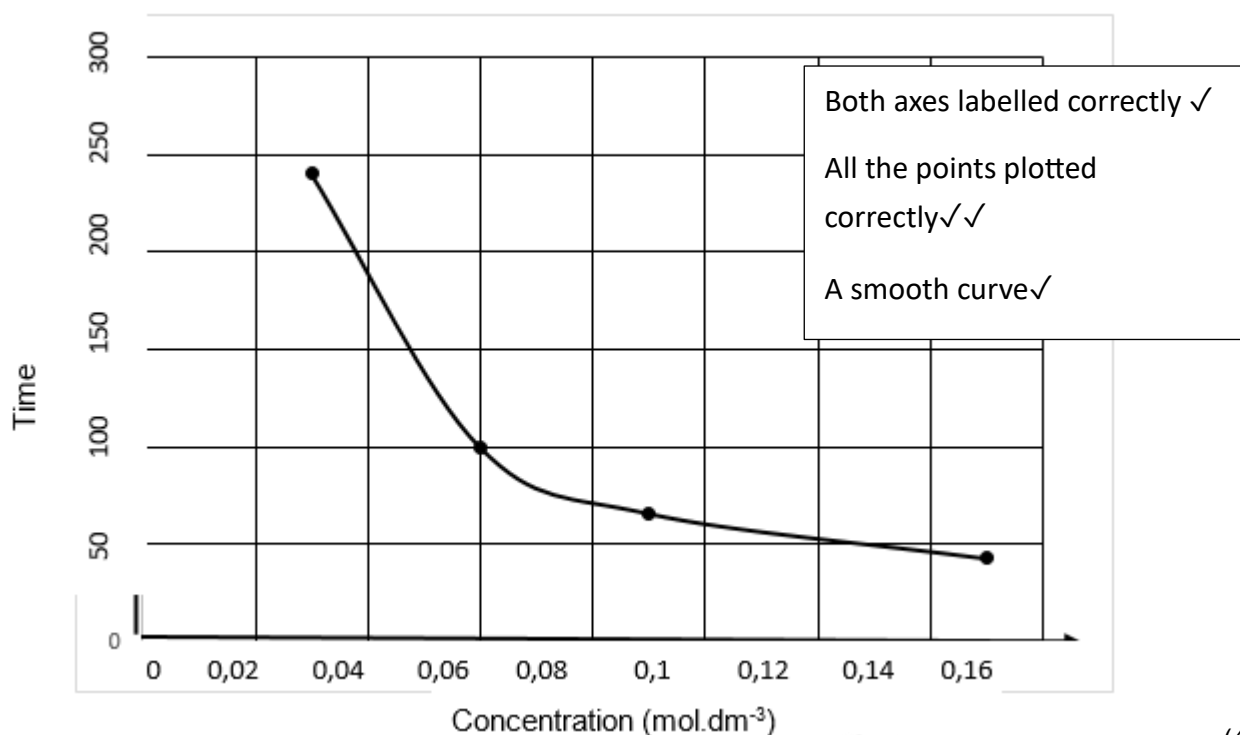
- 1.1 Define the term reaction rate. (2)
- 1.2 For the experiment described above, name the:
 - 1.2.1 Independent variable (1)
 - 1.2.2 ONE control variable (1)
- 1.3 Write down the NAME or FORMULA of the substance responsible for the cloudiness. (1)
- 1.4 Consider the table of results and write down which trial (1, 2, 3 or 4) occurred at the highest reaction rate? (1)

- 1.5 Draw a graph of concentration of sodium thiosulphate against time for the mark X to disappear. (4)
- 1.6 Use the graph to make a conclusion for the above investigation. (2)
- 1.7 Name TWO other ways in which the rate of this reaction can be increased. (2)

SOLUTIONS

- 1.1 The rate of a reaction is the change in concentration of reactant/product per unit time. ✓✓ (2)
- 1.2.1 Concentration of sodium thiosulphate✓ (1)
- 1.2.2 Concentration of hydrochloric acid or Temperature✓ (1)
- 1.3 S✓ (1)
- 1.4 Trial 1✓ (1)

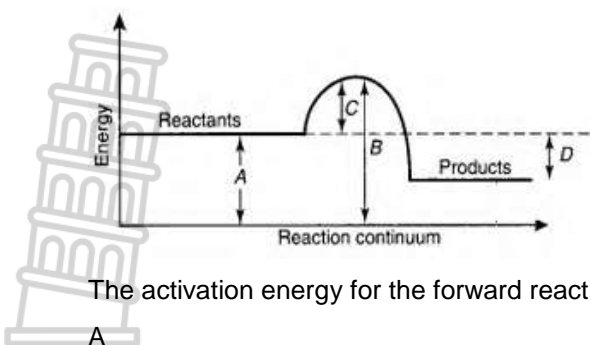
1.5



- 1.6 The rate of reaction increases as the concentration (of Na₂S₂O₃) increases ✓✓ (2)
- 1.7 Increase the temperature of the reaction mixture. ✓ Use a catalyst✓ (2)

QUESTION 1 QUESTION1

- 1.1 Consider the following potential energy diagram for a chemical reaction. Which arrow indicates the activation energy of the forward reaction?



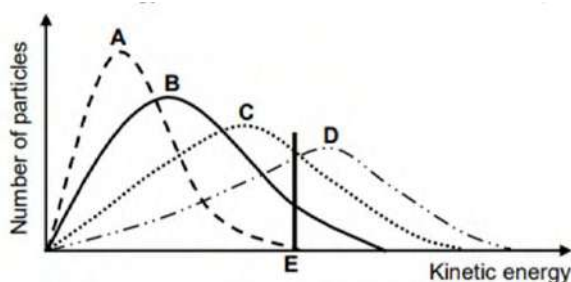
The activation energy for the forward reaction is ...

- A A
- B B
- C C
- D D

1.2 The temperature of a substance is a measure of the ... of the particles.

- A average potential energy
- B average kinetic energy
- C total kinetic energy
- D total potential energy

1.3 The Maxwell-Boltzmann energy distribution curves below show the number of particles as a function of their kinetic energy for a reaction at four different temperatures. The minimum kinetic energy needed for effective collisions to take place is represented by E.



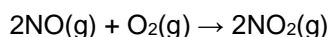
Which ONE of these curves represents the reaction with the highest rate?

- A
- B
- C
- D

1.4 The rate of a chemical reaction can be expressed in ...

- A Grams per mole.
- B Energy consumed per mole.
- C Volume of gas per unit time.
- D Moles of product formed per litre of solution.

1.5 Consider the balanced equation for a chemical reaction below.

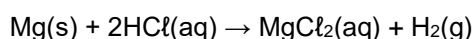


The activation energy of the forward and reverse reactions are $156 \text{ kJ}\cdot\text{mol}^{-1}$ and $175 \text{ kJ}\cdot\text{mol}^{-1}$ respectively. The heat of reaction, in $\text{kJ}\cdot\text{mol}^{-1}$, for this reaction is...

- A -19.
- B +19.
- C +331.
- D -331.

(2)

- 1.6 2 g piece of magnesium reacts with EXCESS hydrochloric acid according to the following balanced equation:

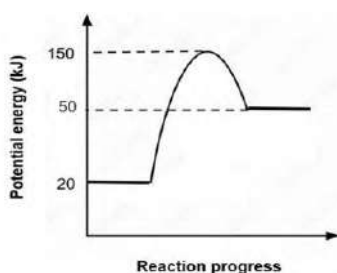


Which ONE of the following changes will INCREASE the YIELD of $\text{H}_2(\text{g})$?

- A Crush the piece of magnesium.
- B Use a 3 g piece of magnesium.
- C Use a greater volume of the acid.
- D Use a higher concentration of the acid.

(2)

- 1.7 Consider the potential energy graph for the reaction shown below:

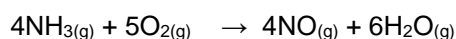


Which ONE of the following statements about the REVERSE reaction is correct?

- A The activation energy for the reaction is **+100 kJ**.
- B The activation energy for the reaction is **+130 kJ**
- C The enthalpy change (ΔH) for the reaction is **+30 kJ**.
- D The enthalpy change (ΔH) for the reaction is **-100 kJ**.

(2)

- 1.8 Consider the balanced equation below:



0,4 mol of NH_3 is mixed with 0,8 mol of O_2 in a closed container. The reaction goes to completion.

What is the total amount of gas in the container at the end of the reaction ?

- A 1,3 mol
- B 10,0 mol
- C 1,0 mol
- D 0,4 mol

(2)

QUESTION 2

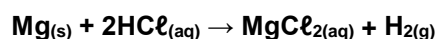
Learners investigate the rate at which 25 cm³ hydrochloric acid reacts with a 2 cm magnesium ribbon to produce hydrogen gas at STP. The learners are provided with three solutions of EXCESS hydrochloric acid with the following concentrations:

Solution A: 0,5 mol·dm⁻³

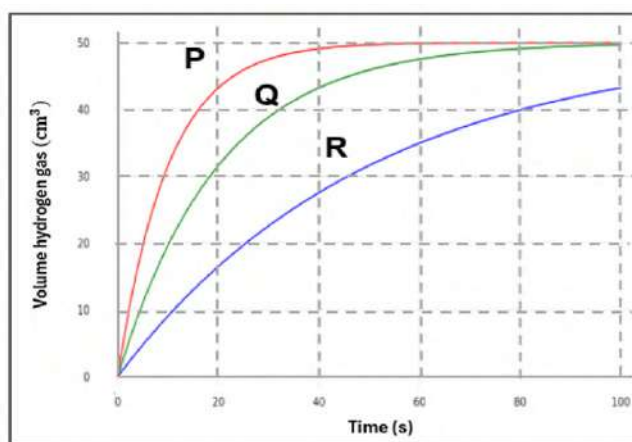
Solution B: 1,0 mol·dm⁻³

Solution C: 2,0 mol·dm⁻³

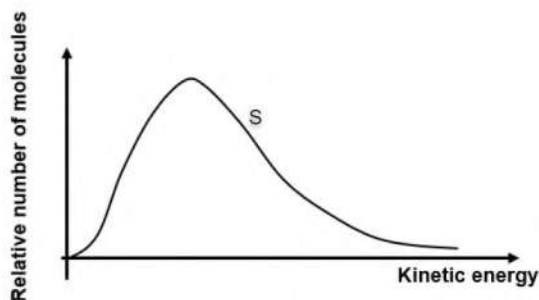
The reaction is represented by the following balanced equation:



The volume of H₂ gas produced, using the three solutions, are represented in the following graphs.



- 2.1 Define the term *reaction rate*. (2)
 - 2.2 For this investigation, write down: (1)
 - 2.2.1 The independent variable. (1)
 - 2.2.2 The controlled variable. (1)
 - 2.3 Which graph represents the reaction for solution **C**?
 - 2.4 For this investigation, write down the conclusion that can be drawn from the results. (2)
 - 2.5 Use curve **Q** to calculate the mass of the magnesium ribbon which reacted. (4)
 - 2.6 The learners repeat their investigation by using POWDERED magnesium, with the same mass as the 2 cm magnesium ribbon, before adding it to the 1 mol·dm⁻³ HCl solution.
 - 2.6.1 How will the gradient of graph **Q** change when the magnesium powder is added to the HCl solution? Choose from STEEPER, LESS STEEP or REMAINS THE SAME. (1)
 - 2.6.2 Use the *Collision Theory* to explain the answer to QUESTION 5.6.1. (3)
- Learners use solution **B**, to draw the Maxwell-Boltzmann graph at a temperature of 25 °C and label it curve **S**.



Keeping the concentration and volume of the solution constant, they increase the temperature to 45 °C.

Redraw this curve in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained at 45°C. Clearly label this as curve T.

Question 3

17

3.1 Sodium nitrate undergoes thermal decomposition to form sodium oxide, nitrogen dioxide, and oxygen.

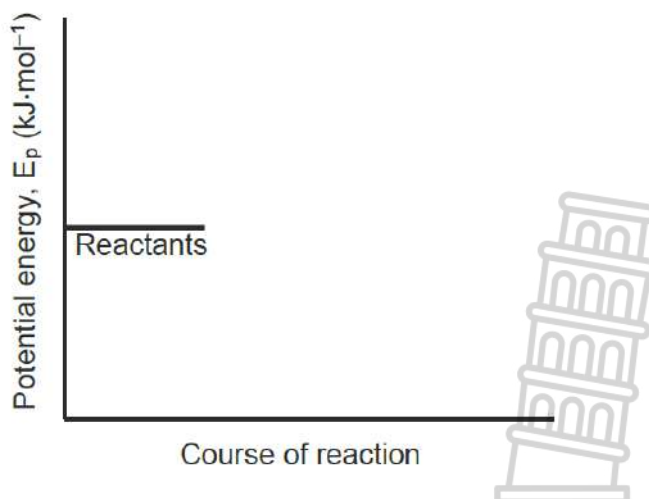
3.1.1 Write a balanced equation for the reaction. (3)

3.1.2 During the reaction, more energy is absorbed than released. Circle the correct option in the table. (1)

3.1.3 The reaction is EXOTHERMIC / ENDOTHERMIC. Define the *activated complex*. (2)

3.1.4 Define *heat of reaction*. (2)

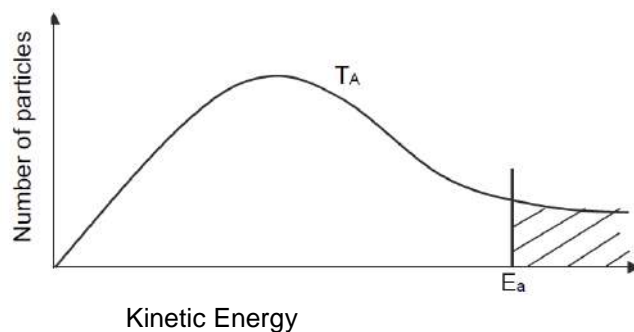
3.1.5 Complete the energy profile graph for this reaction.



3.1.6 On the graph, label E_a , the activation energy, and ΔH , the heat of reaction. (2)

3.1.7 On the y-axis, mark the potential energy of the activated complex with a **P**. (1)

3.2 Consider the curve shown below for a reaction mixture at temperature T_A :

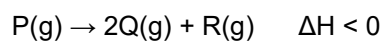


- 3.2.1 Supply the name for this type of curve. (1)
- 3.2.2 On the above diagram, redraw the curve for the mixture at a **lower** temperature, T_B . (2)
- 3.2.3 On the above diagram, show and label the effect of adding a catalyst. (2)
- 3.2.4 A Grade 12 learner says that adding a catalyst will result in more collisions between reactant particles. Circle the answer in the table and explain. (3)
The learner is CORRECT / INCORRECT because

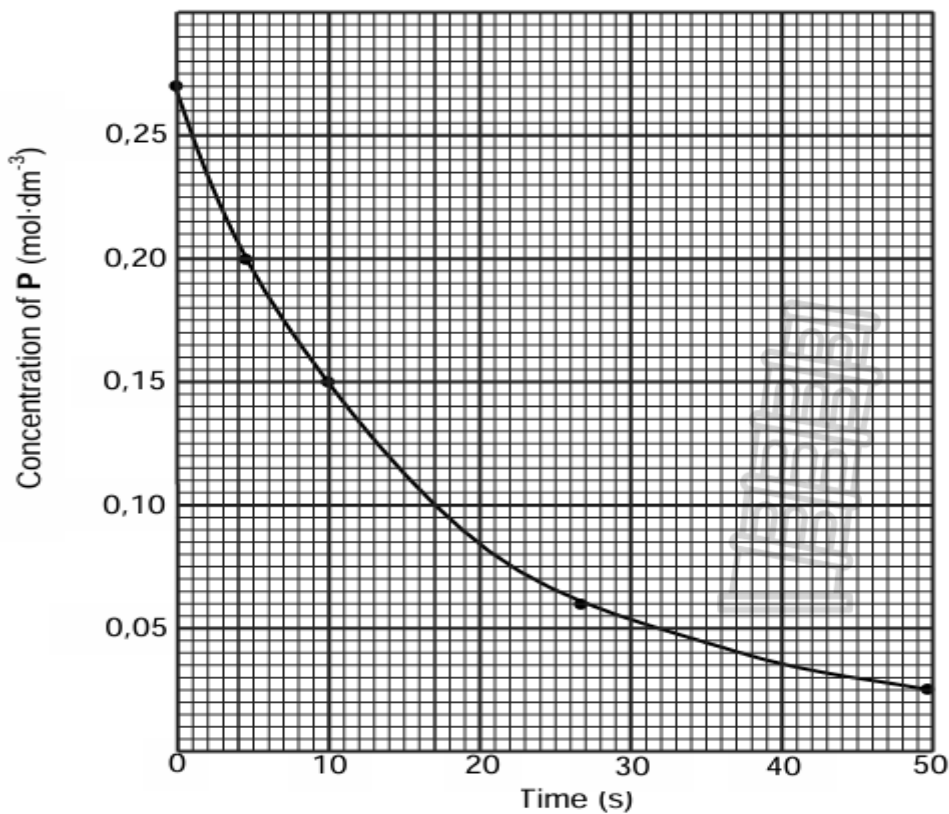
[19]

QUESTION 4

The graph below shows the decomposition of gas P according to the following equation:



Graph of concentration of P versus time

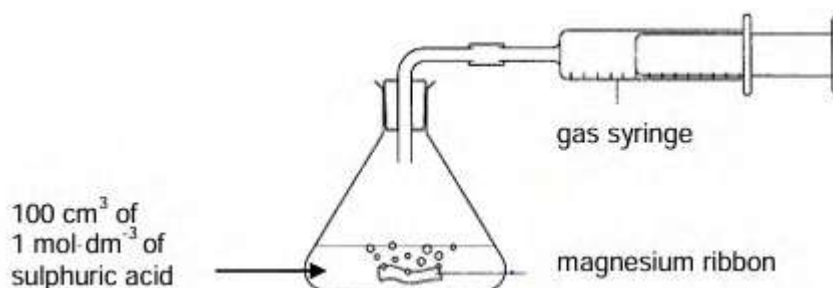


- 4.1 Define the term *rate of reaction* in words by referring to the graph. (2)
- 4.2 At which time, 10 s or 30 s, does the decomposition take place at a higher rate? Refer to the graph to give a reason for the answer. (2)
- 4.3 Write down the initial concentration of P(g). (1)
- 4.4 The decomposition is carried out in a 2 dm³ container. Calculate the average rate (in mol·s⁻¹) at which P(g) is decomposed in the first 10 s. (6)
- 4.5 An increase in temperature will increase the rate of decomposition of P(g). Explain this statement in terms of the collision theory. (2)

[13]

QUESTION 5

The following apparatus was used by a group of learners in an investigation to find out how surface area affects the rate of reaction between solid magnesium metal and 100 cm³ dilute sulphuric acid with a concentration of 1 mol·dm⁻³. During the reaction, the gas that forms is collected in the gas syringe which measures the volume of gas produced. The equation for the reaction is: **Mg (s) + H₂SO₄(aq) → MgSO₄(aq) + H₂ (g)**

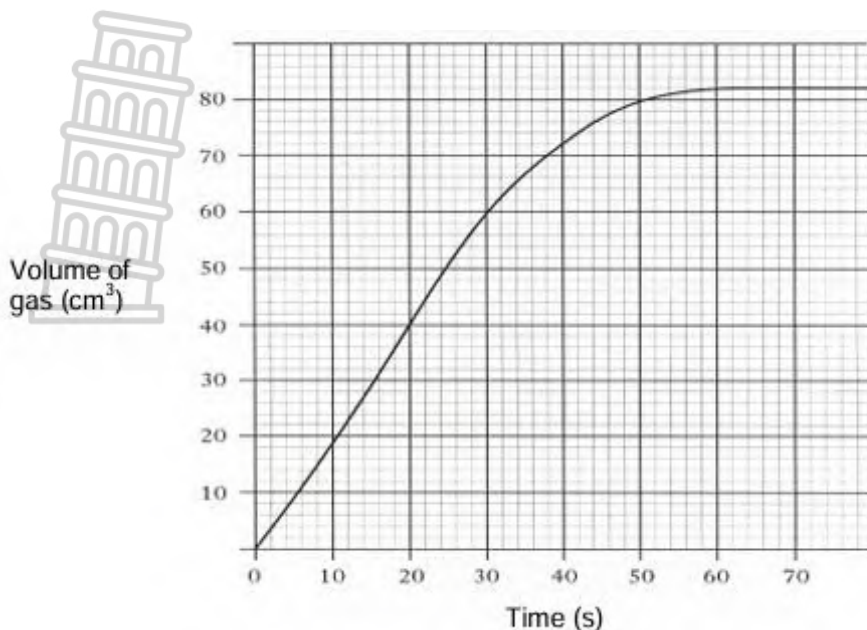


In **EXPERIMENT I**, 20 g of magnesium, in the form of 5 small pieces, was used.

In **EXPERIMENT II**, 20 g of magnesium, in the form of one big piece was used.

The learners performed the experiments and plotted a graph of their results for experiment one, which is represented below.





- 5.1 Besides the mass and the volume of the reactants, give ONE other variable that must be kept constant in this investigation (1)
- 5.2 Name the dependent variable for **EXPERIMENT I**. (1)
- 5.3 Use the graph to calculate the average rate of the reaction (in $\text{cm}^3 \cdot \text{s}^{-1}$) for the first 30 seconds. (3)
- 5.4 Will the rate of the reaction at 50s be GREATER THAN, LESS THAN or EQUAL TO that rate calculated in QUESTION 2.3? Give a reason for your answer (1)
- 5.5 Predict how the gradient of **EXPERIMENT II** results would compare to **EXPERIMENT I** plotted above. Write only INCREASE, DECREASE or NO CHANGE. (1)
- 5.6 Use the collision theory to explain how the increase in surface area of the magnesium metal affects the rate of the reaction. (3)
- 5.7 Calculate the mass of magnesium metal that remains after the reaction has stopped. (5)
- 5.8 Catalytic converters are substances that are coated onto surfaces of car exhausts to act as positive catalysts. (2)
- Define a positive catalyst.

[18]

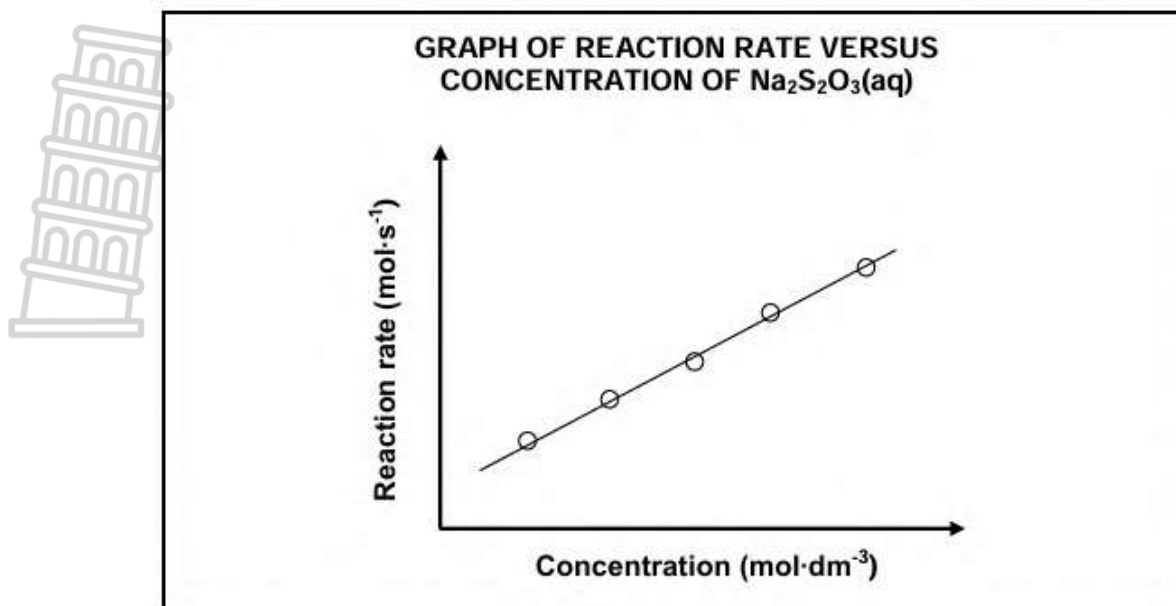
QUESTION 6

Learners use the reaction of a sodium thiosulphate solution with dilute hydrochloric acid to investigate several factors that affect the rate of a chemical reaction.

The balanced equation for the reaction is:



- 6.1 Define *reaction rate*. (2)
- Three investigations (I, II and III) are carried out.
- 6.2 **INVESTIGATION I**
- The results obtained in INVESTIGATION I are shown in the graph below.



For this investigation, write down the:

6.2.1 Dependent variable

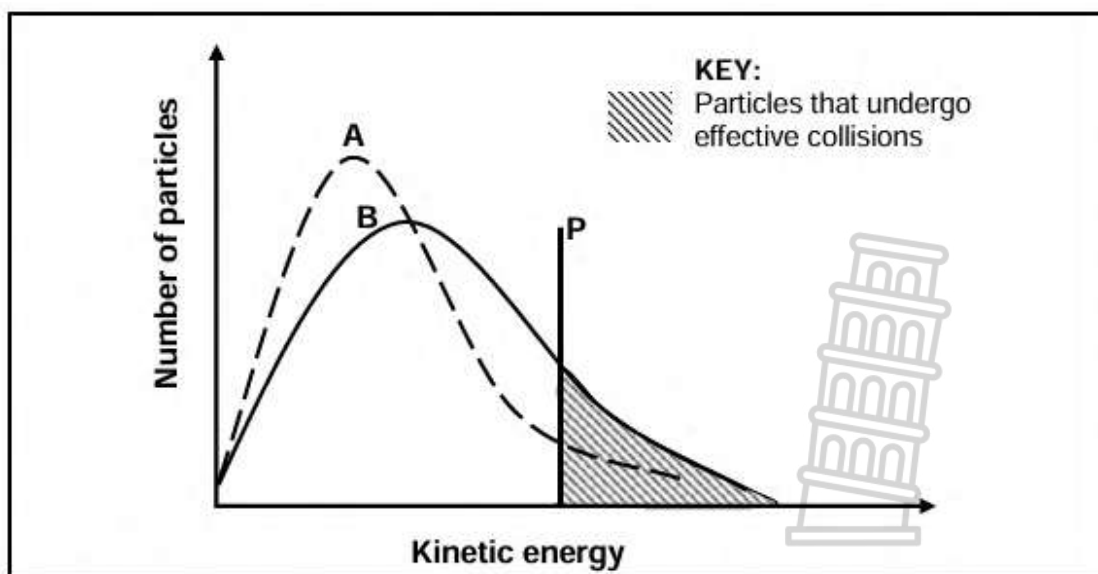
(1)

6.2.2 Conclusion that can be drawn from the results

(2)

6.3 **INVESTIGATION II**

The Maxwell-Boltzmann distribution curves, A and B, below represent the number of particles against kinetic energy for the reaction at two different temperatures.



6.3.1 What does line P represent?

(1)

6.3.2 Which curve (A or B) was obtained at the higher temperature?

(1)

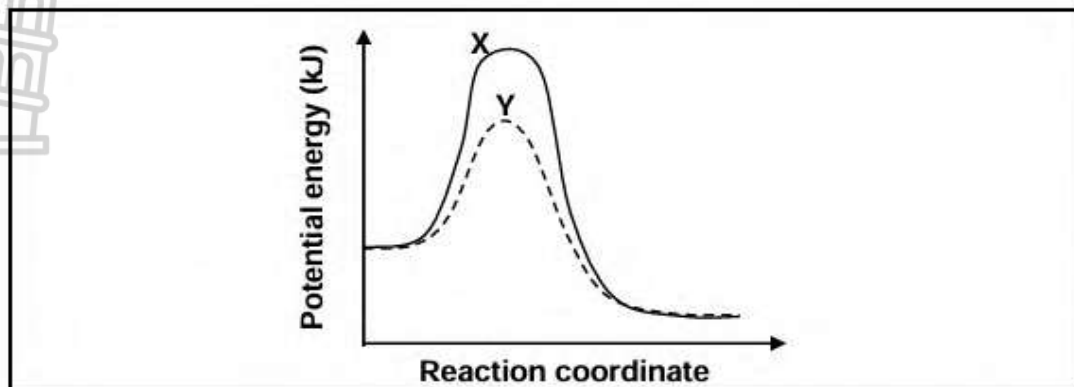
6.3.3 Explain, in terms of the collision theory, how an increase in temperature influences the rate of a reaction.

(4)

6.4 INVESTIGATION III

(1)

The potential energy diagrams, X and Y, below represent the reaction under two different conditions.



Give a reason why curve Y differs from curve X.

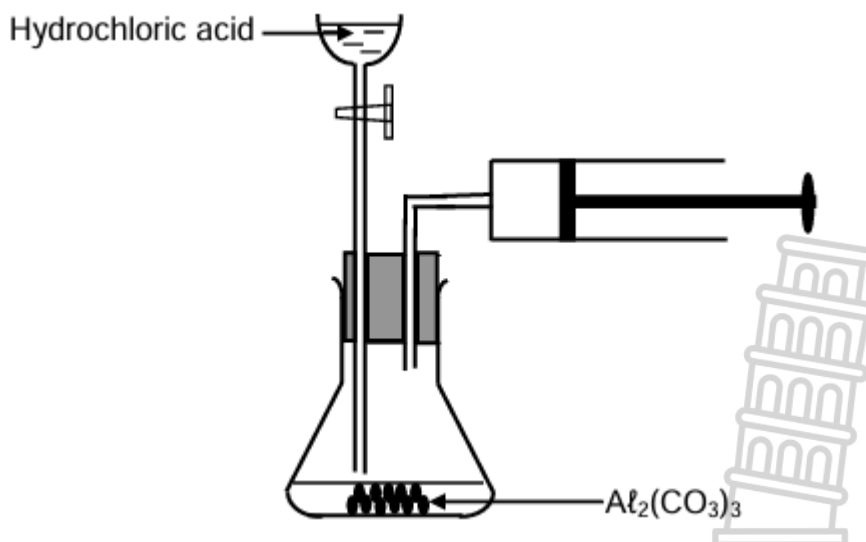
[12]

QUESTION 7

Two experiments, I and II, are conducted to investigate one of the factors that affects the rate of the reaction of aluminium carbonate, $\text{Al}_2(\text{CO}_3)_3$, with EXCESS hydrochloric acid, HCl . The balanced equation for the reaction is:



The apparatus used is shown below.



The reaction conditions used for each experiment are as follows:

Experiment I: 100 cm³ of 1,5 mol·dm⁻³ $\text{HCl}(\text{aq})$ reacts with 0,016 mol $\text{Al}_2(\text{CO}_3)_3$ granules at 25 °C

Experiment II: 50 cm³ of 2 mol·dm⁻³ $\text{HCl}(\text{aq})$ reacts with 0,016 mol $\text{Al}_2(\text{CO}_3)_3$ granules at 25 °C

7.1 Define the term *rate of a reaction*.

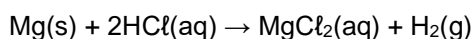
(2)

- 7.2 Using the experimental setup above, state the measurements that must be made to determine the rate of this reaction (2)
- 7.3 Use the collision theory to explain how the average reaction rate in Experiment I differs from the average reaction rate in Experiment II. (3)
- 7.4 The average rate of the reaction in **Experiment II** during the first 2,5 minutes is $4,4 \times 10^{-3} \text{ mol} \cdot \text{min}^{-1}$. (3)
Calculate the number of moles of $\text{Al}_2(\text{CO}_3)_3$ that remains in the flask after 2,5 minutes.
- 7.5 Calculate the maximum volume of $\text{CO}_2(\text{g})$ that can be prepared at 25°C in **Experiment I** Take molar gas volume at 25°C as $24\,000 \text{ cm}^3 \cdot \text{mol}^{-1}$. (3)

[13]

QUESTION 8

Two experiments are carried out to investigate one of the factors that affects the reaction rate between magnesium and dilute hydrochloric acid. The reaction that takes place is represented by the following balanced equation:



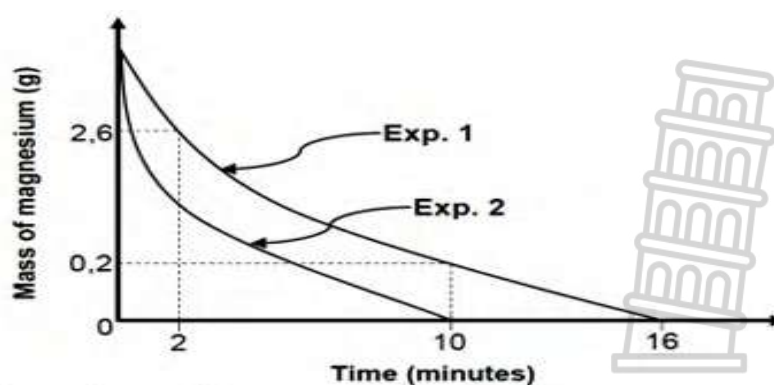
In experiment 1 a certain mass of magnesium ribbon reacts with excess dilute hydrochloric acid.

In experiment 2 magnesium powder of the same mass as the magnesium ribbon, reacts with the same volume of excess dilute hydrochloric acid.

The concentration of the acid is the same in both experiments.

- 8.1 Define *reaction rate*. (2)
- 8.2 For this investigation, write down the:
- 8.2.1 Independent variable (1)
- 8.2.2 Controlled variable (1)

The change in mass of magnesium is calculated and recorded in 2-minute intervals for both experiments. The results obtained are shown in the graph alongside (NOT drawn to scale).



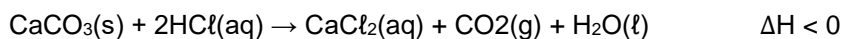
- 8.3 Use the information on the graph to:
- 8.3.1 Calculate the volume of hydrogen gas produced in experiment 1 from $t = 2$ minutes to $t = 10$ minutes (Take the molar gas volume as $25 \text{ dm}^3 \cdot \text{mol}^{-1}$.) (5)

- 8.3.2 Calculate the initial mass of magnesium used if the average rate of formation of hydrogen gas in experiment 2 was $2,08 \times 10^{-4} \text{ mol}\cdot\text{s}^{-1}$ (5)
- 8.3.4 Use the collision theory to explain why the curve of experiment 2 is steeper than that of experiment 1. (3)

[17]

Question 9

The calcium carbonate (CaCO_3) in antacid tablets reacts with dilute hydrochloric acid (HCl) according to the following balanced equation:



- 9.1 Is the above reaction EXOTHERMIC or ENDOTHERMIC? Give a reason for the answer. (2)

An antacid tablet of mass 2 g is placed in $\text{HCl}(\text{aq})$. After 30 s the mass of the tablet was found to be 0,25 g.

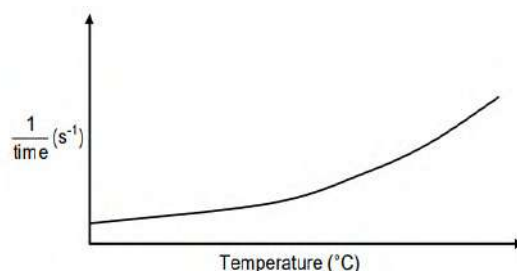
- 9.2 Calculate the average rate (in $\text{g}\cdot\text{s}^{-1}$) of the above reaction. (3)

The antacid tablet contains 40% calcium carbonate. Another antacid tablet of mass 2 g is allowed to react completely with $\text{HCl}(\text{aq})$.

- 9.3 Calculate the volume of carbon dioxide, $\text{CO}_2(\text{g})$ that will be collected at STP. (5)

Assume that all the $\text{CO}_2(\text{g})$ produced is from the calcium carbonate.

The reaction rate of similar antacid tablets, with excess $\text{HCl}(\text{aq})$ of concentration $0,1 \text{ mol}\cdot\text{dm}^{-3}$ at DIFFERENT TEMPERATURES is measured. The graph below was obtained.



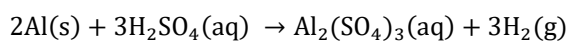
Use the information in the graph to answer the following questions.

- 9.4 Write down ONE controlled variable for this investigation. (1)
- 9.5 Write down a conclusion that can be made from the graph. (2)
- 9.6 Use the collision theory to fully explain the answer to **QUESTION 9.5** (3)
- 9.7 Redraw the graph above in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained if $\text{HCl}(\text{aq})$ of concentration $0,2 \text{ mol}\cdot\text{dm}^{-3}$ is now used. Label this curve **Y**. (2)

[18]

Question 10

The reaction between aluminium and EXCESS sulphuric acid is used to investigate factors affecting rates of reactions.

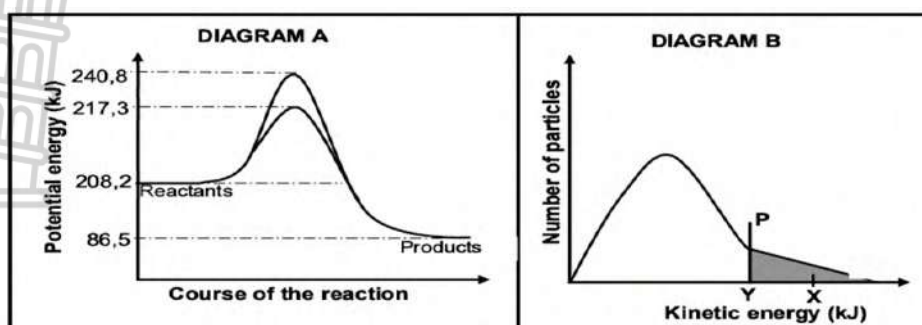


- 10.1 **Investigation I**

The effect of a catalyst on the rate of reaction is determined.

Aluminium powder of mass of 5g reacts with excess $0,1 \text{ mol. dm}^{-3} \text{ H}_2\text{SO}_4$ at 60°C .

Consider the following energy diagrams (not drawn to scale) for this investigation. **X** and **Y** on diagram **B** represent the activation energies.



10.1. Is the reaction between $\text{Al}(\text{s})$ and dilute $\text{H}_2\text{SO}_4(\text{aq})$ ENDOTHERMIC or EXOTHERMIC? (2)

1 Give a reason for the answer by referring to the above diagrams.

10.1. What does the shaded area to the right of line P represent? (1)

2

10.1. Determine the numerical value represented by the letter **X** on diagram **B**. (2)

3

10.2 INVESTIGATION II

The investigation is now repeated at 30°C using the same reactants (5g Al powder and excess $0,1 \text{ mol. dm}^{-3} \text{ H}_2\text{SO}_4$) and catalyst.

How will this affect EACH of the following when compared to INVESTIGATION I? Choose from INCREASES, DECREASES or REMAINS THE SAME.

10.2. The size of the shaded area (diagram B). (1)

1

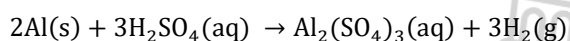
10.2. The value of Y. (1)

2

10.2. The TOTAL volume of hydrogen gas produced. (1)

3

10.3 In this investigation, 5 g of the same sample of IMPURE aluminium powder reacts with an EXCESS diluted H_2SO_4 at 60°C in each of three runs. The table below summarizes the conditions and the results obtained. (Assume that the impurities do not react.)



run	Concentration H_2SO_4 (aq) (mol.dm ⁻³)	AVERAGE RATE OF VOLUME H_2 gas PRODUCED (cm ³ .s ⁻¹)
1	0,1	15
2	0,2	19
3	0,4	40

- 10.3 10.3. Write down the independent variable for this investigation. (1)
- 10.3. Use the collision theory to explain how the average rate of the reaction is affected in this investigation. (3)
- 10.3. The time for the reaction to reach completion in RUN 3 is 2,6 minutes. (6)
- 10.3. Calculate the percentage purity of the aluminium. Take the molar gas volume at 60 °c to be 27 000 cm³·mol⁻¹. (6)
- [18]

Question 11

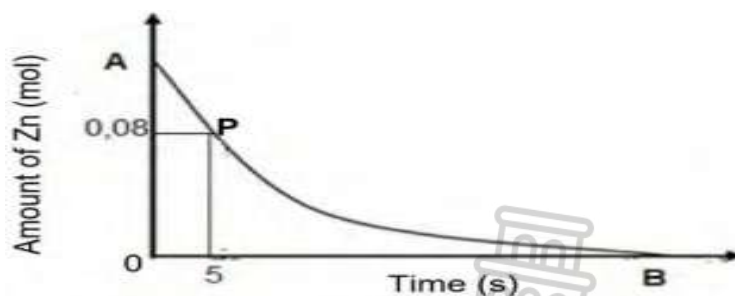
A group of learners use the reaction between zinc and sulphuric acid to investigate one of the factors that affects reaction rate. The equation below represents the reaction that takes place.

$$\text{Zn(s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2(\text{g})$$

They add 6,5 g of zinc granules to excess DILUTE sulphuric acid and measure the **mass of zinc used per unit time**. The learners then repeat the experiment using excess CONCENTRATED sulphuric acid.

- 11.1 Define the term reaction rate. (2)
- 11.2 Which factor influencing reaction rate is investigated? (1)
- 11.3 Write down the hypothesis for this investigation. (2)
- 11.4 The learners must use the same mass of ZINC GRANULES in both experiments. Which variable is controlled by doing this? (1)

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

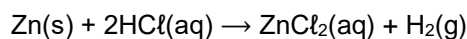


- 11.5 Calculate the value of **A** on the y-axis. (3)
- 11.6 Calculate the value of **B** on the x-axis if the average rate of reaction was 0,15 g·s⁻¹ for the part of the graph represented by **PB**, where **P** is at t = 5 s. (5)
- 11.7 Copy the above graph into your ANSWER BOOK. ON THE SAME SET OF AXIS, use a dotted line to draw the curve that will be obtained when concentrated sulphuric acid is used. (3)

[17]

Question 12

The reaction of zinc and EXCESS dilute hydrochloric acid is used to investigate factors that affect reaction rate. The balanced equation for the reaction is:

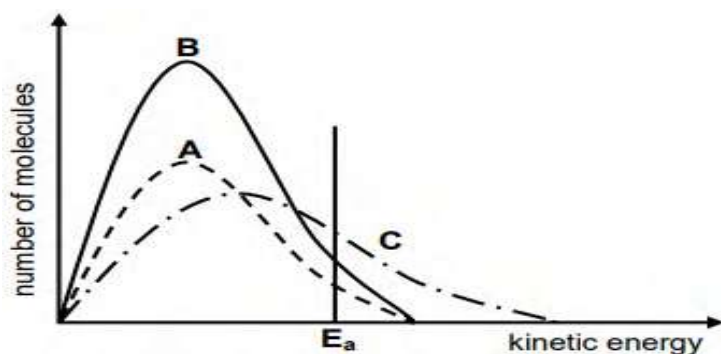


The reaction conditions used and the results obtained for each experiment are summarised in the table below.

The same mass of zinc is used in all the experiments. The zinc is completely covered in all reactions. The reaction time is the time it takes the reaction to be completed.

EXPERIMENT	CONCENTRATION OF HCl (mol·dm ⁻³)	VOLUME OF HCl (cm ³)	STATE OF DIVISION OF Zn	TEMPERATURE OF HCl (°C)	REACTION TIME (min.)
1	2,0	200	powder	25	7
2	1,5	200	granules	25	14
3	5,0	200	powder	25	5
4	1,5	400	granules	25	x
5	2,0	200	powder	35	4

- 12.1 Experiment 1 and experiment 5 are compared. Write down the independent variable. (1)
- 12.2 Define reaction rate. (2)
- 12.3 Write down the value of x in experiment 4. (2)
- 12.4 The Maxwell-Boltzmann energy distribution curves for particles in each of experiments 1, 3 and 5 are shown below. (2)



Identify the graph (A or B or C) that represents the following:

- 12.4. Experiment 3 (2)
- 1 Give a reason for the answer.
- 12.4. Experiment 5 (2)
- 2 Give a reason for the answer.
- 12.5 Experiment 6 is now conducted using a catalyst and the SAME reaction conditions as for Experiment 1. (1)
- 12.5. What is the function of the catalyst in this experiment? (1)
- 1
- 12.5. How will the heat of reaction in experiment 6 compare to that in experiment 1? Choose from: GREATER THAN, EQUAL TO or LESS THAN. (1)
- 2

- 12.6 Calculate the average rate of the reaction (in $\text{mol}\cdot\text{min}^{-1}$) with respect to zinc for experiment 2 if 1,5 g of zinc is used. (4)

[15]

Question 13

Learners use the reaction between IMPURE POWDERED calcium carbonate and excess hydrochloric acid to investigate reaction rate. The balanced equation for the reaction is:



They perform four experiments under different conditions of concentration, mass and temperature as shown in the table below. They use identical apparatus in the four experiments and measure the volume of gas released in each experiment.

	EXPERIMENT			
	1	2	3	4
Concentration of acid ($\text{mol}\cdot\text{dm}^{-3}$)	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid ($^{\circ}\text{C}$)	30	30	40	40

- 13.1. Independent variable (1)

1

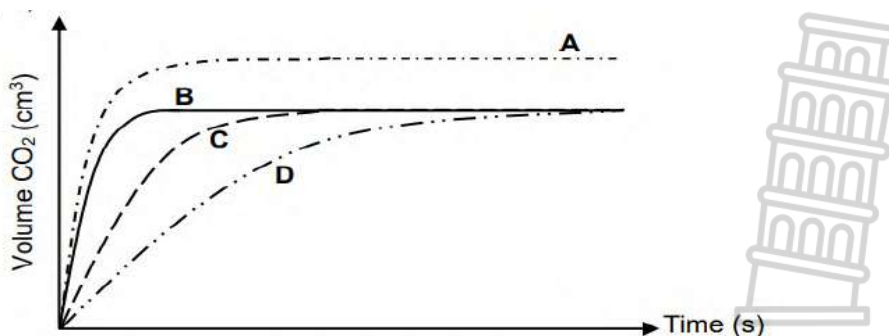
- 13.1. Dependent variable (1)

2

- Use the collision theory to explain why the reaction rate in experiment 4 will be higher than that in (3)

- 13.2 experiment 3.

The learners obtain graphs A, B, C and D below from their results.



- 13.3 Which ONE of the graphs (A, B, C or D) represents experiment 1? Fully explain the answer by comparing experiment 1 with experiments 2, 3 and 4. (6)

- 13.4 When the reaction in experiment 4 reaches completion, the volume of gas formed is $4,5 \text{ dm}^3$ (5)

Assume that the molar gas volume at 40°C is equal to $25,7 \text{ dm}^3$.

Calculate the mass of the impurities present in the calcium carbonate.

Chemical Equilibrium

CHEMICAL EQUILIBRIUM

Open System

An open system is the one in which mass or energy can be transferred into or out of the system during a reaction. An open system continuously interacts with its environment.

Figure 1 below shows a beaker containing some water is left standing for a few days, the level of the water in the beaker drops until there is no more water left. The water has escaped into the atmosphere. This is an example of an open system because the mass of the system decreases.



Figure 1: open system

Closed System

For equilibrium to be reached, the reaction must be reversible, and the change has to take place in a closed system. A *closed system* is one in which the system is isolated from its surrounding environment in such a way that there is no mass transferred into or out of the system.

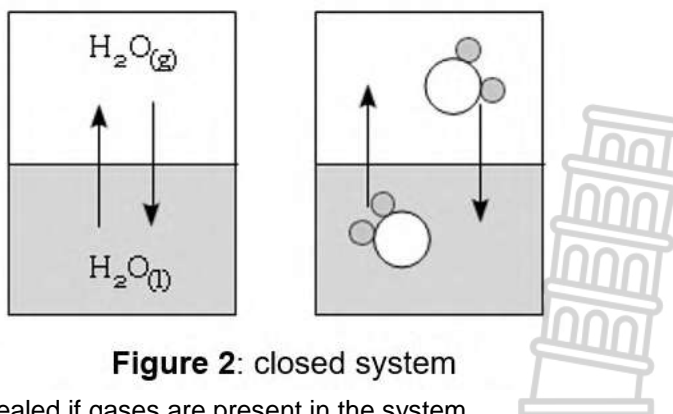
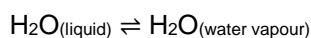


Figure 2: closed system

This means that the container must be sealed if gases are present in the system.

In Figure 2, evaporation takes place. Also, droplets of water form on the inside of the bell jar. Condensation occurs. Eventually the level of the water in the beaker becomes constant. At this stage equilibrium is reached. The rate of the evaporation is equal to the rate of condensation. This is an example of dynamic phase equilibrium.



Remember the following:

- “ \rightleftharpoons ” means *reversible reaction*.

- “Equilibrium” means that the rate of forward reaction is EQUAL to the rate of the reverse reaction.

Consider a situation where some $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ are sealed in a flask. Initially, there will be a fast forward reaction. However, as the $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ are used up, their concentrations decrease. Therefore, the rate of the forward reaction decreases.

Initially there is no product. Therefore, the rate of the reverse reaction is zero. As more and more product is formed, the concentration of the product increases. Therefore, the rate of the reverse reaction increases.

There will be a time when the rate of the forward reaction is equal to the rate of the reverse reaction. When this happens, the system has reached dynamic chemical equilibrium.

At a macroscopic level, the reactions appear to have stopped. The macroscopic physical properties such as temperature, pressure, concentration and colour become constant.

However, at a microscopic level the particles are still in continuous random motion and both the forward and the reverse reactions occur at precisely the same rate.

- *Macroscopic* level: Visible to the naked eye,
- *Microscopic* level: So small as to be visible only with a microscope

Factors Affecting Equilibrium

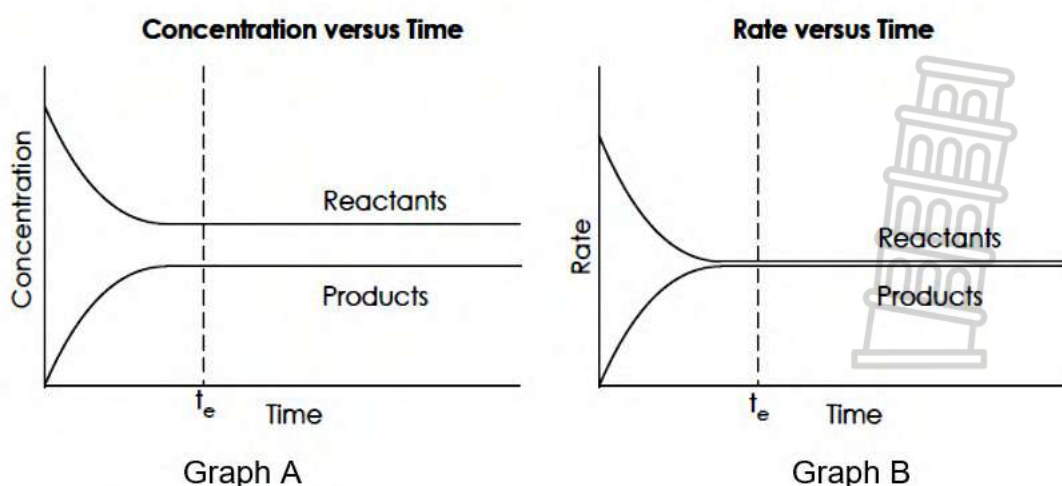
- Concentration
- Temperature
- Pressure (gases only)

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

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.

Graphical Representation

How systems achieve equilibrium can be demonstrated through concentration versus time graphs and rate versus time graphs, such as the following:



At equilibrium, the concentrations of both the products and reactants remains constant (graph A), while the rate of forward and reverse reactions are equal (graph B).

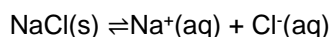
General Application of Le Chatelier's Principle

- When the *temperature* is increased, energy is added to the system. To maintain equilibrium, some of this energy must be used up (absorbed). Therefore, the endothermic reaction is favoured.
- Increasing temperature favours the endothermic reaction.
- When the *temperature* is decreased, energy is removed from the system. To restore equilibrium, the system must replace this lost energy. Hence, the exothermic reaction is favoured.
- Decreasing temperature favours the exothermic reaction.
- If the *pressure* is increased, then the reaction producing fewer gas particles is favoured.
- If the *pressure* is decreased, then the reaction producing more gas particles is favoured.
- If a suitable *catalyst* is added to a system in equilibrium, then the rate of both the forward and reverse reactions increase equally.
- Therefore, the equilibrium position is unaltered (NOT CHANGED).

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

Practical Demonstration of the Common-ion Effect

If a compound is added to a system in equilibrium and that compound contains an ion that is already present in the equilibrium system, then the reaction that uses up that ion will be favoured.

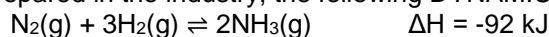


By adding HCl(l), the concentration of Cl⁻(aq) ions increases. According to LCP, the reaction using some of the added Cl⁻(aq) is favoured. In this case the reverse reaction is favoured (i.e. the reverse reaction is faster than the forward reaction for a short while until a new equilibrium is established). Therefore, the formation of NaCl(s) is observed.

Worked Example 1

Question 1

When ammonia is prepared in the industry, the following DYNAMIC equilibrium is achieved:



- 1.1 Why is it called a *dynamic equilibrium*? (1)
- 1.2 Is the forward reaction exothermic or endothermic? Give a reason for your answer. (2)
- 1.3 Determine the value ΔH of per mol of ammonia formed (2)
- 1.4 Explain how each of the situations below will affect the equilibrium concentration of ammonia (answer by simply writing INCREASE, DECREASE or REMAINS THE SAME).
 - 1.4.1 The temperature of the system is increased. (1)
 - 1.4.2 More H₂(g) is added to the system. (1)
 - 1.4.3 A catalyst is added. (1)
 - 1.4.4 The pressure in the system is reduced. (1)

Solutions

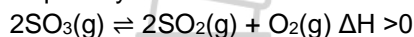
- 1.1 Both the forward and reverse reactions take place at the same rate. P (1)
- 1.2 Exothermic. P ΔH -92 KJ indicates a release of energy by the system P (2)
- 1.3 -92 kJ for 2 moles P
 $\Delta H = -46 \text{ kJ} \cdot \text{mol}^{-1}$ P (2)

- 1.4.1 Decrease P (1)
 1.4.2 Increase P (1)
 1.4.3 Stays the same P (1)
 1.4.4 Decrease P (1)

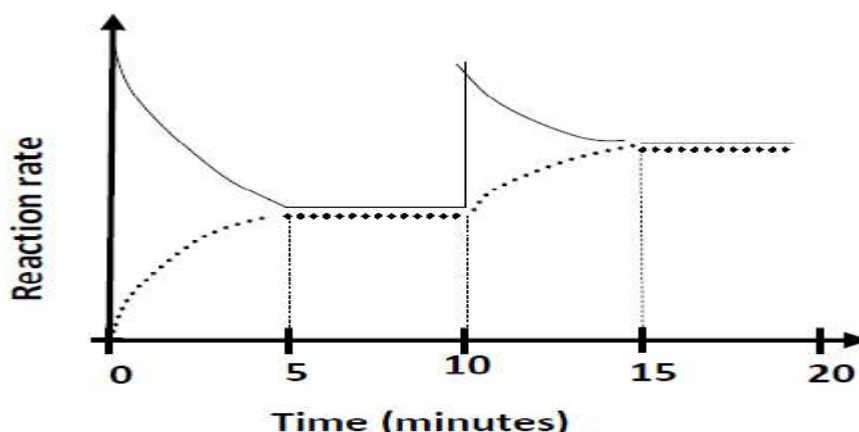
Worked Example 2

Question 2

A quantity of SO_3 is sealed in a container at 400°C and the following reversible reaction occurs:



The accompanying graph shows how the rate of the reaction changes over time.



- 2.1 State, giving a reason, whether the forward reaction is homogeneous or heterogeneous. (2)
 2.2 Write down the equation for the reaction represented by the solid line on the graph. (1)
 2.3 How long does it take, from the start of the reaction, for first equilibrium to be established? (1)
 2.4 What could possibly have happened to the system during the tenth minute? (2)
 2.5 Why is the horizontal part of the graph at a higher level between the fifteenth and twentieth minute compared to between the fifth and tenth minute (2)
 2.6 Will an increase in pressure influence the amount of $\text{SO}_2(\text{g})$ present at equilibrium? (1)

Solutions

- 2.1 Reaction is homogeneous because all the reactants are in the same phase. PP (2)
 2.2 $2\text{SO}_3(\text{g}) \rightleftharpoons 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g})$ P (1)
 2.3 5 minutes (forward reaction = reverse) P (1)
 2.4 The temperature is increased. P Because $\Delta H > 0$ (endothermic), the rate of forward reaction will increase more than the rate of reverse reaction. P (2)
 2.5 At a higher temperature, more molecules have more energy than the activation energy and both reactions will be faster than before the temperature was increased. PP (2)
 2.6 Decrease (According to Le Chatelier's Principle increasing pressure favours the less particles side, which is the reverse reaction that will be favoured) P (1)

Equilibrium Constant (K_c)

The equilibrium constant can be defined as being an expression, or ratio, of the concentration of the products over the concentration of the reactants for a reaction that is in equilibrium.

$$K_c = \frac{[\text{Products}]}{[\text{Reactants}]} \quad (K_c \text{ is a number without units})$$

The brackets “[]” represent the concentration of the species ($\text{mol}\cdot\text{dm}^{-3}$).

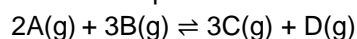
The equilibrium constant (K_c) indicates the yield of a reaction. A large K_c value indicates a large yield, i.e. at equilibrium there is a relatively small amount of reactants compared to the products.

A small K_c indicates a low yield, i.e. at equilibrium there is a relatively small amount of products compared to the reactants.

The equilibrium constant (K_c) is temperature dependent.

When writing the K_c expression, first balance the equation and then IGNORE all solids and pure liquids since their concentrations are constant.

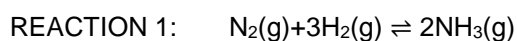
Consider the following chemical reaction that reached equilibrium at 90°C .



At equilibrium, the concentrations of reactants and products in the chemical system remain constant. Therefore, the mathematical product of the concentrations of the products is also constant.

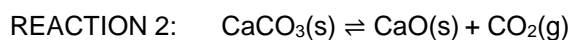
$$\frac{[\text{C}]^3[\text{D}]}{[\text{A}]^2[\text{B}]^3} = K_c$$

Consider the following chemical reactions:



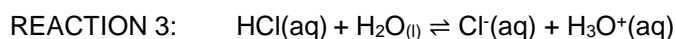
$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$$

This is an example of a homogeneous equilibrium because all the substances in the system are in the same phase.



$$K_c = [\text{CO}_2]$$

NB: The concentrations of all the solids are constant and taken as 1, it will not change the K_c value



$$K_c = \frac{[\text{Cl}^-][\text{H}_3\text{O}^+]}{[\text{HCl}]}$$

NB: Solvents of dilute solutions remain constant and are taken as 1; $[\text{H}_2\text{O}]$ remains constant and as a rule does not appear in the K_c expression.

If substances of different phases occur in the system, we say it is a heterogeneous equilibrium.

IMPORTANT:

- The K_c value indicates to what extent reactants have changed into products by the time equilibrium is reached.
- This is of particular importance in the high K_c evaluation of the efficiency of industrial processes:
- A high K_c value ($K_c > 1$) indicates that there is a lot of product has been formed and there is higher concentration of products than reactants (the equilibrium lies to the right).
- A low K_c value ($K_c < 1$) indicates that there is a higher concentration of reactants than products are present (the equilibrium lies to the left).
- $K_c = 1$ indicates equal concentrations of reactants and products.

Increase in Temperature

- Endothermic reaction is favoured
- Forward reaction is endothermic
- $[\text{Products}] > [\text{Reactants}]$
- K_c value Increases

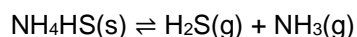
Decrease in Temperature

- Exothermic reaction is favoured
- Reverse reaction is exothermic
- $[Products] < [Reactants]$
- K_c value decreases

Worked Example 3

Question 1

A 2 g sample of ammonium hydrogen sulphide is sealed in a 2 dm³ flask at a temperature of 375K. It dissociates as follows:

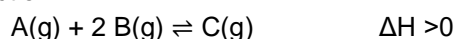


At equilibrium it is found that the concentration of ammonia is equal to $1,82 \times 10^{-3} \text{ mol.dm}^{-3}$.

- 1.1 Calculate the equilibrium constant for this reaction. (3)
- 1.2 It is found that by repeating the experiment at a higher temperature the equilibrium constant increases. Is the forward reaction exothermic or endothermic? (1)
- 1.3 Give an explanation for your answer to QUESTION 1.2 (2)

Question 2

Consider the following hypothetical reaction.



Initially 5 mol of A and 10 mol of B are pumped into a 4 dm³ reaction flask at 650 K. At equilibrium, the concentration of C was found to be $1,2 \text{ mol.dm}^{-3}$

Calculate the:

- 2.1 Concentration of A at equilibrium (3)
- 2.2 Concentration of B at equilibrium (1)
- 2.3 Equilibrium constant for this reaction (3)

Solutions

Question 1

- 1.1 Ratio: $H_2S : NH_3$
1:1
 $[H_2S] = 1,82 \times 10^{-3}$
 $K_c = [H_2S][NH_3] P$ (solids are excluded)
 $= (1,82 \times 10^{-3})(1,82 \times 10^{-3})P$
 $= 3,3 \times 10^{-6}P$ (3)
- 1.2 Endothermic P (1)
- 1.3 To obtain a larger K_c value, more $H_2S(g)$ and $NH_3(g)$ should be produced. According to Le Chatelier's Principle, an increase in temperature favours the endothermic reaction. P Therefore, the forward reaction will be endothermic and $\Delta H > 0$ P (2)

Question 2

2.1

Ratio	1	2	1
Initial mol	5	10	0
Change(mol)	-4,8	-9,6	+4,8 P
Eqbm (mol)	0,2	0,4 P	4,8
Eqbm concentration	0,05	0,1	1,2

$[A]_{\text{Equilibrium}} = 0,05 \text{ mol.dm}^{-3} P$ (3)

2.2 $[B]_{\text{Equilibrium}} = 0,1 \text{ mol}\cdot\text{dm}^{-3} \text{ P}$ (1)

2.3
$$K_c = \frac{[C]}{[A][B]^2} \text{ P}$$

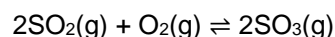
$$= \frac{(1,2)}{(0,05)(0,1)^2} \text{ P}$$

$$= 2400 \text{ P}$$
 (3)

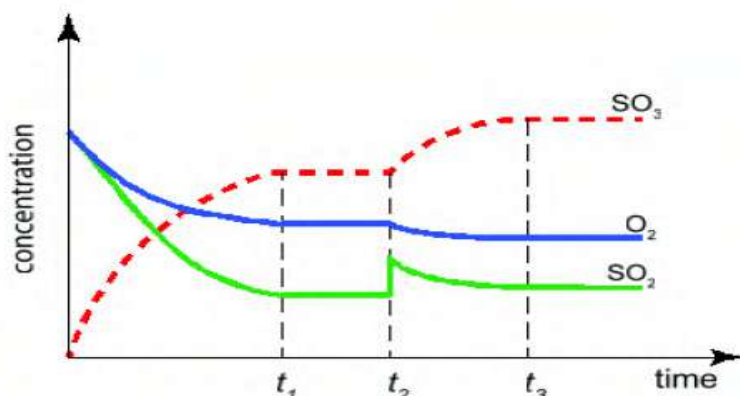
Graphs for Chemical Equilibrium

1. Changing the Concentration of Reactants or Products

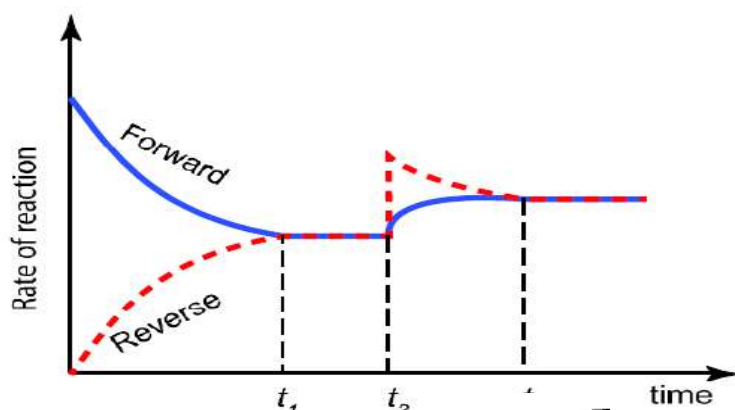
Increasing concentration of a reactant will favour the forward reaction. After a while the concentration of the products will increase and the reverse reaction will also speed up. Forward reaction will be favoured to re-establish the equilibrium at a higher rate.





At time t_2 , the concentration of SO_2 is increased



Forward reaction will be favoured to re-establish the new equilibrium at a higher rate.



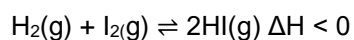
NB: "Notice that an increase in a concentration looks like  and NOT like 

Also, a decrease in concentration looks like  and NOT like 

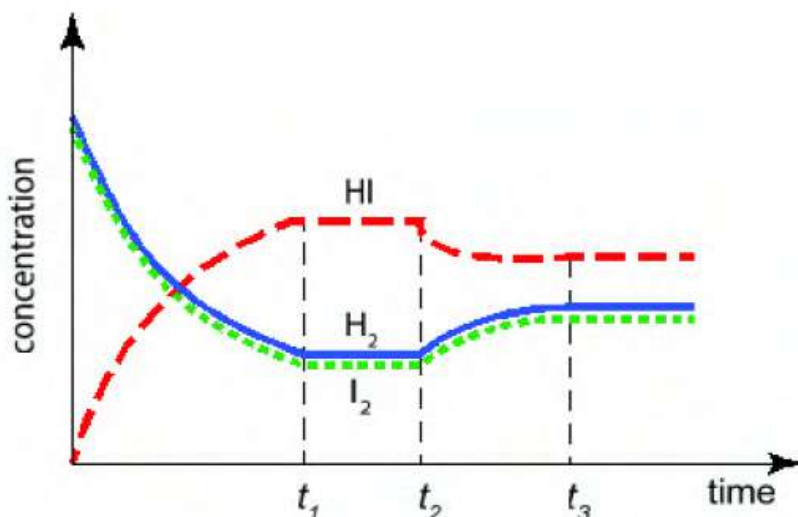
2. Changing the Temperature

Increasing temperature increases the rates of both reactions but the rate of the endothermic reaction increases more than the rate of the exothermic reaction. An increase in a temperature will favour the endothermic reaction to re-establish a new equilibrium at a higher rate.

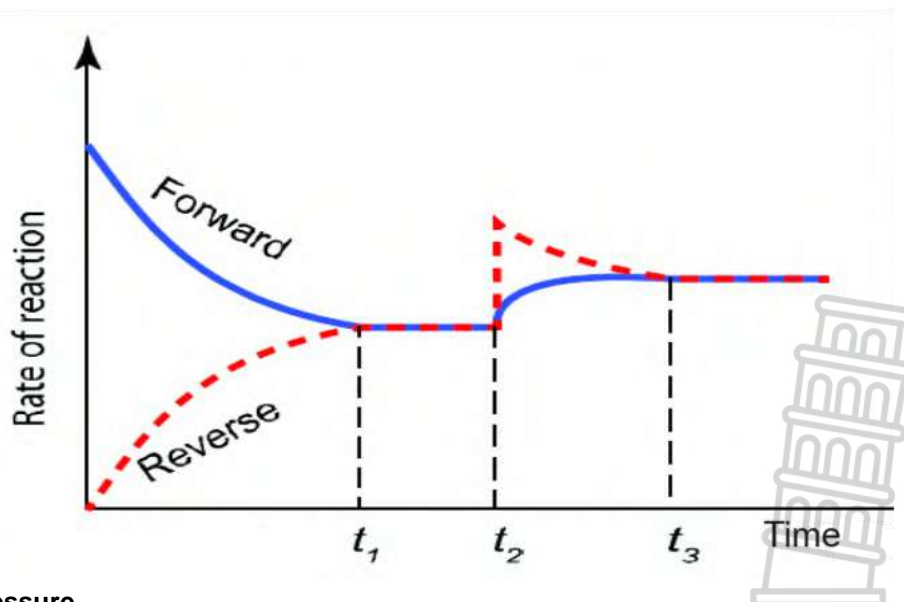
A decrease in temperature decreases the rates of both reactions, but the rate of endothermic reaction decreases more than the rate of exothermic reaction. Consider the following reaction:



At time t_2 , the temperature of the container is increased. Increasing the temperature favours the endothermic reaction, therefore the reverse reaction is favoured, concentration of the reactants will increase and that of products will decrease.



Both the rate of forward and reverse reactions will increase, but the rate of reverse reaction will be the most favoured, the new equilibrium will be at a higher rate (increase in temperature favours the endothermic reaction)

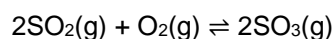


3. Changing the Pressure

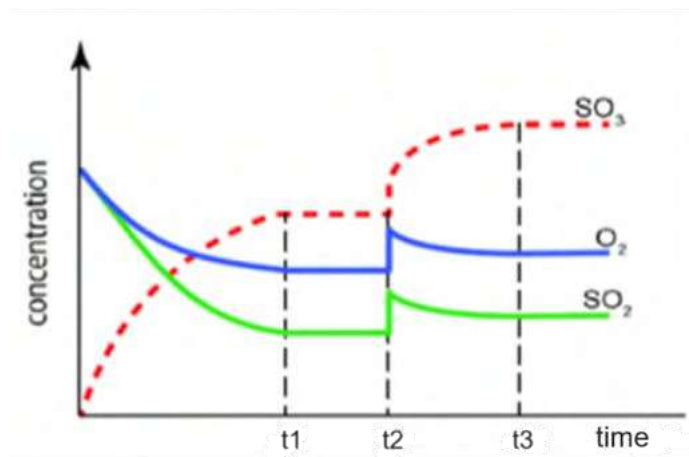
Changing the volume of the gases will change the pressure in system. But this change will also change the concentration of both reactants and products.

If the *pressure is increased* by decreasing the volume of the container, concentration of both reactants and products are increased $\{c=n/v\}$. The reaction with the least moles will be favoured to re-establish the new equilibrium.

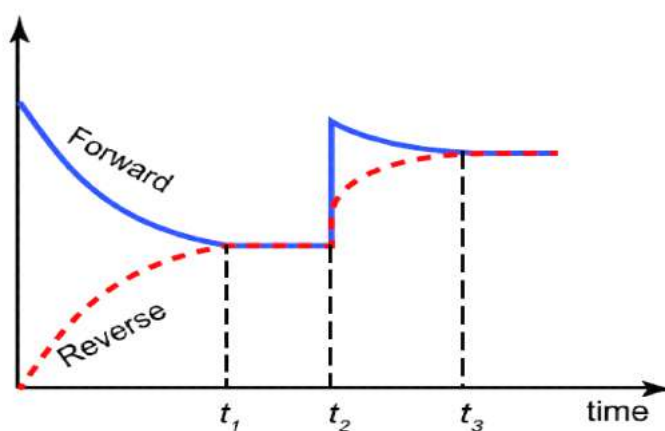
If the *pressure is decreased* by increasing the volume, concentrations of both the reactants and products are decreased. The reaction with the highest moles will be favoured to re-establish the new equilibrium. Pressure is applicable to gases only.



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



Increase in pressure increases the rates of both the forward and reverse reaction, but the forward reaction is mostly favoured, the new equilibrium will be at a higher rate.



4. Use of a Catalyst

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

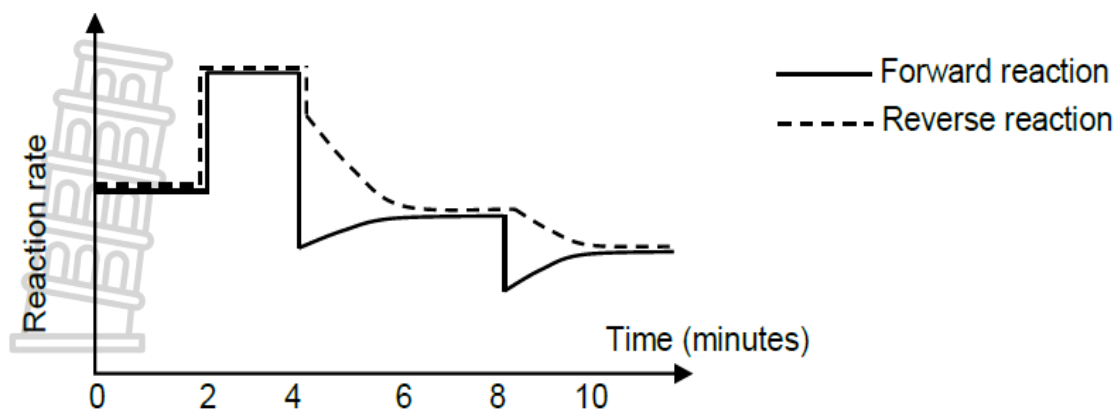
Worked Example 4

Hydrogen and iodine are sealed in a 2 dm³ container. The reaction is allowed to reach equilibrium at 700 K according to the following balanced equation: $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$

1.1 Give a reason why changes in pressure will have no effect on the equilibrium position.

(1)

The reaction rate versus time graph below represents different changes made to the equilibrium mixture.



- 1.2 What do the parallel lines in the first two minutes indicate? (1)
- 1.3 State TWO possible changes that could be made to the reaction conditions at $t = 2$ minutes (2)
- 1.4 The temperature of the equilibrium mixture was changed at $t = 4$ minutes.
- 1.4.1 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Fully explain the answer. (3)
- 1.4.2 How will this change influence the K_c value? Choose from INCREASES, DECREASES or REMAINS THE SAME (1)
- 1.5 What change was made to the equilibrium mixture at $t = 8$ minutes? (1)

Solutions

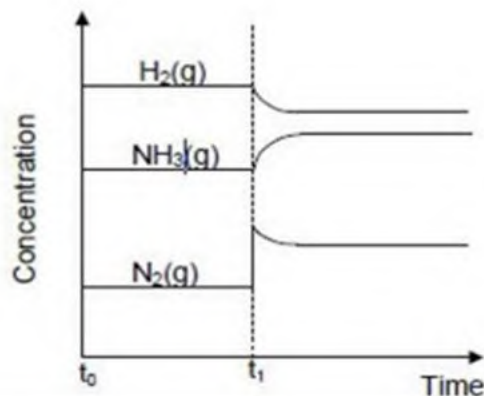
- 1.1 Amount / number of moles / volume of (gas) reactants equals amount/number of moles/volume of (gas) products. P (1)
- 1.2 Chemical/dynamic equilibrium P (1)
- 1.3 Addition of a catalyst P and increase in pressure P (2)
- 1.4.1 Endothermic P
- The rate of the forward reaction decreases more/ The rate of the reverse reaction decreases less. P
- A decrease in temperature favours the exothermic reaction. P (3)
- 1.4.2 Decreases P (1)
- 1.5 Reactants / H_2 / I_2 removed P (1)

ACTIVITIES

MULTIPLE CHOICE QUESTIONS

- 1.1 The graph below shows a change made to a chemical equilibrium in a closed container at a time t_1 . The equation for the reaction is
- $$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H < 0$$





The change made at t_1 is...

- A addition of a catalyst
- B increasing temperature
- C increasing the concentration of N_2 gas
- D increasing the pressure

(2)

1.2 Consider the following balanced equation for a reaction at equilibrium

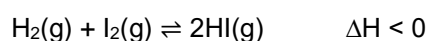


Which one of the following changes in temperature and pressure will result in the highest yield of the solid?

	TEMPERATURE	PRESSURE
A	Decrease	Decrease
B	Decrease	Increase
C	Increase	Decrease
D	Increase	Increase

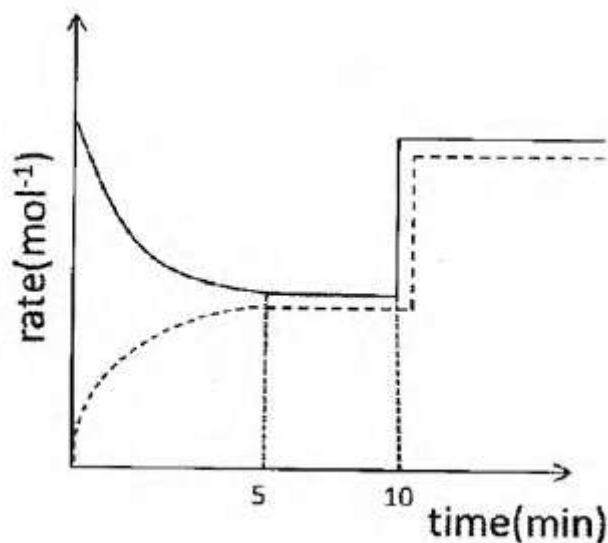
(2)

1.3 The graph below represent the change in the rate of reaction versus time for a reversible reaction that took place when an amount of hydrogen gas and iodine gas were sealed in a container. The equation for a reaction is.



The equilibrium was first reached at 5 minutes



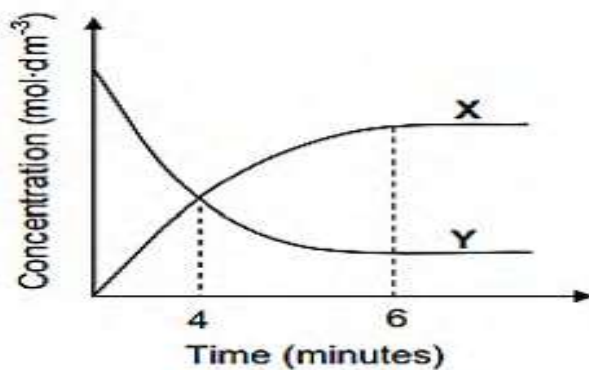
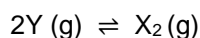


What change in conditions was made at 10 minutes to change the rate of the reaction as indicated on the graph.

- A Catalyst was added
- B Temperature was increased
- C Temperature was decreased
- D The external pressure of the reaction was decreased

(2)

1.4 The graph below represent the following reversible reaction.



How does the rate of the forward reaction compare to that of the reverse reaction at 4 minutes?

- A Equal to.
- B Higher than
- C Lower than
- D Half of.

(2)

1.5 The reaction, $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\Delta H < 0$, reaches equilibrium at a temperature of 445 °C in a sealed container.

Which ONE of the following changes will INCREASE the concentration of HI(g)?

- I. Adding a catalyst
- II. Decreasing the temperature

III. Increasing the pressure by reducing the volume

Which ONE of the following changes will INCREASE the concentration of HI(g)?

- A Only II
- B Only III
- C I and II only
- B II and III only

(2)
[10]

STRUCTURED QUESTIONS

Question 1

1.1 Equilibrium is established at 25 °C in a saturated calcium hydroxide solution according to the reaction:



- 1.1.1 State Le Chatelier's principle. (2)
- 1.1.2 A few drops of concentrated hydrochloric acid, HCl(conc.) are added to the equilibrium mixture. What effect does this addition have on the mass of Ca(OH)₂(s)? Choose from INCREASES, DECREASES or REMAIN THE SAME. (1)
- 1.1.3 Explain the answer to QUESTION 7.1.2 by using Le Chatelier's principle. (2)

1.2 Initially 70g of NH₄HS(s) is placed in a 3 dm³ container at 250 °C. The container is sealed and the reaction is allowed to reach equilibrium according to the balanced equation:



The K_c values for the decomposition of NH₄HS(s) at different temperatures are given in the table below.

TEMPERATURE (°C)	k _c
200	7,5 x 10 ⁻²
250	18 x 10 ⁻²
300	40 x 10 ⁻²

- 1.2.1 Is the decomposition of NH₄HS(s) an Exothermic or Endothermic reaction? (1)
- 1.2.2 Explain the answer to QUESTION 7.2.1 by using Le Chatelier's principle. (3)
- 1.2.3 Calculate the mass of NH₄HS(s) that will be present at equilibrium at 250 °C. (8)

[17]

Question 2

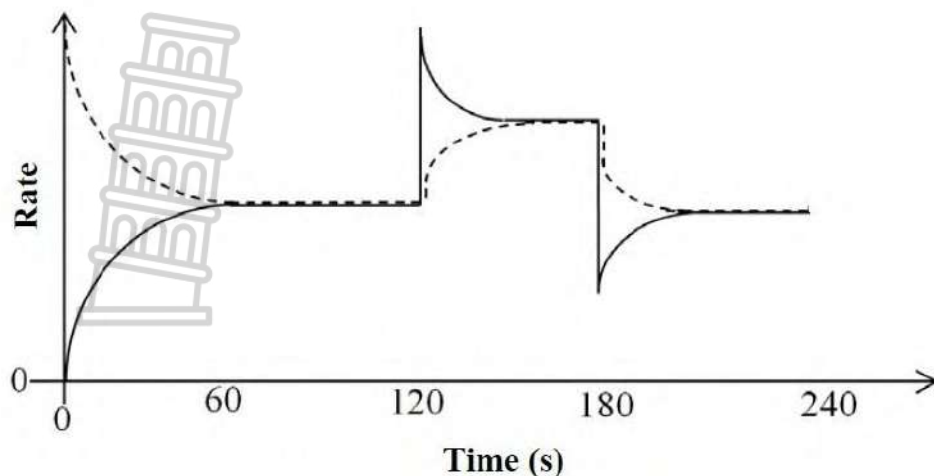
Gas A₂Q is introduced into a flask, which is then sealed, and allowed to reach dynamic chemical equilibrium at a certain temperature. The gas A₂Q decomposes as shown in the balanced chemical equation below:



- 2.1 Describe ONE method to FAVOUR ONLY the FORWARD reaction. (1)
- 2.2 Initially 5 moles of the gas A₂Q are introduced into the reaction flask. The flask is then sealed and kept at a constant temperature. When dynamic chemical equilibrium is established, 70.59 % of the gas A₂Q has decomposed and the concentration of gas Q₂ in the flask is 0,8825 mol.dm⁻³.

Calculate the value of the equilibrium constant (K_c) for this reaction at this constant temperature. (9)

The graph below shows the changes in the rates of the forward and reverse reactions with time for the reaction above.

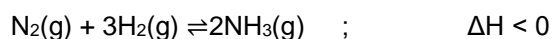


- 2.3 A change was made to the reaction at 120 s. Refer to the graph and write down a reason for why this change is NOT the addition of a catalyst. (1)
- 2.4 State Le Chatelier's Principle. (2)
- 2.5 The temperature was changed at 180s. Refer to the graph and Le Chatelier's principle to write down how this change in temperature will affect the K_c Value. Choose from GREATER THAN, EQUAL TO or LESS THAN the value calculated in question 8.2. (1)
- 2.6 Refer to the graph and Le Chatelier's Principle to explain the answer to question 8.5. (3)

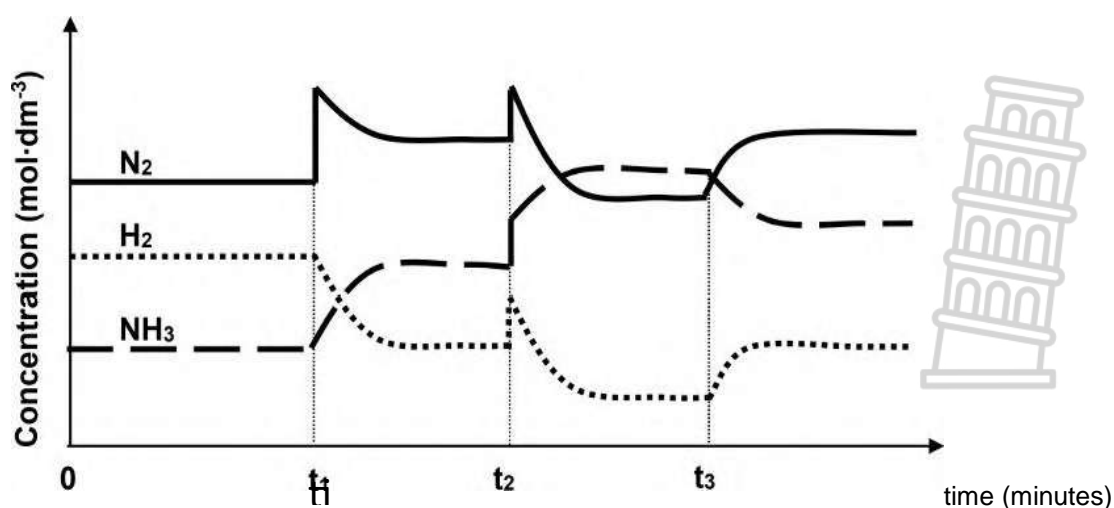
[17]

QUESTION 3

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



Adjustments are made to the TEMPERATURE, PRESSURE, CONCENTRATION and use of a CATALYST in the equilibrium mixture. The graphs below represent the results obtained.



- 3.1 Was the reaction at equilibrium at $t = 0$ s? Give a reason for your answer. (2)
- 3.2 Identify the changes made to the equilibrium mixture at each of the following time: (2)
- 3.2.1 t_1 (2)

3.2.2 t_3 (2)

3.3 At t_2 a possible change in pressure took place.

3.3.1 Did the pressure INCREASE, DECREASE or REMAIN THE SAME? (1)

3.3.2 Give a reason for your answer in question 9.3.1. (2)

3.3.3 Refer to the principle of Le Chatelier and explain what would happen the concentration of the NH_3 if the pressure was DECREASED. (3)

3.4 At which of the above times did the change to the reaction mixture lead to a higher yield of ammonia? Write down only t_1 , and/or t_2 and/or t_3 (2)

A laboratory technician now injects 5 mol of N_2 and 5 mol of H_2 into a 5 dm^3 sealed, empty container. Equilibrium is reached at 450°C . Upon analysis of the equilibrium mixture, it is found that the mass of NH_3 is 20,4 g

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

3.6 What would happen to the K_c value calculated in question 9.5 if 10 mol of N_2 and 10 mol of H_2 were used? (2)

[25]

QUESTION 4

The rapidly increasing human population is resulting in an ever-increasing demand for food. To meet this demand, farmers apply fertiliser to the same cultivated land EACH YEAR.

Sulphuric acid is an important substance used in the manufacture fertilisers. The equation below represents one of the steps in the industrial preparation of sulphuric acid.



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

4.2 Is the forward reaction exothermic or endothermic? Give a reason for your answer. (2)

4.3 How will EACH of the following changes affect the number of moles of $\text{SO}_3(\text{g})$ at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME. (2)

4.3.1 The addition of more oxygen. (1)

4.3.2 An increase in temperature
Use Le Chatelier's principle to explain the answer. (4)

The reaction above, reaches equilibrium at a certain temperature in a 2 dm^3 closed container. On analysis of the equilibrium mixture, it is found that 0,6 mole of $\text{SO}_2(\text{g})$, 0,5 mole of $\text{O}_2(\text{g})$ and 0,4 mole of $\text{SO}_3(\text{g})$ are present in the container.

4.4 List THREE changes that can be made to this equilibrium to increase the yield of $\text{SO}_3(\text{g})$. (3)

4.5 The temperature is NOW increased, and the reaction is allowed to reach equilibrium for the second time at the new temperature.

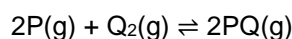
On analysis of this new equilibrium mixture, it is found that 0,2 mole of $\text{SO}_3(\text{g})$ is present in the container.

Calculate the equilibrium constant for this reaction at the new temperature. (8)

[21]

QUESTION 5

Consider the balanced equation below for a hypothetical reaction that takes place in a sealed 2 dm^3 container at 300 K.



5.1. State Le Chatelier's principle (2)

- 5.2 The amount of each substance present in the equilibrium mixture at 300 K is shown in the table below.



	AMOUNT (mol) AT EQUILIBRIUM
P	0.8
Q ₂	0.8
PQ	3.2

The temperature of the container is now increased to 350 K.

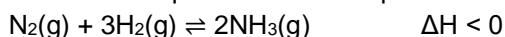
When a NEW equilibrium is established, it is found that 1,2 mol P(g) is present in the container.

- 5.2.1 Is the heat of the reaction (ΔH) POSITIVE or NEGATIVE? (when is the forward reaction favoured when temperature changes) (1)
- 5.2.2 Use Le Chatelier's principle to explain the answer to QUESTION 2.2.1 (3)
- 5.2.3 Calculate the equilibrium constant at 350 K. (8)
- 5.2.4 How will the equilibrium constant calculated in QUESTION 2.2.3 be affected when the volume of the container is decreased at constant temperature?
Choose from INCREASES, DECREASES or REMAINS THE SAME.
Give a reason for the answer. (2)
- 5.3 More Q₂(g) is now added to the reaction mixture at constant temperature.
How will EACH of the following be affected?
Choose from INCREASES, DECREASES or REMAINS THE SAME.
- 5.3.1 The yield of PQ(g) (1)
- 5.3.2 Number of moles of P(g) (1)

[18]

QUESTION 6

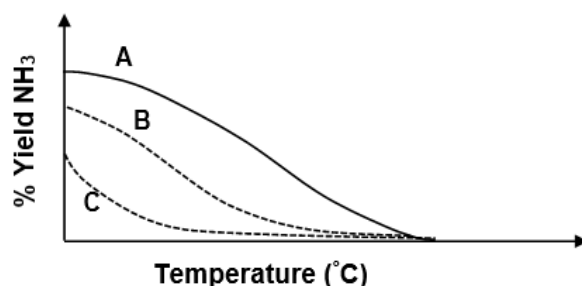
- 6.1 The following reaction reaches equilibrium at a temperature of 327 °C.



- 6.1.1 What is the meaning of the double arrow " \rightleftharpoons "? (1)
How does the rate of the forward reaction compare to the rate of the reverse reaction during the following time intervals?
Choose from HIGHER THAN, LOWER THAN or EQUAL TO.
- 6.1.2 Before equilibrium is reached for the first time (2)
- 6.1.3 At equilibrium (1)



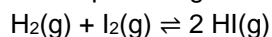
- 6.2 The graph below shows how the percentage yield of NH_3 varies with pressure at different temperature values.



(4)

Which graph (**A**, **B** or **C**) represents percentage yield values obtained at the HIGHEST pressure? Explain the answer by referring to Le Chatelier's principle.

- 6.3 Hydrogen gas, $\text{H}_2(\text{g})$, of mass 3,50 g and iodine gas, $\text{I}_2(\text{g})$, of mass 635 g were placed in a sealed container of volume $1,50 \text{ dm}^3$ and allowed to react. The reaction reached equilibrium at $300 \text{ }^\circ\text{C}$. The balanced equation for the reaction that takes place is given below:



When equilibrium is reached, 1,45 moles of $\text{I}_2(\text{g})$ is present.

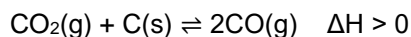
Calculate the value of the equilibrium constant (K_c) at $300 \text{ }^\circ\text{C}$ for this reaction.

(8)

[16]

QUESTION 7

Carbon dioxide reacts with carbon in a closed system to produce carbon monoxide, $\text{CO}(\text{g})$, according to the following balanced equation:



- 7.1 Define a *closed system*. (2)

- 7.2 How will the equilibrium constant be affected if more carbon is added at constant temperature?

Choose from INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for the answer.

(2)

Initially an UNKNOWN amount of carbon dioxide is exposed to hot carbon at $800 \text{ }^\circ\text{C}$ in a sealed 2 dm^3 container. The equilibrium constant, K_c , for the reaction at this temperature is 14. At equilibrium it is found that 168,00 g carbon monoxide is present.

- 7.3 How will the equilibrium concentration of the product compare to that of the reactants? Choose from LARGER THAN, SMALLER THAN or EQUAL TO.

Give a reason for the answer. (No calculation is required.)

(2)

- 7.4 Calculate the initial amount (in moles) of $\text{CO}_2(\text{g})$ present.

(9)

- 7.5 State how EACH of the following will affect the yield of $\text{CO}(\text{g})$ at equilibrium. Choose from INCREASES, DECREASES or REMAINS THE SAME.

7.5.1 More carbon is added at constant temperature.

(1)

7.5.2 The pressure is increased.

(1)

7.5.3 The temperature is increased.

(1)

[18]

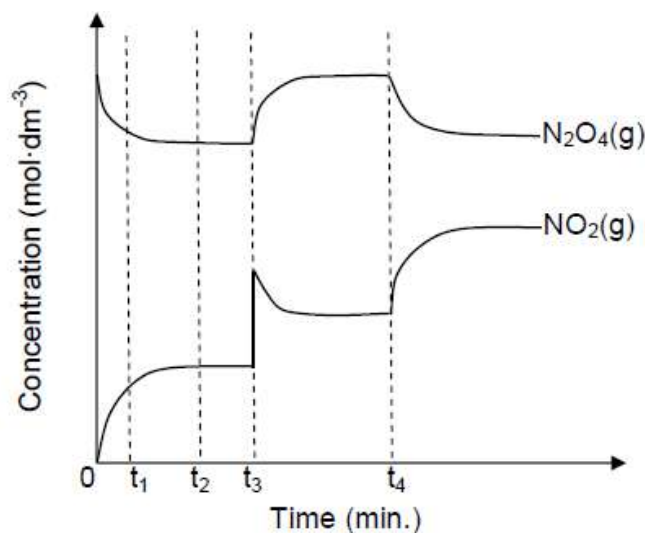


QUESTION 8

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



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



- 8.1 Give a reason why this reaction will only reach equilibrium in a SEALED container. (1)
- 8.2 How does the rate of the forward reaction compare to that of the reverse reaction at each of the following times? Only write down HIGHER THAN, LOWER THAN or EQUAL TO.
- 8.2.1 t_1 (1)
- 8.2.2 t_2 (1)
- 8.3 What change was made to the reaction conditions at each of the following times? In both instances, the equilibrium constant for the reaction did not change.
- 8.3.1 t_3 (1)
- 8.3.2 t_4 (1)
- 8.4 How will an increase in temperature influence the yield of $\text{NO}_2(\text{g})$? Write down INCREASES, DECREASES or REMAINS THE SAME. Use Le Chatelier's principle to explain the answer. (3)
- 8.5 Initially 0,92 mol N_2O_4 gas is sealed in a 2 dm^3 container and heated to 100 °C. At equilibrium it is found that 20,7% of the N_2O_4 gas has decomposed to NO_2 gas. Calculate the equilibrium constant (K_c) for this reaction at 100 °C. (7)

[16]

Acids and Bases

ACIDS AND BASES

Terminology

- **Lowry-Bronsted acid:** a proton (H^+ ion) donor.
Example: $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$
- **Lowry-Bronsted base:** a proton (H^+ ion) acceptor.
Example: $\text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+$
- **Arrhenius acid:** a substance that produces hydronium ions (H_3O^+) when it dissolves in water.
 $\text{HNO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ \text{NO}_3^-$
- **Arrhenius base:** a substance that produces hydroxide ions (OH^-) when it dissolves in water.
 $\text{NaOH (aq)} \rightarrow \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq})$
- **Strong acid:** an acid that ionises completely in water to form a high concentration of H_3O^+ ions.
Examples: HCl , HNO_3 , H_2SO_4 , ...
- **Weak acid:** an acid that ionises incompletely in water to form a low concentration of H_3O^+ ions.
Examples: HF , CH_3COOH , H_2CO_3 , ...
- **Strong base:** a base that dissociates completely in water to form a high concentration of OH^- ions.
Examples: NaOH , KOH , Ca (OH)_2 , ...
- **Weak base:** a base that dissociates incompletely in water to form a low concentration of OH^- ions.
Examples: NH_3 , CaCO_3 , K_2CO_3 , ...
- **Monoprotic acid:** an acid that donates only one Hydrogen ion.
Example: HBr , HNO_3 , CH_3COOH , ...
- **Diprotic acid:** an acid that donates two hydrogen ions.
Examples: H_2SO_4 , H_2CO_3 , ...
- **Concentrated acid or base:** a solution that contains a large amount (number of moles) of acid or base in proportion to the volume of water.
- **Dilute acid or base:** a solution that contains a small amount (number of moles) of acid or base in proportion to the volume of water.
- **Ampholyte:** a substance that can act as either an acid or a base.
- **Hydrolysis:** a reaction of a salt with water.
- **Standard solution:** a solution of precisely known concentration.
- **Endpoint:** a point where the indicator changes colour.
- **Equivalence point:** a point at which the acid/base has completely reacted with the base/acid.



WORKED EXAMPLES

WORKED EXAMPLE 1

- 1.1 Define an acid according to the Arrhenius theory. (2)
- 1.2 The table below shows aqueous solutions of different substances, each with a concentration of $1 \text{ mol}\cdot\text{dm}^{-3}$ at room temperature.

$\text{HNO}_3(\text{aq})$	$\text{H}_2\text{SO}_4(\text{aq})$	$\text{NaCl}(\text{aq})$	$(\text{COOH})_2(\text{aq})$
$\text{HCO}_3^-(\text{aq})$	$\text{NH}_3(\text{aq})$	$\text{NaOH}(\text{aq})$	$\text{CH}_3\text{COOH}(\text{aq})$

Identify from the table and write down the FORMULA for:

- 1.2.1 A weak diprotic acid. (1)
- 1.2.2 A solution with a pH of 7. (1)
- 1.2.3 An ampholyte. (1)
- 1.2.4 A weak base. (1)
- 1.2.5 The solution, which when neutralised with $(\text{COOH})_2(\text{aq})$, will have a pH greater than 7. (2)
- 1.3 Potassium hydroxide (KOH) is a strong base that dissociates when placed in water. A standard solution of potassium hydroxide with a concentration $0,45 \text{ mol}\cdot\text{dm}^{-3}$ is prepared in a 250 cm^3 volumetric flask at 298 K.
- 1.3.1 State what is meant by the term 'standard solution'. (2)
- 1.3.2 Calculate the mass of potassium hydroxide that was used to prepare this standard solution. (4)
- 1.3.3 The ionisation constant for water (K_w) is 1×10^{-14} at 298 K. Calculate the concentration of hydronium ions (H_3O^+) in the potassium hydroxide solution at 298 K. (4)

[18]

SOLUTIONS

- 1.1 A substance that produces hydronium ions (H_3O^+) when it dissolves in water. ✓✓ (2)
- 1.2.1 $(\text{COOH})_2$ ✓ (1)
- 1.2.2 NaCl ✓ (1)
- 1.2.3 HCO_3^- ✓ (1)
- 1.2.4 NH_3 ✓ (1)
- 1.2.5 NaOH ✓✓ (2)
- 1.3.1 A solution of precisely known concentration. ✓✓ (2)
- 1.3.2 $n = c \cdot v = 0,45 \times 0,25 \checkmark = 0,1125 \text{ mol}$.
 $m = n \cdot M \checkmark = 0,1125 \times 56 \checkmark = 6,3 \text{ g}$ ✓ (4)
- 1.3.3 Ratio $\text{KOH}:\text{OH}^-$ is 1:1
 $[\text{OH}^-] = [\text{KOH}] = 0,45 \text{ mol}\cdot\text{dm}^{-3}$. ✓
 $[\text{H}_3\text{O}^+]\cdot[\text{OH}^-] = 1 \times 10^{-14}$ ✓
 $[\text{H}_3\text{O}^+] \times 0,45 = 1 \times 10^{-14}$ ✓
 $[\text{H}_3\text{O}^+] = 2,22 \times 10^{-14} \text{ mol}\cdot\text{dm}^{-3}$. ✓ (4)

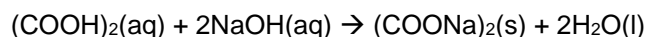
[18]

WORKED EXAMPLE 2

A standard solution is prepared by adding 4.5 g of oxalic acid to 250 cm^3 of distilled water.

- 2.1 Is oxalic acid classified as a weak or strong acid? Give a reason. (2)
- 2.2 Calculate the concentration of the oxalic acid solution. (3)

25 cm³ of this solution is then neutralised by 20 cm³ of sodium hydroxide. The balanced equation for the reaction is:



- 2.3 Will the pH of the solution at the end point be LESS THAN 7, GREATER THAN 7, or EQUAL TO 7? (3)
Justify your answer with a relevant equation.
- 2.4 Write down a suitable indicator for the titration described above. (1)
- 2.5 Calculate the concentration of sodium hydroxide neutralised by 25cm³ of this standard solution. (5)

[14]

SOLUTIONS

- 2.1 Weak. ✓
It ionises incompletely in water to form a low concentration of hydronium ions. ✓ (2)
- 2.2 **Option 1**

$$c = \frac{m}{MV} \checkmark$$

$$= \frac{4,5}{90 \times 0,25} \checkmark$$

$$c = 0,2 \text{ mol.dm}^{-3} \checkmark$$
- Option 2**

$$n = \frac{m}{M} = \frac{4,5}{90} = 0.05 \text{ mol}$$

$$c = \frac{n}{V} \checkmark = \frac{0,05}{0,25} \checkmark$$

$$c = 0,2 \text{ mol.dm}^{-3} \checkmark$$
 (3)

- 2.3 Greater than 7. ✓

$$\text{C}_2\text{O}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \checkmark \rightleftharpoons \text{C}_2\text{HO}_4^-(\text{aq}) + \text{OH}^-(\text{aq}) \checkmark$$
 (3)
- 2.4 Phenolphthalein. (1)

- 2.5 **Option 1**

$$(\text{COOH})_2: n = c \cdot v \checkmark$$

$$= 0,2 \times 0,025 \checkmark = 0.005 \text{ mol.}$$
 Ratio: $n_{(\text{NaOH})} = 2 \times n_{(\text{COOH})_2}$

$$= 2 \times 0,005 = 0,01 \text{ mol} \checkmark$$
 NaOH: $c = \frac{n}{V} = \frac{0,01}{0,02} \checkmark$

$$c = 0,5 \text{ mol.dm}^{-3} \checkmark$$
 (5)
- Option 2**

$$\frac{c_a \times v_a}{c_b \times v_b} = \frac{n_a}{n_b} \checkmark$$

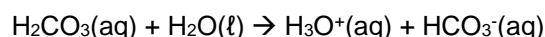
$$\frac{0,2 \times 0,025 \checkmark}{c_b \times 0,02 \checkmark} = \frac{1}{2} \checkmark$$

$$C_b = 0,5 \text{ mol.dm}^{-3} \checkmark$$
 (5)

[14]

WORKED EXAMPLE 3

Carbonic acid (H₂CO₃) is a weak diprotic acid that ionises according to the following equation:

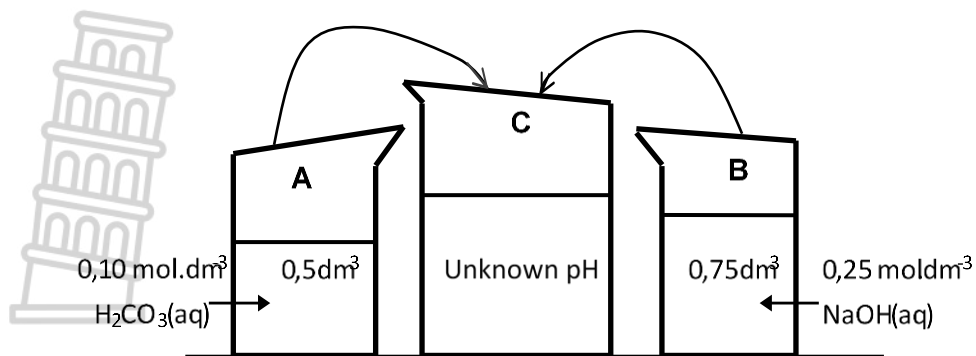


- 3.1 Define *diprotic acid*. (2)
- Two beakers, **A** and **B**, contain the acid and a strong base, respectively.

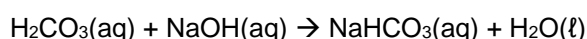
Beaker A	0,5 dm ³ of H ₂ CO ₃ (aq) of concentration 0,10 mol.dm ⁻³ .
Beaker B	0,75 dm ³ of NaOH(aq) of concentration 0,25 mol.dm ⁻³ .

- 3.2 Calculate the number of moles of H₃O⁺(aq) ions present in the H₂CO₃ solution in beaker **A**. (3)

The contents of beakers **A** and **B** are added together in beaker **C**.
The solution in beaker **C** has an unknown pH.



The balanced equation for the reaction, in beaker C, is:



3.3 Calculate:

3.3.1 The number of moles of hydroxide (OH^-) ions in beaker **B**. (3)

3.3.2 The pH of the solution at the completion of the reaction in beaker **C**. (7)
[15]

SOLUTIONS

3.1 An acid that donates two hydrogen ions. ✓ (1)

3.2 $[\text{H}_3\text{O}^+] = [\text{HCO}_3^-] = 0,01 \text{ mol.dm}^{-3}$ ✓
 $n = c.v = 0,01 \times 0,5$ ✓
 $n = 0,005 \text{ mol}$ ✓ (3)

3.3.1 $n = c.v = 0,25 \times 0,75 = 0,1875 \text{ mol}$.
 Ratio: $\text{NaOH} : \text{OH}^-$ is 1:1 ✓
 $n_{(\text{OH}^-)} = 0,1875 \text{ mol}$ ✓ (3)

3.3.2 Ratio: $\text{H}_2\text{CO}_3:\text{NaOH}$ is 1:1. NaOH is in excess. ✓
 $n_{(\text{OH}^-) \text{ in excess}} = 0,1875 - 0,005 = 0,1825 \text{ mol}$
 $c = \frac{n}{V} = \frac{0,1825}{(0,5+0,75)} = 0,146 \text{ mol.dm}^{-3}$.
 $K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1 \times 10^{-14}$,
 $[\text{H}_3\text{O}^+] \times 0,146 = 1 \times 10^{-14}$ ✓
 $[\text{H}_3\text{O}^+] = 6,85 \times 10^{-14}$
 $\text{pH} = -\log [\text{H}_3\text{O}^+]$ ✓
 $\text{pH} = -\log(6,85 \times 10^{-14})$ ✓
 $\text{pH} = 13,16$ ✓ (7)
[14]

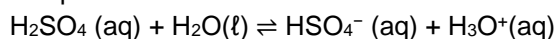
ACTIVITIES

QUESTION 1: MULTIPLE CHOICE

1.1 Which ONE of the following represents the products formed during the hydrolysis of ammonium chloride?

- A $\text{Cl}^-(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$
 B $\text{NH}_4^+(\text{aq})$ and $\text{Cl}^-(\text{aq})$
 C $\text{HCl}(\text{aq})$ and $\text{OH}^-(\text{aq})$
 D $\text{NH}_4^+(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$ (2)

1.2 A conjugate acid-base pair in the reaction:



is:

- A H_2SO_4 and H_3O^+
 B H_2SO_4 and HSO_4^-
 C H_2O and H_2SO_4
 D HSO_4^- and H_3O^+ (2)

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

- A is a proton donor.
 B is a proton acceptor.
 C forms hydroxide ions in water.
 D forms hydronium ions in water. (2)

1.4 A hydrochloric acid solution, $\text{HCl}(\text{aq})$, and an acetic acid solution, $\text{CH}_3\text{COOH}(\text{aq})$, of EQUAL CONCENTRATIONS are compared.

How do the $\text{H}_3\text{O}^+(\text{aq})$ concentration of $\text{HCl}(\text{aq})$ and the pH of $\text{HCl}(\text{aq})$ compare to that of $\text{CH}_3\text{COOH}(\text{aq})$?

	$[\text{H}_3\text{O}^+]$ of $\text{HCl}(\text{aq})$	pH of $\text{HCl}(\text{aq})$
A	Higher than	Higher than
B	Higher than	Lower than
C	Equal to	Equal to
D	Higher than	Equal to

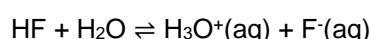
(2)

1.5 CH_3COOH is a weak acid. Which ONE of the following statements is correct for a 0,01 mol.dm⁻³ aqueous solution of CH_3COOH ?

- A There are more hydronium ions than acetate ions.
 B There are fewer acetate ions than unionized CH_3COOH
 C There are more hydronium ions than ionized CH_3COOH
 D There is an equal quantity of unionized CH_3COOH , hydronium ions, and acetate ions. (2)

QUESTION 2

2.1 The acid HF ionises according to the following equation:



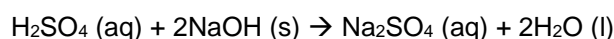
When a 0,10 mol.dm⁻³ solution of HF is prepared, it is found that the concentration of the F^- ions is 0,018 mol.dm⁻³ at 25 °C.

- 2.1.1 Define a *strong acid*. (2)
 2.1.2 Is HF a strong acid? Choose from YES or NO.

Give a reason for the answer. (2)

2.1.3 Calculate the concentration of hydroxide ions (OH⁻) in this solution. (3)

- 2.2 Sodium hydroxide (NaOH) pellets of mass **X** grams are added to sufficient distilled water to prepare a solution of volume 25 cm³ in a flask.
12 cm³ of sulphuric acid, H₂SO₄, of concentration 0,10 mol·dm⁻³ is added to the flask containing the sodium hydroxide. The total volume of the mixture formed is 37 cm³ and its pH is 12,56.



2.2.1 Explain the term *dilute acid*. (2)

2.2.2 How does the concentration of the hydronium ions compare to the concentration of the hydroxide ions in the mixture?
Choose from LARGER THAN, SMALLER THAN, or EQUAL TO.

(1)

2.2.3 Calculate the value of **X**. (8)

[18]

QUESTION 3

To identify metal **M** in an unknown metal carbonate, **MCO**₃, the following procedure is carried out:

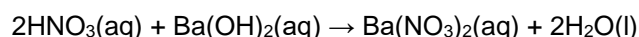
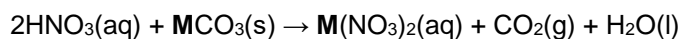
Step 1:

0,198 g of IMPURE **MCO**₃ is reacted with 25 cm³ of 0,4 mol·dm⁻³ nitric acid, HNO₃(aq).

Step 2:

The EXCESS HNO₃(aq) is then neutralised with 20 cm³ of 0,15 mol·dm⁻³ Barium hydroxide, Ba(OH)₂(aq).

The following reactions take place:



3.1 Define the term strong base. (2)

3.2 Calculate the:

3.2.1 Number of moles of Ba(OH)₂(aq) that reacted with the excess HNO₃(aq). (3)

3.2.2 pH of the solution after Step 1. (5)

3.3 The percentage purity of the **MCO**₃(s) in the sample is 85%. Identify metal **M**. (8)

[18]

QUESTION 4

4.1 Nitric acid (HNO₃), an important industrial acid, is a strong acid.

4.1.1 Give a reason why nitric acid is classified as a strong acid. (1)

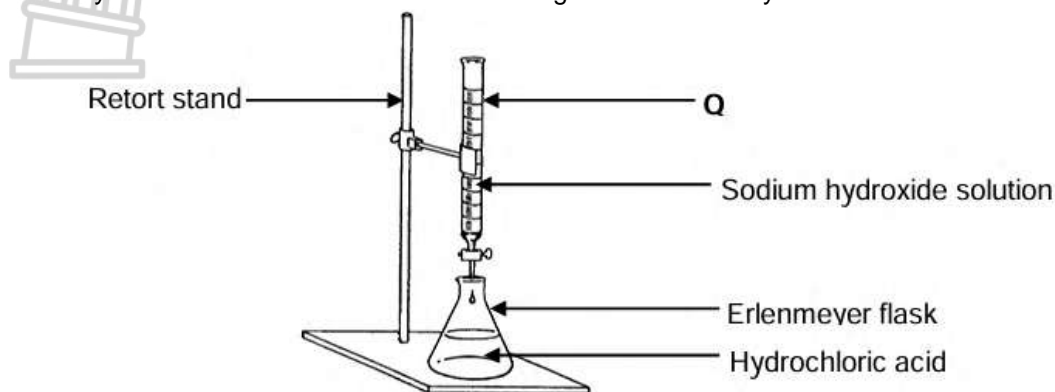
4.1.2 Write down the NAME or FORMULA of the conjugate base of nitric acid. (1)

4.1.3 Calculate the pH of a 0,3 mol·dm⁻³ nitric acid solution. (3)

- 4.2 A laboratory technician wants to determine the percentage purity of magnesium oxide. He dissolves a 4,5 g sample of magnesium oxide in 100 cm³ hydrochloric acid of concentration 2 mol·dm⁻³.

4.2.1 Calculate the number of moles of hydrochloric acid added to the magnesium oxide. (3)

The technician then uses the apparatus shown below to titrate the EXCESS hydrochloric acid in the solution above against a sodium hydroxide solution.



4.2.2 Write down the name of apparatus Q in the above diagram. (1)

4.2.3 The following indicators are available for the titration:

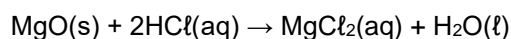
INDICATOR	pH RANGE
A	3,1 – 4,4
B	6,0 – 7,6
C	8,3 -10,0

Which ONE of the above indicators (A, B or C) is most suitable to indicate the exact endpoint in this titration? Give a reason for the answer. (3)

4.2.4 During the titration, the technician uses distilled water to wash any sodium hydroxide that spills onto the sides of the Erlenmeyer flask into the solution. Give a reason why the addition of distilled water to the Erlenmeyer flask will not influence the results. (1)

4.2.5 At the endpoint of the titration, he finds that 21 cm³ of a 0,2 mol dm⁻³ sodium hydroxide solution has neutralised the EXCESS hydrochloric acid. Calculate the number of moles of hydrochloric acid in excess. (3)

4.2.6 The balanced equation for the reaction between hydrochloric acid and magnesium oxide is:

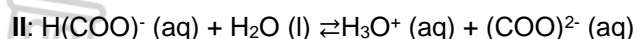
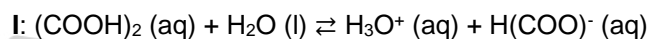


Calculate the percentage purity of the magnesium oxide. Assume that only the magnesium oxide in the 4,5 g sample reacted with the acid. (5)

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QUESTION 5

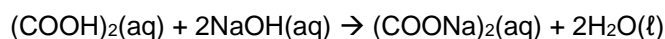
5.1 Anhydrous oxalic acid is an example of a diprotic acid and thus ionises in two steps as represented by the equations below:



Write down:

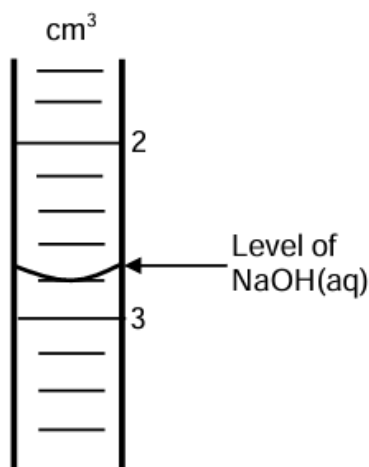
- 5.1.1 What is meant by a diprotic acid? (1)
- 5.1.2 The formula of each of the TWO bases in reaction II. (2)
- 5.1.3 The formula of the substance that acts as an ampholyte in reactions I and II. (1)
- 5.2 Give a reason why oxalic acid is a weak acid. (1)
- 5.3 A standard solution of $(\text{COOH})_2$ of concentration $0,2 \text{ mol}\cdot\text{dm}^{-3}$ is prepared by dissolving a certain amount of oxalic acid, $(\text{COOH})_2$, in water in a 250 cm^3 volumetric flask.
Calculate the mass of oxalic acid needed to prepare the standard solution. (4)
- 5.4 During a titration, 25 cm^3 of the standard solution of $(\text{COOH})_2$ prepared in QUESTION 5.3 is neutralised by a sodium hydroxide solution from a burette.

The balanced equation for the reaction is:

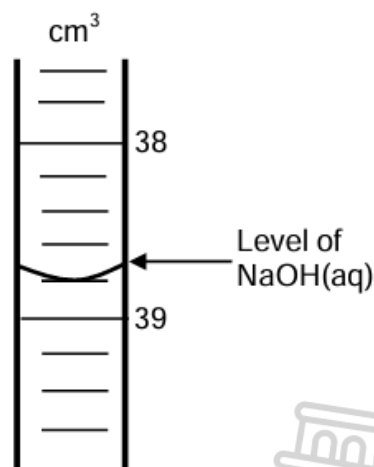


The diagrams below show the burette readings before the titration commenced and at the endpoint, respectively.

Before the titration



At the endpoint



- 5.4.1 Use the burette readings and calculate the concentration of the sodium hydroxide solution. (5)
- 5.4.2 Write down a balanced equation that explains why the solution has a pH greater than 7 at the endpoint. (3)

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